SUMMARY

ISBN: 978-85-7717-187-3

Enhancing Water Management Capacity in a Changing World:

The Challenge of increasing global access to water and sanitation

ORGANIZERS
Fernando Rosado Spilki
Marcos Cortesão Barnsley Scheuenstuhl
José Gazilia Tundisi

iap SCIENCE RESEARCH HEALTH
the interacademy partnership

ACADEMIA BRASILEIRA DE CIÊNCIAS

UNIVERSIDADE FEEVALE

IANAS INTERAMERICAN NETWORK OF ACADEMIES OF SCIENCES

SUMMARY

Associação Pró-Ensino Superior em Novo Hamburgo - ASPEUR
Universidade Feevale

Enhancing Water Management Capacity in a Changing World:
The Challenge of increasing global access to water and sanitation

ORGANIZADORES
Fernando Rosado Spilki
Marcos Cortesão Barnsley Scheuenstuhl
José Gazilia Tundisi

UNIVERSIDADE FEEVALE

Novo Hamburgo
2016

COORDENAÇÃO EDITORIAL
Denise Ries Russo

EDITORA FEEVALE
Celso Eduardo Stark
Graziele Borguetto Souza
Adriana Christ Kuczynski

PROJETO GRÁFICO E EDITORAÇÃO ELETRÔNICA
Adriana Christ Kuczynski

COMO MELHOR UTILIZAR ESTE E-BOOK

Não desperdice papel, imprima somente se necessário.

Este e-book foi feito com intenção de facilitar o acesso à informação. Baixe o arquivo e visualize-o na tela do seu computador sempre que necessitar.

É possível também imprimir somente partes do texto, selecionando as páginas desejadas nas opções de impressão. Os botões interativos são apenas elementos visuais e não aparecerão na impressão, utilize-os para navegar pelo documento. Se preferir, utilize as teclas “Page Up” e “Page Down” do teclado ou o “Scroll” do mouse para retornar e prosseguir entre as páginas.

DADOS INTERNACIONAIS DE CATALOGAÇÃO NA PUBLICAÇÃO (CIP)
Universidade Feevale, RS, Brasil
Bibliotecária responsável: Tatiane de Oliveira Bourscheidt - CRB 10/2012

Enhancing water management capacity in a changing world [recurso eletrônico] : the challenge of increasing global access to water and sanitation / Fernando Rosado Spilki [et. al], organizadores. – Novo Hamburgo : Universidade Feevale, 2016.

Sistema requerido: Adobe Acrobat Reader.
Modo de acesso: <www.feevale.br/editora>
ISBN 978-85-7717-187-3

1. Água - Abastecimento. 2. Saneamento básico. 3. Água – Consumo. I. Spilki, Fernando Rosado. II. Scheuenstuhl, Marcos Cortesão Barnsley. III. Tundisi, José Galizia. IV. Título.

CDU 628.1

Universidade Feevale
Câmpus I: Av. Dr. Maurício Cardoso, 510 – CEP 93510-250 – Hamburgo Velho
Câmpus II: ERS 239, 2755 – CEP 93525-075 – Vila Nova
Fone: (51) 3586.8800 – Homepage: www.feevale.br

ACADEMIA BRASILEIRA DE CIÊNCIAS

Institutional members of the Brazilian Academy Of Sciences:

BG BRASIL

FAPEG FUNDAÇÃO DE AMPARO À PESQUISA DO ESTADO DE GOIÁS

FAPEMIG

FAPERJ Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro

FUNDAÇÃO CONRADO WESSEL FCW

Finep INOVAÇÃO E PESQUISA

impa

Itaú

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA, INOVAÇÕES E COMUNICAÇÕES

BRASIL

VALE

Organized by:

ACADEMIA BRASILEIRA DE CIÊNCIAS (1916 2016)

iap SCIENCE RESEARCH HEALTH – the interacademy partnership

IANAS – Interamerican Network of Academies of Sciences

Sponsored by:

UNESCO – Organização das Nações Unidas para a Educação, a Ciência e a Cultura

UNITWIN – Cátedra UNESCO Memorial da América Latina

MEMORIAL

sabesp

GOVERNO DO ESTADO SÃO PAULO

unesp

USP

UNICAMP

CAPES

FINEP – FINANCIADORA DE ESTUDOS E PROJETOS – MINISTÉRIO DA CIÊNCIA E TECNOLOGIA

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA, INOVAÇÕES E COMUNICAÇÕES – BRASIL

Institutional support:

COPPE UFRJ

Itaú

INMETRO

impa

VALE

FAPEMIG

Fundação Conrado Wessel FCW

BR PETROBRAS

FAPERJ – Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro

SESSION 1

Extending Global Access to Clean Water and Sanitation: an Unpostponable Commitment

SESSION 2

More with Less: Managing Water for Agriculture

SESSION 3

Water Governance for Development and Sustainability

SESSION 4

Transboundary Waters and Conflicts: Managing Water for Peace

SESSION 5

Water for Economic Growth and Development

SESSION 6

Managing Water in Urban Areas and Metropolitan Regions: an Ever-Growing Challenge

SESSION 7

Climate Change and Adaptive Water Management: Challenges for a Changing World

SESSION 8

Mining and Water Resources: Coping with the Impacts

SESSION 9

Challenges for Sustainable Groundwater Management

SESSION 10

Ecohydrology: an Ecosystem Approach to Water Management

Universidade Feevale

The global scientific community, in its different areas of expertise, spent hundreds of hours to consider issues related to water and strategies on how society can conduct the distribution and use of this resource which emerges as the principle of life.

In Brazil, hydric resources are present in abundance. Thus, the fact that Brazilian researches dwell for so long on so many academic programs and on the production of scientific papers could be seen as a paradox. This book signals us to great distortions, when we discuss about quantity, geographical distribution and quality of our water resources. It connects us with different issues, from a rural perspective to the comprehensive growth of cities, where sanitary control and public policies are still developed with a focus on a first modernity, a society grounded on development based on industrialization.

The rampant growth caused by large-scale economic action inhibits the control and implementation of environmental resources management actions. Nonetheless, this is the great challenge of our time. Based on the reflections and results of the different scientific investigations provided by this work, the problem of “water” clearly cannot be thought in terms of “micro processes”, or through theories that abstractly reveal the so-called “environmental awareness”. The vision must be systemic and, more than ever, economic feasibility must be observed in consonance with human relations and the environment.

Universidade Feevale is honored to participate in the publishing of this work; contributing to such important discussion and referring to scientific technological solutions for mankind´s purest symbolism of life: water.

Prof. Dr. João Alcione Sganderla Figueiredo
Pró-reitor de Pesquisa e Pós-graduação

Brazilian Academy of Sciences

Understanding that Academies of Sciences could play a role in coping with the challenge of enhancing global access to water and sanitation, the Brazilian Academy of Sciences (ABC) proposed in 2002 to the Global Network of Academies of Sciences (IAP) the establishment of the IAP Water Program. Under the framework of this program, an intense effort was developed to engage the Academies of Sciences of the world in collaborative work on water related issues. Under the leadership of ABC, several regional water workshops were organized, bringing together top-notch water experts from over 60 countries.

To promote an interchange of experiences between the Academies from the different regions, ABC organized in 2012 an international workshop on "Enhancing Water Management Capacity in a Changing World: Science Academies Working Together to Increase Global Access to Water and Sanitation". Held at the headquarters of the Latin American Memorial, the workshop was supported by IAP, the Inter-American Network of Academies of Sciences (IANAS), Sabesp (Water and Wastewater Treatment Company of the State of São Paulo), the Coordination for the Improvement of Higher Education Personnel (CAPES), and the Brazilian Agency for Innovation and Research (FINEP).

Experts from 34 different countries attended this meeting, being 7 from Africa, 14 from the Americas, 8 from Asia, and 5 from Europe. The leadership of a few of the most important international water programs also attended the workshop: International Lake Environment Committee (ILEC), International Hydrological Programme - UNESCO (IHP-UNESCO), United Nations University - Institute for Water, Environment & Health (UNU-INWEH) e United Nations Environment Programme (UNEP).

During three days, participants identified and discussed key problems and challenges for water research and management in the different regions of the world. Besides the scientific agenda, the symposium appraised regional experiences and discussed further opportunities of collaboration between Academies in the effort to contribute to the enhancement of global access to clean water and sanitation services.

With this publication, which brings together an array of views and recommendations, we wish to share with you the rich discussion held during the workshop. I here acknowledge and thank each one of the authors for kindly taking their time to prepare a paper summarizing their talks at the meeting. I must also give a special thanks to Prof. José Galizia Tundisi. Throughout the years, he has been a champion chairing the IAP Water Program, co-chairing the IANAS Water Program, and coordinating the Water Committee of the Brazilian Academy of Sciences. He has inspired not only the Brazilian Academy of Sciences, but also several Academies worldwide. Today, if many Science Academies play an active role in the national water debate, providing scientifically sound advice to water management and policymaking, probably at some level Tundisi's enthusiasm has been inspirational. Last, but not least, I must also thank FEEVALE University for generously supporting and making possible this publication.

Luiz Davidovich
President
Brazilian Academy of Sciences

Organizers

Water resources management is presently a very important and essential worldwide challenge. Due to the complexity of the water problems, and it's interrelations with ecosystem sustainability and the support to life in the planet, water resources should be managed through an integrated approach, and with advanced technologies that include biogeochemical, social and economic approaches.

The water crisis is escalating at the global level. Continents, regions and countries are facing dry periods, as well as very intense hydrological disasters such as flooding. These phenomena impair the economy, the ecosystems and all life, including human life. Therefore, increasing vulnerability and lack of availability of water is a problem that needs to be tackled.

To discuss the major problems and challenges for water management and research in the different regions of the planet, the Brazilian Academy of Sciences and the Latin America Memorial of the São Paulo State Government promoted the international workshop "Enhancing Water Management Capacity in a Changing World: Science Academies Working Together to Increase Global Access to Water and Sanitation". This meeting was organized with the support of the Global Network of Academies of Sciences (IAP), the Inter-American Network of Academies of Science (IANAS), Sabesp (Water and Wastewater Treatment Company of the State of São Paulo), the Coordination for the Improvement of Higher Education Personnel (CAPES), and the Brazilian Agency for Innovation and Research (FINEP).

Experts from 34 different countries, coming from the different regions of the world, attended this workshop, discussing a vast and complex array of problems. Participants also contributed with ideas, solutions and new and advanced technological approaches for water management. Social and economic aspects were also presented and discussed.

This book is an important outcome of this most interesting workshop. University Feevale, through it's Editor and Publishing Office, prepared all the manuscripts with the collaboration of the Brazilian Academy of Sciences.

We thank all authors for their high-level and excellent work. We are sure that this book will be an important reference for managers, students, and scientists working with water problems all over the world.

Fernando Rosa Spilki

Marcos Cortesão Barnsley Scheuenstuhl

José Galizia Tundisi

SESSION 1

EXTENDING GLOBAL ACCESS TO CLEAN WATER AND SANITATION: AN UNPOSTPONABLE COMMITMENT

TOWARDS ACHIEVING THE MDGs: PROGRESS IN UGANDA'S RURAL WATER AND SANITATION SECTOR

Albert I. Rugumayo[1]

[1] Dr. - Uganda National Academy of Sciences. Ndejje University and Makerere University, Kampala, Uganda.

ABSTRACT

The MDGs provide us with a target of halving the people without access to safe drinking water and basic sanitation by 2015. To achieve these Uganda has initiated key policies in both the water and health sectors. These were followed by a rural water strategy that defined the key players and the institutional framework which has a water sector working group at the apex that has golden indicators to monitor sector performance. Sustainability safeguards followed the principles of the community based management system (CBMS), which operates at the source, sub-county and district levels. Technology options include protected springs, boreholes, shallow wells, gravity flow systems, rainwater harvesting and piped water systems. The paper discusses major rural water supply initiatives over the past 20 years together with the lessons learned and shows that although the functionality increased from 20% to 85% in less than 20 years, it was dependent upon project interventions and a gap remained in monitoring CBMS and making it more effective. Sanitation promotion included several on-site technology options ranging from pit latrines to flush systems and school sanitation is a major intervention. The lessons learned show the need for a well-defined institutional framework that can support behaviour change. Recent studies conducted in four districts each in western and northern Uganda, demonstrate the need to ensure the presence and strengthen the functioning of water user committees and the need to diversify their activities to include a savings or business component. Furthermore, the presence of a designated proximate hand pump mechanic is crucial for the source functionality and with these improvements Uganda remains on course to achieve some of the MDGs and sustainable water and sanitation.

1 POLICY AND INSTITUTIONAL FRAMEWORK

1.1 RURAL WATER AND SANITATION POLICIES

The Millennium Development Goal *Target 7.C* requires us to: Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation (UNDP, 2001).

The National Water Policy of Uganda (MWLE, 1999) provides an elaborate set of strategies and approaches to be used in the water and sanitation sector. In the Rural Water Supply and Sanitation Sub-sector, the goal and targets are: Sustainable safe water supply and sanitation facilities, based on management responsibility and ownership by the users, within easy access of 77% of the rural population by the year 2015, with an 80% - 90% effective use and functionality of facilities. Access is defined as 20 litres of water per capita, per day within 1.5 km for rural water supplies.

The National Health Policy (MOH, 1999) addresses the increasing burden of disease resulting from poor environmental health, with particular emphasis on rural areas, where the population has low access to safe water and poor latrine coverage. This will be achieved through the promotion of personal household, institutional, community and food hygiene. Sanitation in rural households is a responsibility of individual households, while the government's role is to sensitise the community and Local governments have responsibility for construction of latrines in public places and institutions such as primary schools, and markets.

1.2 RURAL WATER STRATEGY

The key strategy concepts and underpinning (MWLE, 2001) approaches are:

I. Demand Responsive Approach will ultimately be adopted so that the people take the initiative and responsibility for improving their water supply situation rather than being passive recipients of government services;

II. Decentralized Implementation: The funds will be channelled directly to districts as conditional grants for implementation;

III. Integrated Approach: A package approach necessary for continued use of facilities and sustainable operation will be used. It includes construction, installation and all software such as mobilization, community-based planning and monitoring, hygiene education, maintaining a safe water chain, promotion of household hygiene and sanitation, gender awareness and capacity building at user level;

IV. Sustainability: as a prime objective of all water and sanitation interventions. No new installations or schemes shall be considered without prior establishment of ownership of the facility and establishment or strengthening the system for operation and maintenance, including sufficient proof that the users are willing and can afford to meet the recurrent costs;

V. Privatization: The Government is committed to the privatization process in all spheres of national development efforts, including various aspects of the rural water sub-sector.

1.3 INSTITUTIONAL FRAMEWORK

A summary of the key players and their respective roles is shown in Table 1.

Table 1 - Institutional Framework of the Rural Water and Sanitation Sector

(continue)

Party	Roles
The Community	• Implementation of Demand Responsive Approach (DRA) • Community mobilization • Ensure community management of water supply and sanitation facilities • Conduct hygiene education
The Sub - County	• Review and prioritize rural communities' requests for WSS improvements • Support communities to plan and budget for community-based WSS • Co-ordinate and supervise WSS work being done in the sub counties including monitoring, accountability and report progress

(continue)

Party	Roles
District Water Office	• Preparation of work plans and budgets for the water and sanitation sector that integrate lower councils plans • Co-ordination and promotion of health education, sanitation, water construction and operation and maintenance activities • Review and prioritization of sub counties for WSS improvements
District Water Office	• Establishment of management information system (MIS); Ensure training and other capacity building measures are in place for lower councils, private sector and communities • Procurement of private sector services for the construction of water and sanitation facilities • Technical supervision, physical and financial accountability Backup technical support for construction, operation and maintenance beyond the capacity of the communities including monitoring and accountability and report progress
Ministry of Water and Environment/Directorate of Water Development (DWD)	• Sector co-ordination • Setting standards • Preparation of guidelines and updating them at the beginning of every financial year through a participatory process involving all stakeholders in light of previous experiences • Monitoring, sector reporting, and carrying out sector-relevant research and development
Technical Support Units (8)	Support districts to • develop and disseminate all required planning data and information • prepare plans and budgets for community-based WSS projects and • provide technical support to sub-counties, rural growth centres and communities, and monitor, report and account for use of funds

(continuation)

Party	Roles
Private Sector	• carrying out construction of water supply and sanitation facilities • supply of goods training materials, pumps, pipes • repairs and maintenance of water supply facilities • provision of consultancy services (e.g. hydrogeological studies, design of piped schemes for rural growth centres) • socio-economic reviews and construction supervision carrying out training and production of promotional materials
Non-Governmental Organisations / Community Based Organisations	• capacity building • resource mobilization • provision of technical expertise to districts and communities
Water Sector Coordination Committee (WSCC); involving all actors i.e. collaborating Ministries, Development Partners, and NGOs)	• To ensure consistency in applied policies and approaches for the delivery of water and sanitation services, especially in the rural areas

1.4 SECTOR COORDINATION AND COLLABORATION

1.4.1 Water Sector Working Group (WSWG)

GOU, through the Ministry of Finance, Planning and Economic Development, has established Sector Working Groups as a mechanism to promote a more consultative and participatory approach in the management of public finances and as a mechanism to increase transparency and accountability in the planning and utilisation of resources.

1.4.2 Sector Performance

The performance of the sector (MWE, 2009) is measured against specific *golden indicators*, which relate to: i) access to safe water in rural areas, ii) functionality of rural water supplies, iii) per capita investment costs for rural water supplies, iv) sanitation in relation to latrine coverage in rural areas, v) hand washing coverage in rural areas, vi) water quality of samples taken from protected sources in rural areas and urban centres managed by National Water and Sewerage Corporation (NWSC), vii) water quantity in terms of the cumulative water for production storage capacity, viii) equity in distribution of rural water supplies, ix) management in terms of functional water and sanitation committees x) gender in terms of women representation on a water and sanitation committee and xi) compliance to water permit conditions.

District Water and Sanitation Committees (DWSC) were reconstituted, so as to carry out over-all coordination more effectively and to oversee all the district water and sanitation activities. Regional meetings will be held under each Technical Support Unit, (the Country has been divided into eight TSUs) on a quarterly basis to share experiences and review the progress of implementation in the districts.

1.5 SUSTAINABILITY SAFEGUARDS

Sustainability will be achieved through the existing management capacity of the community and institutions especially those established by earlier water and sanitation interventions. These will follow the principles of the community based maintenance system (CBMS) and will occur at the following levels.

I. Source Level: a village source committee, Water User Committee (WUC) or Borehole Management Committee will have been created, with at least half of the members being women, during the community mobilization phase. At least two caretakers will be appointed for each source, preferably women. The WUC will collect a user feefrom the residents and are responsible for the maintenance of the installation, including the use of bank accounts to safeguard the maintenance funds;

II. Sub-county Level: the private sector will be responsible for the activities at sub-county level. Private hand pump mechanics (HPMs) will undertake repairs and half yearly preventive maintenance of the hand pumps. Retail distribution of spare parts will take place through shops at sub-county level. The Local Council III (LC3) and sub-county water and sanitation committees will select the HPMs, spare parts dealers and pay for the training of mechanics. Extension staff and local chiefs will provide back-up support and supervision;

III. District Level: wholesale and retail distribution of spares will take place through district-level spare parts dealers, appointed by the local spare parts manufacturers. The District Water Officer will monitor the function of the maintenance system and will undertake the rehabilitation and repairs beyond the capacity of hand pump mechanics.

1.6 WATER SUPPLY TECHNOLOGY OPTIONS

I. Protected Springs: They offer the lowest cost per capita, serving about 150 individuals. This resource is now almost fully utilized in the areas where they are prevalent and accessible. An typical protected spring is shown in Figure 1;

II. Boreholes: Drilled boreholes are and will continue to be the main option for rural water supply, particularly over the long term and will substitute for the shortfall in cheaper supply options. Acceptable yield from boreholes should be in the order of 700 litres per hour, to cater for the estimated 300 people per installation;

Figure 1 - a protected spring

Figure 2 - a ferrocement rainwater tank

XVI. Shallow Wells: shallow (augured) wells offer low cost and generally reliable source for water supply, to cater for approximately 300 people per installation with a hand pump. Unfortunately there has been a misconception about the effectiveness of shallow wells in terms of their restricted aquifer sustainability, water quality and availability. This has been coupled with a poor image among policy makers, development partners, contractors and NGOs. There needs to be a concerted effort to promote shallow well technology and one way is by the use of technological option maps (MULDERS; SLOOTS, 2008). Shallow wells, which dry up during the dry season show a delicate balance between groundwater recharge and demand. A study (MUSIIGE, 2008) undertaken in Kabubbu village, Wakiso District Uganda showed the importance of considering the seasonal variability, institutional and funding options, social cultural dimensions, participatory implementation, flexibility of design options, climate education, environmental concerns and land requirements;

XVII. ***Gravity Flow Systems:*** are relatively expensive to construct, however, they are also relatively cheap to maintain and for this reason are in areas where the population is relatively dense;

XVIII. ***Rainwater Harvesting:*** This water supply source is acceptable from a quality basis but is usually limited to individual households. Rainwater harvesting systems for the community will be considered where there are no other viable water options. An example of ferrocement rainwater tank is shown in Figure 2;

In a study (BAGAMUHUNDA et al., 2007) noted poor quality of the roof surface, the small size of the tank, the long payback period for the tank, lack of knowledge of proper designs and lack of construction skills as some constraints to domestic rainwater harvesting (DRWH). He noted that investing in a domestic rain water harvesting system is economical for a house that is over 500m away from an alternative water source and recommended Government subsidies of 90% for communal facilities and 30% for household systems. The above recommendation is consistent with (KAYONDO et al., 2006) who noted RWH as a feasible option of water supply in the whole country, but the storage capacities varying from region to region dependent on the rainfall amounts, distribution and pattern. This is similar to earlier work, where relationships were developed for tank sizes in bimodal and unimodal climatic areas in different parts of Uganda (RUGUMAYO, 1995). It also bears the *geographical and architectural* constraint of being uneconomical in areas with less than 900 mm rainfall and inequitable in settlements; where over 50% households do not have 5 m^2 per capita of suitable roofing (THOMAS, 2004) and suggests the promotion of *adaptive* DRWH, where it caters for about 70% of the supply.

Currently only NGOs and Community Based Organizations (CBOs) are involved in promotion of RWH. However, for its effective promotion, both a holistic approach to the utilisation of rainwater, and group training in construction and management skills should be considered. Legal, institutional and planning frameworks coupled with government subsidies are required for the promotion of RWH as water supply technology that can be effective in alleviation of poverty. These should be included in the policy, investment strategies, and other planning documents for the water sector. DRWH should also be included as part of District Development Plans, as well as in the supply chain market for spares. A combined implementation approach is recommended, to be coordinated by GOU through DWD.

XIX. Piped Water Supply Systems: In Rural Growth Centres (i.e. areas of population between 1500 and 5000), it may be prudent and more economical in the long run to consider a limited mechanized piped-water system. This number of growth centres is projected to increase to approximately 670 by 2015.

2 SOME MAJOR RURAL WATER SUPPLY INITIATIVES

2.1 THE NURP WATER AND SANITATION PROJECT: CONSTRUCTION OF BOREHOLE SOURCES

Over 330 boreholes were drilled during the period 1992 – 1996 in selected districts Northern Uganda (RUGUMAYO, 1998) as part of the above project, under DWD. Over 260 boreholes were drilled directly by DWD rigs and the balance, were done by an NGO and a private drilling company.

2.1.1 Lessons Learned

Among the challenges experienced by DWD, in the implementation of the project were; slow procurement of casings and spare parts for the drilling rigs, and also logistical problems in timely delivery of materials due to Government bureaucratic procedures. This indicated DWD's limited capacity to carry out an extensive drilling programme. Privatization of drilling operations, with the retention of a small drilling unit for emergency situations was recommended.

2.2 THE SWAP EXPERIENCE

The Ugandan Rural Water Supply and Sanitation (RWSS) sub-sector adopted a Sector-Wide Approach to Planning (SWAp) in 2000/1, whereby all sub-sector funding:

- Followed a common approach;
- Is within a framework of a single expenditure plan (Sector Investment Plan (SIP 15);
- Relies on GoU procedures for disbursement, accounting, monitoring and reporting on progress.

All funds for RWSS investments are transferred to the GoU consolidated fund and then remitted to the Districts as Conditional Grant for RWSS. This has enabled RWSS implementation to take place in all districts at the same time (MWLE, 2004).

2.2.1 Lessons Learned

Despite the difficulties that RWSS has experienced with regards to SWAp, Development Partners and Government should continue, with this approach as it creates Development partner harmonisation. However, when implementing and supporting this approach, a high level of commitment among all stakeholders, and a long time horizon (more than ten years) is required. Also administration and management systems need to be revised.

2.3 THE KIGEZI DIOCESE WATER AND SANITATION PROGRAMME (KDWSP)

The (KDWSP) in Uganda is a good example of a poverty focused community model in a low income country, that has delivered sustainable development and provided a lasting impact in rural development and understanding sustainability in practice (CARTER et al., 2006).

KDWSP has been working with rural communities in south-west Uganda for nearly 20 years. It has so far served around 200,000 people with basic water supply, sanitation and hygiene education, and it adds 20-25,000 to that number annually.

2.3.1 Lessons Learned

The impact of the performance monitoring and evaluation was as follows:

- It led to cost recovery with gravity flow schemes; each scheme maintains over UShs. 50,000 for O&M on their accounts;

- In gravity flow scheme communities, it led to increased spare parts with all the schemes developed with support of KDWSP having spare parts;
- Improved domestic hygiene and reduction in sanitation related illnesses especially among children;
- Effective maintenance of facilities as community members have skills to carry out minor repairs;
- It has led to continued reduction in distance and time in water carrying;
- It creates collaboration between communities and service providers.

This is a good example of best practices which should be replicated elsewhere.

2.4 THE DEMAND RESPONSIVE APPROACH AND EQUITABLE DISTRIBUTION

One of the key policy requirements in the provision of safe water and sanitation services is the demand-responsive approach (DRA). However adherence to the principles of DRA implies that communities that fail to express effective demand are left un-served. Actual adherence to DRA is also sometimes hampered by late release of funds and the pressure to spend funds in time. Overall DRA is partially abused in order to fit in the existing circumstances, which lead to inequitable resource distribution. A study (ASINGWIRE et al*.,* 2006) identified the following as factors that influence the equitable distribution of water supply and sanitation services.

a) Interpretation and understanding of sector strategies and policies;
b) Applicability of policies and guidelines;
c) Resource allocation;
d) Donor and NGO funded projects;
e) Water coverage and monitoring data;
f) Other factors include population distribution and mobility, under-prioritization of community socio-economic status, leadership and commitment in relation to promoting sanitation, people's attitudes and values, insecurity, natural hydro-geological factors, cost of water technology and political influence (real and perceived) among others.

2.5 SELF-HELP INITIATIVES

Self-supply refers to initiatives undertaken by individuals or households, sometimes extending to wider communities, to improve water supply services, without Government or NGO intervention (KABIRIZI et al., 2006). The self-supply initiatives include rainwater harvesting and shallow groundwater.

The notion of self-supply is difficult for many organisations and individuals who are used to implementing "conventional" approaches to community water supply.

2.5.1 Lessons Learned

There are three initial considerations on self-supply support options. These are:

- The use of scoring framework to identify incremental (low-cost) source improvements such as protection, deepening etc.;
- Support and subsidy to private source owners to develop water sources, on the basis that such sources will also be used by the surrounding community;
- Support to private source operators, to enable them to carry out source management and maintenance without the need for water user committees, but with sensitization of user households about the need to contribute financially in return for source reliability.

2.6 CAPACITY BUILDING INITIATIVES

The GOU together with its Development Partners are funding a capacity building program for 94 NGOs/CBOs that are registered with the Uganda Water and Sanitation NGO Network (UWASNET), which is the umbrella organisation for NGOs and CBOs in the water and sanitation sector.

The programme entailed participatory training needs identification by member NGOs/CBOs, use of creative and cost effective capacity building methods and selection of activities such that several organizations in a region benefit (DDAMULIRA, 2006).

To improve skills in financial resources, the members were trained in resource mobilisation and proposal writing/financial management, marketing, and entrepreneurship.

The experience and lessons learnt so far show:

I. Cost effective and efficient capacity building can be realized when the needs assessment/planning and implementation is participatory;

II. Using other training methods such as coaching and apprenticeship is less costly and more effective than workshops and seminars;

III. Building capacity of individual staff leads to developed capacity of NGOs/CBOs which eventually improves their general performance and contribution towards the sector.

2.7 WATER AND SANITATION AND THE DISABLED

People with disabilities are among the poorest and most disadvantaged in Uganda. They lack access to water and sanitation in institutions, e.g. schools, in public places, and especially in their own homes. For these reasons they are more vulnerable to water borne diseases and death.

They therefore need both knowledge about good health and hygiene practices and assistive devices to enable them use facilities that provide easy access to water and sanitation. The Uganda Society of Hidden Talents (HITS) has developed some of these facilities in its own premises. It has also developed assistive devices made of locally available materials for other people to copy (MUSEYENTE, 2006).

2.7.1 Lessons Learned

- There is lack of awareness of the community, government, and institutions about the needs of disabled people;
- Lack of information about accessibility options and the funding for accessible facilities;
- Structures are designed and constructed without considering disabled people’s needs, and are then either impossible or too costly to adjust.

2.8 THE 1995 - 2000 GOU-UNICEF COUNTRY PROGRAMME

The 1995-2000 GoU-UNICEF Country Programme contributed to the achievement of UNPAC goals by collaborating with and providing support to the people of Uganda. the GoU, Non-Governmental Organisations (NGOs) and Community-Based Organisations (CBOs) worked towards ensuring children's rights and equal development opportunities for women and the girl child.

The Programme's overall objective was to improve the public health and general socio-economic development by contributing to the reduction of WES related diseases and reducing the overall workload of women, adolescents and children through improved access to safe WES facilities.

- The country programme intended to provide 2400 new sources in 30 districts over the 5 year period with a budget of US$ 47.58 million and contribute about 25% towards the UNPAC targets in the specific districts.

I. The Impact and Lessons Learned

The Water and Environmental Sanitation (WES) Programme, under the 1995–2000 GoU-UNICEF Country Programme, resulted in a rise in coverage of improved sanitation from 30 percent to 47 percent and a rise in access to safe drinking water from virtually zero to 47 percent. Under the WES Programme alone, safe drinking water was provided to more than 1.8 million rural poor, and improved sanitation to more than 1,500 primary schools. As a result almost 10 million people have access to safe drinking water and adequate sanitation. Regardless of this considerable progress, over 10 million adults and 5 million children still did not have their rights to safe water and sanitation fulfilled.

Two components of the WES Programmes in particular were internationally recognized as best practices:

- School sanitation and water; environmental health conditions improved more than 1,500 schools during its first year of implementation and
- Guinea worm eradication; there was a reduction in the incidence of guinea worm from 126,700 in 1991 to 10,425 in 1994 to 321 in 1999.

I. Following these successes, the GoU requested UNICEF to continue to support WES activities under the 2001-2005 Country Programme. The rapid move to SWAp, with significant new resources being made available by the GoU through the Heavily Indebted Poor Countries Initiative (HIPC), provided UNICEF with a unique opportunity to ensure that implementation was undertaken in a *rights-based, child-friendly* and *community-managed manner*. Emphasis of the 2001-2005 CP is on duty-bearer's capacity development and rights-holder empowerment, the further development of the highly successful *School Sanitation, Hygiene and Water Sub-Programme* and the completion of guinea worm eradication. The *School and Community Sanitation, Hygiene and Water Programme* positioned itself strategically as the interface between the community and service delivery.

II. Sector Achievements

The programme underscored the importance of working through the existing structures to foster sustainability. In the implementation, the WES programme pioneered the process of decentralization. This resulted in district and sub-counties being meaningfully involved in the planning and implementation of water and sanitation sector activities.

WES led the implementation of private sector participation resulted in development of tools for procurement and supervision of private contractors.

Partnerships of NGOs in WES implementation have been particularly successful in areas of internal conflict, where district capacity tends to be particularly weak. These breakthroughs have enhanced Government staff's opportunities to concentrate on planning, supervision and monitoring for Quality Assurance.

The WES Programme initiated the establishment of a well-designed and functioning Management Information System (MIS), As part of this system, a global positioning system approach is being introduced in a phased manner. The programme successfully contributed to raising the confidence of the Government to unreservedly invest its resources into the sector. The Government of Uganda raised its contribution from UShs 4.5 billion in 1998/99 (US$3 million) to UShs 24 billion (US$16 million) under the enhanced HIPC initiatives, which was implemented starting July 2000.

The programme annual review revealed that latrine construction was not matching population growth leading to a complete re-appraisal of the entire field of hygiene and sanitation. Nationally, the *definition of sanitation* was expanded to include:

- Excreta disposal;
- Solid and liquid waste disposal;
- Personal and food hygiene;
- The safe water chain and;
- Vector control.

The WES programme also developed a concept paper on sanitation, *on whose basis* a Cabinet Memorandum was written and approved and a draft Environmental Law and Policy drafted. The most important achievement of this initiative was the holding of the National Sanitation forum of 16 - 17 October 1997, in close collaboration with all sector partners. The culmination of the forum was the signing of the Kampala Declaration on Sanitation. The programme contributed to national efforts to prevent and control the cholera epidemic that broke out in late 1997.

As one of the main strategies, the programme has successfully collaborated and integrated efforts with other partners in the sector such as Cranfield University, Department for International Development (DFID), European Union (EU), Irish Aid, Denmark International Development Agency DANIDA's Rural Water and Sanitation (RUWASA) project, Water Aid, World Health Organisation WHO and the World Bank in the development of the Rural Water Sector Strategy Paper. The WES Programme is also a founder member of the participatory Hygiene and Sanitation for Transformation (PHAST) initiative by the World Bank, WHO and UNICEF.

However, less progress was made in the area of hygiene behaviour due to the focus on latrine coverage as the only indicator for sanitation and due to the many factors involved in effecting behaviour change. Water usage rules remain very low and the contamination of water between the source and consumption referred to as *safe water chain* remain high.

This low level of water use (amongst the lowest in the world) is directly related to access and consequently to women's and children's workload. In the era of Universal Primary Education UPE, school sanitation and water supply has become a particularly serious issue, the pupil: stance ratio remaining extremely high. It is estimated that 2.7% of students' time is lost due to sickness related to poor school sanitary conditions as being one of the leading causes of girls dropping out of school.

2.9 THE OPERATIONS AND MAINTENANCE OF RURAL WATER SUPPLY FACILITIES

A study of Operations and Maintenance of Rural Water Supply Facilities (MWLE, 2001) findings pointed to a largely functioning hence effective Community-Based Maintenance System (CBMS), with the functionality rate of water sources rising from 20 percent before 1986 to over 70.8 percent in 2000. However, the study revealed that the effectiveness of the CBMS relied on projects (SWIP, WES, RUWASA, NGO interventions) that have only a designated duration. Within the government system, there seemed to remain a gap between an active and reliable institutional framework for enforcing the CBMS, and a system that ensures and monitors the respective stakeholders to perform their roles.

2.10 FACTORS AFFECTING CBMS OF RURAL WATER FACILITIES

I. ***Water Source Technology***

The technology of hand pumps has been subject to various modifications and changes, without corresponding training of (HPMs) and provision of spare parts.

II. ***Presence and Functionality of Water User Groups (WUGs)***

Problems faced by WUGs' roles included lack of funds, users refusal to pay for O & M, users refusal to participate in cleaning of source, lack of commitment by some WUC members to attend meetings and lack of spare parts.

III. ***Presence and Functionality of Source Caretakers SCTs***

74.6 percent of the water sources had caretakers who lacked simple tools for use in carrying out their day-to-day work.

IV. ***Presence and Functionality of Hand Pump Mechanics HPMs***

In over a half of the hand pumps (52.1 percent), the WUGs reported an absence of a HPM to carry out repairs in case the source broke down.

On the other hand HPMs complained of delayed under or no-payment for their services and a general lack of tools.

V. ***Presence of Spare Part Distributors and Availability of Spare Parts***

Few districts in the sample were found to have established Spare Parts Distributors SPDs.

VI. ***Back-up support from Projects, NGOs, Sub-county and District Local Governments***

Back-up support from DWD and districts was not readily forthcoming.

VII. ***Supply Driven and Demand Driven Water Facilities***

A majority of sources (77.5 percent) that had been initiated by village leaders/LCs and users/community members were fully functional compared to those whose initiation was external to the community. This was evident in Iganga, and Mubende and Bushenyi respectively.

VIII. Accessibility to Water Facilities

In communities with several cheap alternatives of water sources such as springs, there was a positive relationship between functionality and the existence of such rules.

IX. Community Sensitization

The study findings revealed a positive relationship between community sanitization and source functionality with 74.6 percent fully functioning sources in communities where users had been sensitized.

X. Year of Source Construction

The period the source has served is related with its functional status.

XI. Approaches to O & M, Community Funding and Accounting Procedures

There were no major differences in approaches to O & M. In general, major GoU projects and most non-governmental providers of water facilities have adopted the CBMS.

XII. Community Funding and Accounting Procedures

While communities, especially in Eastern Uganda, had made initial contribution, several WUGs (55.5 percent) were not regularly collecting funds from users for O & M.

XIII. The role of women in CBMS and provision for vulnerable groups

All WUGs were found to have women members, usually in equal proportion to men, but several not occupying positions of authorities.

2.10.1 Lessons Learned

- The strategy for O & M of Rural Water Facilities should not seek to institute major changes but to strengthen the existing system and provide for major breakdowns;
- There is need for monitoring partners in their performance of respective roles, clearly define and publicize each actor's role;
- For CBMS to be effectively sustained, it has to be de-linked from project implementation and have institutional framework that ensures that key players effectively and efficiently perform their roles.

In his study (SENTABA, 2009) notes that the CBMS system is still the best option for rural areas, but little has been done to actualize this. He recommends constant sensitization of the rural community, availability of spare parts at the sub county level, availability of repair tools to HPMs and some form of remuneration as actions that would support CBMS.

3 SANITATION

Sanitation and hygiene promotion is a responsibility of the Ministries of Health, Education and Sports and Water and Environment in Uganda. The slow adoption of behavioural change with regard to Sanitation has led to poor health and poverty -with about 440 children dying of diarrhoea every week and 84% latrine coverage in rural areas (MOFPED, 2004). The following initiatives have been put in place to address these problems.

3.1 TECHNOLOGY OPTIONS

The different on-site technology options include:

a) Traditional Pit Latrines;
b) Pit Latrine with Concrete Slab;
c) Alternating Pit Latrine;
d) Ventilated Pit Latrine (Ventilated Improved Pit, VIP);
e) Alternating ventilated pit latrine;
f) Dry-box Latrine;
g) Pour-flash Latrine;
h) Offsetting pour flash latrine;
i) Modified dry toilet system (NTABADDE et al.,2006).

I. The UPA-Ecosan Concept

The (urban and peri-urban agriculture) UPA-Ecosan concept facilitates sustainable natural resource management and the improvement of urban sanitation and livelihoods. By sanitizing human excrements in an environmentally sustainable approach and providing organic fertilizer, which does not contaminate urban land and water resources, the

UPA-Ecosan concept maximizes both, the benefits of environmental sanitation and agriculture.

II. Human Excreta Treatment Technologies

After faeces are excreted their microorganism concentrations including any pathogens decrease with time in the natural environment during storage handling or sanitation treatment. Faecal treatment includes storage for specific periods, alkaline and other chemical treatment and heat treatment (NIWAGABA, 2007).

3.2 SCHOOL SANITATION

The school sanitation programme is designed to protect the rights of girls, boys and women to improved sanitation, hygiene and safe water in realization of the rights of children to learning, survival and development. Many girls drop out of school due to inadequate sanitation and hygiene facilities to cater for their needs during menstruation, among other factors.

Education, quality of life, good health and economic activity have a positive correlation. Studies have shown that 50% of child morbidity in Uganda is attributed to poor sanitation (RUGUMAYO et al., 2005). The burden of disease study, in 1995 (Uganda Ministry of Health), showed 8.4% deaths as a result of poor sanitation.

During the 1997 cholera outbreak, 560 primary schools were closed due to poor sanitation and several children died. National latrine coverage was 90% in the 1960s, but dropped to 47% in the nineties. In 1995, primary school enrolment was 2.5 million with a pupil: latrine cubicle of 328:1 but rose to 700:1 with the introduction of Universal Primary Education (UPE) in 2001.

A Baseline Survey on sanitation conducted by UNICEF in 1999 across the districts in Uganda revealed that: 99% of the schools in the study area had latrines but only 44% of them had privacy. Majority of the pupils used latrines but only 2% of the schools had the recommended pupils: latrine cubicle ratio of 40:1. 16% of the schools had a latrine assigned to girls or boys only. 20% of the schools had hand-washing facilities next to the latrine. 86% of the schools had urinals and of these 30% were smelly with flies and 15% were poorly drained. Solid waste disposal was reported in schools at only 25% and these were burnt in their pit. 44% of the pupils had knowledge of sanitation and hygiene. 91% of the students mentioned teachers as the main source of information, but 64% of them were not trained on sanitation. In most schools, posters (50%) and books (31%) were present but inadequate and pinned in wrong places.

The Baseline Survey showed considerable progress in sanitation infrastructure and little focus on awareness and behavioural change among the beneficiaries. By this period, few schools had benefited from the projects that were mostly still in the pilot phases and were facing various challenges despite the visible progress. In reaction to this, there were dramatic changes at legislative and policy levels and increased involvement of Government Ministries, External Support Agencies and NGOs in School sanitation projects. The Poverty Eradication Action Programme (PEAP) provided the overall macro framework, while the National Health Policy and National Water Policy elaborated the sectoral responsibilities under sanitation. The Public Sector Reforms of Privatization, Decentralization and Civil Service Reform contributed towards streamlining the roles of the various actors.

3.3 THE KAMPALA DECLARATION ON SANITATION 1998

In 1998/99, initiatives began to clarify policy, assign roles to stakeholders and from a wider perspective, introduce government commitment to poverty eradication and the provision of basic services. Strong emphasis was put on decentralising of the School Programmes in terms of institutional framework. The Kampala Declaration on Sanitation I998 was the landmark in spearheading all these new initiatives. All stakeholders in sanitation formulated ten guidelines in order to improve the sanitation status in the country. These guidelines included: exemplary leadership and commitment; full community mobilization; a focus on schools; the central role of women; focus at the sub-county level; private sector and NGOs in development and service delivery; capacity building at the district level and policies, guidelines and standards.

The overall strategy was through increased funding to support the provision of sanitation infrastructure capacity building and O&M of installed facilities. The key actors in the Programme are; The District Management Team (DMT), Directorate of District Health Services (DDHS), NGOs and CBOs, the District Education Officers and District Water Officers.

3.4 UNICEF WATER AND ENVIRONMENTAL SANITATION

The UNICEF Water and Environmental Sanitation WES (1995-2000) project established productive programmes in community and school sanitation in 34 districts. Its key characteristics were; private sector involvement in sanitation infrastructure and strengthening hygiene education in 735 schools and training 2468 teachers in hygiene and sanitation.

For over 100,000 primary school children, there was adequate sanitation and safe water and another 300,000 had safe sanitation. A total of 1,449 five-cubicle latrines with hand washing facilities were constructed and the pupil: cubicle ratio was reduced from an estimated 700:1 to just above 100:1.

The UNICEF School and Community Hygiene and Water Programme (2001-2005) had by the end of 2002 covered 105,040 children and had reduced the pupil: cubicle ratio from 700:1 to 86:1. 97.2% of the schools were provided with easily maintainable latrines, separate latrines and washing rooms for girls, safe water and hand washing facilities; built next to the latrines. A high level of knowledge of sanitation issues among the pupils was observed. New designs led to more sustainable latrine construction.

The School Facilities Grant Programme (1998-2003) was a direct response to the increased school enrolment, following the introduction of Universal Primary Education. It was aimed at promoting school sanitation in selected districts by building latrines with proper hand washing facilities, classrooms and teachers' quarters. To date, the Programme has built latrines and classrooms in over 8000 schools countrywide.

In April 2002, a survey was conducted in a number of districts and a fairly typical example is Nebbi district which increased coverage with support of a local NGO, from a pupil: latrine cubicle ratio of 130:1 to 97:1 in 2 years.

The Rural Water and Sanitation Programme (1996-2001) (RUWASA) was a Government of Uganda Project funded by the Government of Denmark through DANIDA, with two phases that lasted until 2001 in 12 districts in Eastern Uganda. A total of 3,650 school latrines cubicles were constructed and approximately 721,800 rural people got access to safe drinking water. It was noted that approximately 50% of the pupils are knowledgeable about hygienic practices through hygiene education. Some latrines however, have been filled to capacity.

I. The Facilities

Latrines were designed with a vent and pre-fabricated movable slabs to allow for mobility. The latrine designs were gender sensitive, and took into account the disabled needs. Deliberate standardization of facilities by the Government helped to ensure quality and value for money across the country.

The provision of hand washing facilities encouraged students to wash their hands after using the latrine and before eating food. PVC tanks with a capacity of 10,000 cubic litres and a tap were centrally purchased and distributed to identified schools, with the greatest needs in the district for instance, St. Kizito Primary school in Kampala, Teachers' seminars were also held on how to mobilize and supervise latrine construction.

II. Changing Hygiene-Related Behaviour

Some of the activities linked to behaviour change included: sensitization of students on the pros and cons of good and poor sanitation and how to improve their overall standards Teachers' training seminars on proper sanitation techniques, and behaviour change. Students' sanitation competitions in essay writing, picture drawing and drama, production of a TV documentary, printing of shirts and caps with the slogan, *"Better school sanitation a responsibility for all"*. Also Health parades and Sanitation clubs were established in schools such as Kavumba Church of Uganda Primary School in Wakiso and Railway Primary School, Kampala so as to maximise awareness and behaviour change.

A sanitation calendar with the District Inspector of Schools caution was published.

III. The Girl Child

Emphasis was put on the special needs of the girls like putting up changing/washing rooms for girls, enclosed latrine facilities to ensure privacy, a school Health and Sanitation Club, a senior woman and health parades. Consequently, the awareness levels increased though behavioural change leaves a lot to be desired. Mafubira Primary School in Jinja won the 2002 Award for the Girl-Child Education, owing to recognition of special needs for girls. Many schools are still faced with the challenge of finances, to buy the sanitary materials needed.

IV. The Disabled

The School Facilities Grant made special provisions for the disabled pupils by providing at least one teacher to be educated on special needs mandatory for all schools. One stance was built specifically for disabled pupils and those with serious disability are in schools for physically handicapped.

3.4.1 Achievements and Lessons Learned

The Overall Achievements were as follows:

Water provision and adequate sanitation to over 400,000 primary schools, reduction of the pupil: cubicle ratio from 700:1 to 100:1, rainwater tanks, educational and media promotional materials were developed. A 20% increase in the total population with access to safe protected water.

More access to safe drinking water within walking distance. 20% increase in safe water coverage.

Improved living conditions and the burden of work for women and children reduced. Sanitation coverage increased by 33%. A new standardised design for latrines was developed. In the different schools, the success of the sanitation program can be attributed to the balance between the hardware sanitation facilities and software components awareness and behaviour change. Children awareness of hygienic practices has been raised through hygiene education and adequate sanitation facilities, but this does not necessarily mean behaviour change. There has been funding by UNICEF, World Bank, DANIDA and World Vision. A community–based operation and maintenance has been emphasized and the continued commitment of teachers in school sanitation has been encouraged in order to achieve sustainability.

3.4.2 Recommendations

A well defined institutional framework, strengthening behavioural change, partly, by better management systems and better monitoring and evaluation, remain the main challenges these programmes are facing. Other challenges at all administrative levels include; political interference in resource allocation, corruption, unfair distribution of facilities, limited funds to build latrines that are gender sensitive, and more flexible technology for differing soil and water conditions, coupled with poor coordination among stakeholders.

This implies that there is need for improved MIS, equitable distribution of sanitation facilities, more funds, school and community co-operation, child-to child approach in ensuring capacity building, training for life skills, practicing PHC and the use of fairly simple technology, Private contractors also need more control, to prevent shoddy workmanship.

Notably, behaviour change still needs to be prioritised; Using Uganda's success in combating the AIDS scourge as a good example of the importance of behaviour change.

3.5 OTHER HYGIENE AND SANITATION EXPERIENCES

I. The Girls Education Movement (GEM)

GEM is a, girl-led global movement of children and young people, operating through schools. GEM's goal is to bring about positive social transformation in Africa by empowering girls through education. While boys act as strategic allies, the adults - women and men - provide the wisdom of age. It makes the decision on how to interact with and help one another at all administration levels in co-operation with appropriate government, civil society and donor organizations.

Their activities (BITATURE et al., 2006) included the following; i) Peer guidance and counselling, mentoring, especially by the older girls in leadership. ii) Income generating activities, such as vegetable growing to create self-reliance. The income generated was used to cater for girls menstruation essentials like sanitary pads,i ii) Music and drama as a tool for mobilisation and sensitisation in girls hygiene and HIV/Aids and advocating for schools to provide sanitation material for girls, iv) Development of Information, Education and Communication (IEC) materials to reinforce verbal messages and act as teaching materials and learning aides, v) Building Bathrooms which gave girls an opportunity to manage menstruation hygienically and more privately.

This shows that girls with the strategic partnerships of the boys can succeed in influencing behaviour change. It further underscores the effectiveness of participatory approaches.

II. Kigezi Diocese Water and Sanitation Programme

Some of the innovative approaches (NKURUNUNGI et al., 2006) used by Kigezi Diocese Water and Sanitation Programme (KDWSP) include: i) Staff Residence: Residing within the community is undertaken after the community has received initial training in hygiene and sanitation related issues. While there, they undertake home visiting, provide hygiene education at household level; follow up action plans drawn by individual households and visit primary schools for health education. ii) Collaboration with the Community leadership and other CBOs such as mother's union. iii) Training Methodology, which include study tours, health and hygiene competitions, use of demonstration villages and homes, among others, iv) Involvement of children

KDWSP has found that good practices such as hand washing and safe excreta disposal can be adopted and sustained through the approaches outlined above, which the programme undertakes. Of particular importance is a high degree of involvement of the communities at all stages of the project.

III. The Participatory Hygiene and Sanitation Transformation (PHAST)

In Uganda, over the past 10 years, (PHAST) approach has become well established. However, a recent study of the Cost-Effectiveness of PHAST has revealed that minimal positive hygiene behaviour change has been sustained despite the fact that this participatory approach is excellent at transferring knowledge (WATERKEYN, 2006).

In Uganda's eastern Busia District, notable improvements in sanitation coverage have been achieved during a two year period by employing a "Carrot and stick" approach by district authorities. The District Director of Health Services initiated a hygiene campaign following a serious cholera outbreak in the district. In this campaign, House owners were told to construct and use latrines and hand-washing facilities and the health extension staff gave explanations as to why this was especially urgent and necessary.

Social marketers use the '4-Ps' of Marketing: product, price, place and promotion. Not only do social marketeers want to sell a product (e.g. soap), they also inspire customers to use the product correctly and behave differently (e.g. wash hands with soap after defecating). This approach has been successful iin Ghana, Senegal and Burkina Faso in promoting behaviour change, with the use of appropriate communication channels.

IV. Community Health Clubs

A programme that initiates a process of behaviour change by strengthening social cohesion and peer pressure within communities, using the Community Health Club approach, has been proven successful in Zimbabwe. A participatory course that is well structured and uses PHAST training materials and methodologies has been developed that targets, not just one or two behaviours, as in most "vertical" interventions to reduce disease; but is "horizontal" and targets a whole raft of hygiene issues.

V. The Internally Displaced People (IDP) Camps of Northern Uganda

In Gulu District, this displacement accounts for 89% of the population in 33 IDP camps all of which, have between 15,000 people and the largest at Pabbo having 68,000. These temporary settlements are characterised by congestion, scarcity of basic sanitary facilities, shortage of water, poor drainage and poor hygiene, with high levels of malaria and diarrhoea.

To address these social constraints within a short time frame the Applied Health, Education and Development AHEAD methodology, used Community Health Clubs (CHCs) (WATERKEYN et al., 2006). By using Community Health Clubs of between 70-150 people, it was possible to effect a rapid transfer of information and improve home hygiene practices, using peer pressure and the development of a 'Culture of Health' (WATERMEN, 1999). The design also incorporated local approaches to health promotion, adapting the standard (PHAST) methodology, which had been used in Uganda during the 1990's.

In response to the emergency situation in the north and south west and. The WES Programme focused on alleviating hardships of (IDP) camps that in Gulu, Kitgum, Bundibugyo, Kabarole and Kasese districts, by providing handpumps as shown in Figure 3.

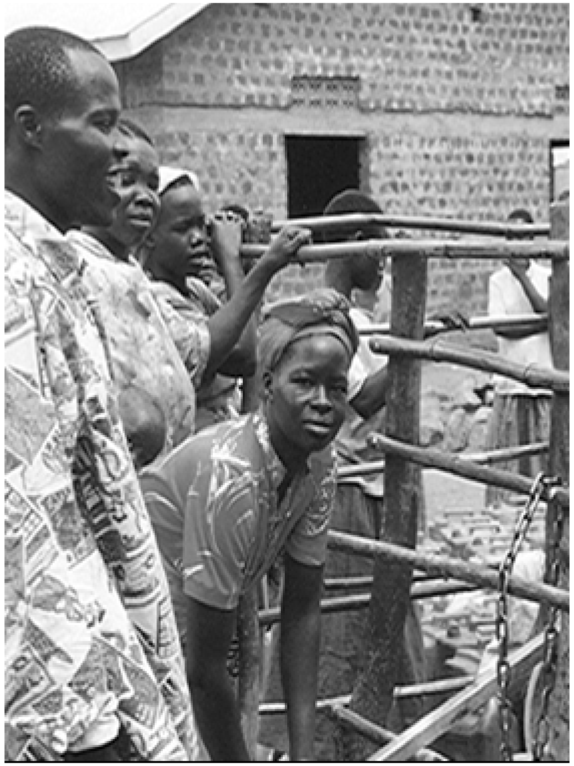


Figure 3 - UNICEF Supported water pumps at IDP camps in northern Uganda
Source: UNICEF (2002)

Also a new design of poly sanplat was employed: it is made of strong, light-weight polyfibre, and can be delivered in bulk, obviating the time-consuming task of training communities to make cement sanplats, as well as the difficulty of transporting, storing and accounting for cement.

VI. Women's Hygiene in Emergency Situations

Under a Concern World Wide project, supported by UNICEF; the following major interventions to poor hygiene in relation to women in IDPS were identified formation and training women group committees leaders, in hygiene education and how to effectively manage menstruation in an IDP camp setting purchase and distribution of underwear, cotton cloth, basins and soap.

Construction of 96 bathing shelters for use by women to improve their personal hygiene and monitoring and evaluation.

There is a high percentage of people satisfied with the project materials and hence the project concept, indicating that women will be willing to replace the perishable materials over time depending on their income.

VII. The National Handwashing Campaign

The National Hand Washing Campaign (NHWC) hosted by Uganda Water and Sanitation Network (UWASNET) started in 2005 on the premise that the leading causes of under five mortality are malaria (23%), pneumonia (21%) and diahorrea (20%) and studies have shown that handwashing with soap at critical times can reduce the incidence of diahorrea by half and almost half for the incidence of respiratory diseases. Soap is affordable for the majority of households and on average represent 4% of the total household expenditure (MFPED, 2004); therefore hand washing is practical, accessible behaviour to Ugandans.

A baseline survey on hand washing behaviour (STEADMAN, 2007) gave the following results:

84% of the adults recognized the need to wash hands with soap after using the toilet, only 14% wer observed to do so.

A National Hand Washing Steering Committee has been set up where government has joined with Development Partners like DANIDA, DFID, UNICEF and WSP World Bank, Private companies, like Mukwano, Unilever and UWASNET. The campaign is engaging social and marketing techniques to reach its primary target audience of mothers of children under 5 years who are most vulnerable to diahorrea and acute respiratory infections. Media like radio, community meetings, hand washing promotion visits will, be among the promotion tools (UWASNET, 2007).

3.5 RURAL WATER AND SANITATION SECTOR PERFORMANCE

I. The Uganda Water Sector has progressed well with overall water coverage standing at 64% while urban contributes 90% and rural 64%. This compares with the average for Africa at 64% overall with urban coverage at 83% and rural coverage at 51%. In the case of sanitation the national coverage is at 33% consisting of 29% urban and 34% rural. This compares with the average for Africa at 37% overall, with 29% for urban and 34% for rural. This means significant investments are still required to improve the coverage (OECD/ADB, 2009).

II. The performance of the Water and Environment Sector against the golden indicators in the Financial Year 2008/2009 (MWE, 2009) is summarised in Table 2.

Table 2 - Performance of the WES, Financial year 2008/2009

	Golden Indicator	Performance
i.	Access to safe water in rural areas	65%
ii.	Functionality of rural water supplies	83%
iii.	Per capita investment costs for rural water supplies	US$ 43
iv.	Sanitation in relation to latrine coverage in rural areas	27%
v.	Equity in distribution of rural water supplies in terms of the number of persons per water point is	178
vi.	Management in terms of functional water and sanitation committees	62%
vii.	Gender in terms of women representation on a water and sanitation committee is	71%

Based on the Water and Environment Sector Performance Report 2011, 65% of the population have access to a safe water source within 1 km and a total of 637,100 persons were served by new water supplies in financial year 2010/2011 with a per capita investment of US$ 47. Low staffing levels especially in the new districts have affected the performance in the implementation of new programmes. There has been a slight increase in the functionality of water user committees from 70.2% in the previous financial year to 71% in 2010/2011. The national functionality of systems has stagnated between 80% - 83% over the past 2- 3 years below the target of 90% by 2015.

The household latrine coverage in rural areas is estimated at 69.8% and the access to handwashing is 24%.

4 RECENT STUDIES

This study (TRIPLE S., 2012) was carried out in the western districts of Kabarole, Kamwenge, Kasese, Kyenjojo and the northern districts of Lira, Kitgum, Alebtong and Nwoya as shown in Figure 4. The objective of the research was to assess the performance of the community based management system CBMS in terms of service delivery and compliance of stakeholders with their roles and responsibilities.

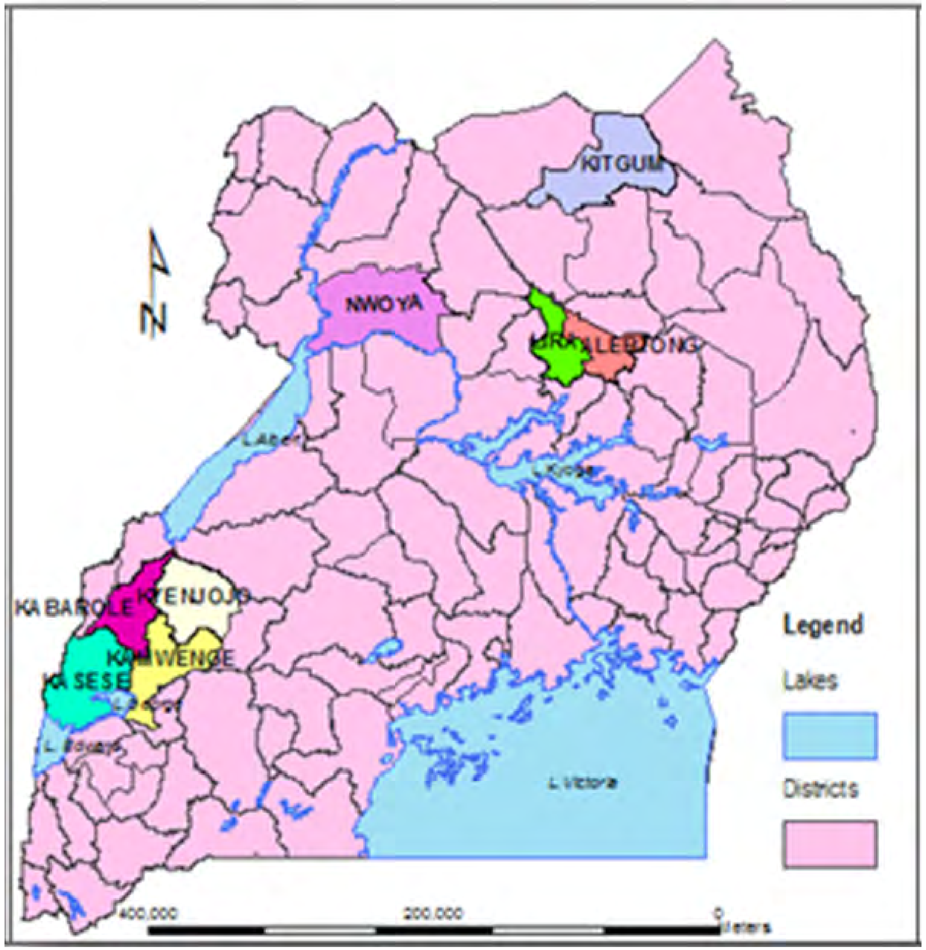


Figure 4 - Study area

The Service delivery baseline survey was conducted as an in-depth assessment using a participatory approach where IIRR and Triple S teams and other key stakeholders were involved in the baseline survey implementation. It used a combination of household questionnaires, semi-structured household interview questions, the Qualitative Information Systems methodology for Focus Group Discussions (FGDs), field observations as well as Key Informant Interviews to gather the necessary data.

A sample size of 5% of the population and in the pilot phase 80 households were interviewed in each sub county, while the full scale up phase was 200 households from each district (a total of 1600 households). A set of sixteen (16) water user groups and water user committees were mobilized in each district, and a random selection of household water users participated in the interviews, while scheduled key informant interviews were conducted for the service authority levels; sub county officials, DWO and TSU).

4.1 MAIN FINDINGS

a) Water Users

Figure 5 - Women and children collecting water at borehole with a handpump

Figure 6 - Water collection at standpipe from a gravity scheme

More than 80% of sources are within 1km. 35% of the respondents pay for their water and for those who pay, 75% find it affordable and it was assessed to be affordable by their monthly expenditure on mobile services as compared to the required monthly water user contributions towards the water services operational maintenances.

The levels of satisfaction with respect to quality, quantity and collection time were 80%, 80% and over 60% respectively. Figure 5 shows women and children collecting water at a borehole with a handpump and Figure 6 shows collection of water with jellicans at a standpipe of a gravity scheme. It was also observed that the presence of a well managed water user committee directly affects the functionality of the water source. The presence of toilet facilities was high (>80%), but handwashing facilities were less than 38%).

b) Service Providers

Most water user committees WUCs were established during the last 10 years through democratic elections. WUCs consist of 8 members on average, 50% of who are female and literate. The number of households using the water source ranges is about 190. The registration of users is 50% and the average households registered is about 80%. Over 92% of the sources have caretakers and only 42% are compensated for their services, only 22%of the caretakers have received training,70% of the sources have handpump mechanics and 81% are easily available, are compensated and 69% have adequate skills. With respect to hand pump mechanics and in of the cases they are readily available, while have adequate skills. 85% of the WUCs have a signed agreement with the LC1. 56% of the users are accountable, with more than 50% providing support for repairs and in most cases the sub-county is accountable. On the whole less than 20% WUCs are functional. Based on the data collected, it can be said that; a) there is a direct relationship between water user satisfaction and reliability of source, and b) there is a direct relationship between the reliability of the source and contribution towards repair.

c) Service Authority

I. Sub County

The following activities are being undertaken at the sub-county level depending on the resource envelope and skills of a particular sub-county. i) conducting baseline surveys to assess the sanitation situation, ii) community mobilization iii) identification of handpump mechanics, iv) training of WUCs and Caretakers and v) signing of a Memoranda of Understanding. WASH coordination varies and in some cases there are regular meetings for planning, implementation and reporting by DWO, Sub county staff, NGOs*. The YY strategy (Credit and Savings scheme) based on water services as noted in Mucwini Sub-county in Kitgum District and Kahungye Sub-county Kamwenge District is an innovative strategy. The YY strategy has enabled some communities to organize and improve their lives around the management of water sources, into an economic vehicle for engaging communities beyond water supply management.*

II. District Water Office

The staffing levels at the district vary and are measured against the staff establishment of a District Water Office. In some cases, the vacant positions include: District Water Officer, Assistant District Water Officer, County Water Officer, Borehole Maintenance Supervisor, Health and Sanitation Officer, Community Development Officer and Extension Workers. DWO need to be properly facilitated for execution of his duties. These include the provision of: a digital camera, a photocopier, GPS, water quality testing equipment and reagents, a motor bike, computers, bicycles and even office space. The full complement of documents include: i) the Conditional Grant Guidelines, ii) the District Implementation Manual, iii) the Community Handbook, iv) the O&M Framework and v) the O&M Guidelines for WSSB. The documents most referred to in the execution of their duties are i) to iv). Except the DWO in Lira, all other districts have a document or two missing. In terms of procurement most districts exhibited average performance with a few showing very efficient and transparent methods. In terms of construction supervision an example of best practices is in Kasese district, whereby there is weekly reporting to the DWO and monthly reporting for the larger projects through the submission of progress reports.

In terms of financing, most districts receive nearly all the grant funds from central government and the expenditure is usually as budgeted. The selection of sources to rehabilitate has been well streamlined in some districts, whereby the HPM, sub county extension staff and the community are involved in source selection, monitoring, operation and maintenance and documentation. An example of best practice is *in Kasese district and Nwoya district. Also In Kamwenge, Kasese, Kyenjojo and Alebtong districts, the association of handpump mechanics has been formed, which have been very instrumental in establishing new water sources and maintaining existing ones. One of the challenges the HPM associations face is the lack of spares or dealers at the subcounties or even at the districts. Sometimes water quality monitoring was done randomly, irregularly and on a quarterly basis.*

III. Service Support-Technical Support Unit

TSUs meet all DWOs and explain all mandatory reporting requirements with deadlines though the compliance is not good. Most guidelines are adhered to though not all but TSUs have no authority to enforce compliancy, so they forward them to higher authorities. They provide training in data management and have developed capacity building plans and participate in field visits with district staff and coordinate inter-district meetings, carry out spot checks on the water atlas mapping information.

Local governments do not involve TSUs in procurement activities; however TSUs follow up in case of delayed procurement though they are not responsible for direct contract management. TSUs also guide and mentor new DWOs on their work. Most districts are well coordinated though TSUs assessment of district performance is very limited because they are few in number yet required to cover a wide operational environment and they are limited by their operational budget, especially with respect to capacity building and field visits.

4.3 CONCLUSIONS AND RECOMMENDATIONS

There is need to strengthen the functioning of the WUCs whose presence contributes positively to the reliability and functioning of the water sources.

Notably, HPMs associations makes it easier for community to access the HPMs and also the sub counties and the districts find it effective to support them through capacity building. This is evidenced by the high levels of water source functionality in districts like Kamwenge and Kyenjojo where HPMs associations are existent. Hence, it is recommended that *all* sources should identify a handpump mechanics and subsequently HPM associations established in each of the sub counties and districts so that they can improve their performance and efficiency and benefit from capacity building initiatives. *The water user groups in some western districts have organized themselves into credit and saving schemes using the water supply management agenda as an economic vehicle in their local communities.* These credit and saving groups are called YY (a**Y**ahuraa**Y**ehoza) which literally means "He *who saves can easily borrow*". This initiative has encouraged local communities to participate in water source management while at the same time promoting a culture of financial saving. The saved resources are available to the water user group members at lower interest rates compared to the market rates. This strategy of integrating part of the community economic life proved to be a sustainable approach for rural water management as evidenced in Kamwenge District.

Based on the success of the YY credit and savings schemes it is recommended that the provision of safe water should be accompanied by *other business activities* that would encourage the community to pay their user fees and even make savings. It could be *integrated rural water supply with a business component.* Other recommendations that apply to WUCs, the Sub county, the District Water Office and TSU are operational in nature. They require more funding, more guidelines and more documentation and more community mobilization and more capacity building.

5 OVERALL CONCLUSION

This paper discusses the policies, the institutional framework, various programs and initiatives and lessons learned and recent studies, in the rural water and sanitation sector in Uganda during the past twenty years. There have been significant successes along with some challenges. What is clear is that Uganda (UBOS, 2012) is on course to achieve the *Millennium Development Goal Target 7C* and sustainable water and sanitation.

REFERENCES

A National Health Policy, Ministry of Health 1999, Entebbe, Uganda.

A National Water Policy, Ministry of Water, Lands and Environment, 1999, Kampala, Uganda.

African Economic Outlook 2009, African Development Bank and the Development Centre of the Organisation for Economic Co-operation and Development, Tunis, Tunisia.

Annual Report 2006/7, UWASNET, 2007, Kampala, Uganda.

Asingwire,P., Muhangi, A., and Odolon,J.,*Factors Influencing Equitable Distribution of Water Supply and Sanitation Services In Uganda*, 31st WEDC International Conference , Kampala, Uganda, Loughborough University,2006, UK.

Bagamuhunda, J.T., Ntale, H.K. and Rugumayo, A.I., *Assessing Constraints of Domestic Roof Water Harvesting for Water Stressed Areas of Kabale District*, Conference on Collaborative Research for Technological Development, 17-18 December, 2007, Kampala, Uganda.

Bitature, A., Barebwoha, C., *Girls Education Movement (GEM) Clubs,* Uganda Proceedings of the 31st WEDC Conference Kampala, Uganda. Loughborough University, 2006,UK.

Carter, R.C., Rwamwanja, R. and Bagamuhunda, G., Uganda, *Achieving a Lasting Impact in Rural water Service*, 31st WEDC International Conference, Kampala, Uganda. Loughborough University, 2006, UK.

Cong, R., *Donor Harmonization in Uganda, Water and Sanitation Sector*, Proceedings of the 31st WEDC Conference Kampala, Uganda. Loughborough University, 2006,UK

Ddamulira, P.D. and Kiiza, S., *Capacity Building for Improved Performance in the Water and Sanitation Sector*, Proceedings of the 31st WEDC Conference Kampala, Uganda. Loughborough University, 2006, UK.

Final Donor Report1996-2001 UNICEF Country Programme, UNICEF 2002, Kampala, Uganda

Issue Paper No 3, *Framework for Sector-Wide Approach to Planning Water Supply and Sanitation Sector.* Joint GOU/ Donor Review of the Water and Sanitation Sector 2001, Directorate of Water Development. Ministry of Water, Lands and Environment, Uganda.

Issue Paper No 5, *Strategy for Rural Water Supply Investment including Operations and Maintenance*, Joint GOU/Donor Review of the Water and Sanitation Sector 2001. Directorate of Water Development, Ministry of Water, Lands and Environment, Uganda.

Kabirizi, A., Carter, R.C., Mpalanyi, J.M. and Ssebalu, J., '*Self-help Initiatives to Improve Water Supplies in Eastern and Central Uganda*', 31st WEDC International Conference, Kampala, Uganda. Loughborough University, 2006, UK.

Kahororo, E.B. and Twanza, E., *Uganda, 'Promoting Women's Hygiene in Emergency Situation*, Proceedings of the 31st WEDC Conference Kampala, Uganda. Loughborough University, 2006,UK.

Kayondo, H.K., Naturinda, D.N., Rubarenzya, M.H. and Kasingye, K., *A Rainwater Harvesting Strategy for Uganda*, Proceedings of the 31st WEDC Conference Kampala, Uganda. Loughborough University, 2006, UK.

Kiconco.G. and Bagamahunda,G., '*Communities take on Operation and Maintenance Responsibilities The Case of Kigezi Diocese*, 31st WEDC International Conference , Kampala, Uganda, Loughborough University, 2006, UK.

Kimanzi, G. and Danert, K., Uganda, '*Out of Projects and into SWAP: Lessons from the Ugandan Rural Water and Sanitation Sub-sector'*, 31st WEDC International Conference, Kampala, Uganda, Loughborough University, 2006, UK.

Ministry of Education and Sports, '*Strategy Paper for the Promotion of Sanitation and Hygiene in the Primary Education sub-sector in Uganda*," September 2001, Kampala, Uganda.

Mulders, C. and Sloots R. *The Overburden Aquifer and its Potential to reaching the MDG Targets for Safe Water*, Proceedings Groundwater and Climate in Africa, 2008, Kampala, Uganda, Ministry of Water and Environment, University College, London., UK.

Musenyente,E., Uganda, '*Low-Cost Assistive Devices for Disabled People's Access to Water and Sanitation*', 31st WEDC International Conference, Kampala, Uganda, Loughborough University, 2006,UK

Musiige, R., *The Challenge of Climate Variability and Change to the Sustainability of Shallow Groundwater Supplies , A Case Study from Kabubbu Village,* Uganda, Proceedings Groundwater and Climate in Africa, 2008, Kampala, Uganda, Ministry of Water and Environment, University College, London,UK.

NGO Performance Report for 2007, UWASNET, 2008, Kampala, Uganda.

Niwagaba, C., *Human Excreta Treatment Technologies – Prerequisites, Constraints and Performance, Licentiate Thesis,* Department of Biometry and Engineering, Swedish University of Agricultural Sciences, 2007, Uppsala, Sweden.

Nkurunungi,M.,Bekunda,K. and Asiimwe,J.,*Community Participation in Improvements of Environmental Hygiene and Sanitation.* Proceedings of the 31st WEDC Conference Kampala, Uganda. Loughborough University, 2006,UK

Ntabadde, M.K., Niwagaba, C.K., Rugumayo, A.I., *Design of a Modified Dry Toilet ventilation System to Accelerate Drying*, Proceedings of the 31st WEDC Conference Kampala, Uganda. Loughborough University, 2006, UK.

NURP Implementation Manual, Directorate of Water Development, Ministry of Natural Resources, 1993, Kampala, Uganda.

Rugumayo, A.I., Baseera, B. and Kesimire, H., *Up Scaling School Sanitation*, Proceedings of the 30thWEDC International Conference Vientine, Laos, Loughborough University, 2005, UK.

Rugumayo, A.I., *Rainwater Harvesting in Uganda* Proceedings of the 21stWEDC International Conference, Kampala, Uganda, Loughborough University,1995, UK.

Rugumayo, A.I., *The NURP Water and Sanitation Project*, Proceedings of the 23rd WEDC International Conference Durban, South Africa, Loughborough University,1998, UK.

Sentaba,S.J., *An Assessment of the Performance of Community Based Management Systems in the Management of Water Facilities in Rakai District*, M.Eng Dissertation, 2009, Department of Civil Engineering, Makerere University, Kampala, Uganda.

Statistical Abstract 2012, Uganda Bureau of Statistics (UBOS) 2012, Kampala, Uganda

Steadman Associates, *A Baseline Survey on Hand Washing Behaviour in Uganda*, UWASNET, 2007, Kampala, Uganda.

Study of the Operation and Maintenance of Rural Water Facilities in Uganda, Directorate of Water Development, Ministry of Water, Lands and Environment, 2001 Kampala, Uganda.

The Burden of Disease Study, Ministry of Health 1995, Entebbe, Uganda.

The Local Governments Act 1997, Uganda Printing and Publishing Company, Entebbe, Uganda.

The Uganda National Plan of Action for the Child (UNPAC) Ministry of Finance, Planning and Economic Development 1993, Kampala, Uganda.

Thomas,T., *Domestic Roof water Harvesting in Rural Uganda – A Proposed Action Plan for the Directorate of Water Development*, 2004, Ministry of Lands, Water and Environment, Kampala, Uganda.

Triple S / IIRR / SNV, Profiling Rural Water Service Delivery Models (SDM) in Uganda, 2012 Kampala, Uganda.

Uganda National Household Survey, Ministry of Finance Planning and Economic Development 2004, Kampala, Uganda.

Uganda National Integrated Survey of 1992/93, World Bank, UNDP, 1994, Ministry of Finance, Planning and Economic Development, Kampala, Uganda.

United Nations Development Programme *Roadmap towards Implementing the United Nations Development Millennium Declaration*, UNDP, 2001, New York, USA.

Water and Environment Sector Performance Report 2009, Ministry of Water and Environment, 2009 Kampala, Uganda

Waterkeyn, A., *Uganda, Hygiene and Sanitation Strategies in Uganda, How to achieve Sustainable Behaviour Change*, Proceedings of the 31st WEDC Conference Kampala, Uganda. Loughborough University, 2006, UK.

Waterkeyn, J.,Okot, P. and Kwame,V., Uganda, *'Rapid Sanitation Uptake in the Internally Displaced People Camps of Northern Uganda through Community Health Clubs*, Proceedings of the 31st WEDC Conference Kampala, Uganda. Loughborough University, 2006,UK

Windberg, C., Otterpohl, R., Nkurunziza, A. and Nasinyama, G., Uganda, *the UPA-Ecosan Concept in Uganda: Socio-acceptability and Hygiene Safety'*, Proceedings of the 31stWEDC Conference Kampala, Uganda. Loughborough University, 2006, UK.

URBAN WATERS IN AN URBANIZED WORLD

Carlos Eduardo Morelli Tucci[1]

[1] Feevale University and IPH – UFRGS. Email: tucci@rhama.net.

ABSTRACT

Urban population is increasing to about 70% of total population in the middle of this century. Water use and impacts are one of the main aspects of a sustainable urban population. Developed countries have a stable urban development and most of the processes will occur in developing countries. Integrated Urban Water Management (IUWM) is the main tool in development sustainable urban environment for developing countries. This paper assess the main issues of developing countries e presents the framework of IUWM for these countries in order to reach a better sustainable human and environment development for the cities.

1 URBANIZATION

In 1900, 13% of the global population was urban; in 2007 it increased to 49.4% (figure 1), occupying only 2.8% of global territory. In 2050, world's urban population would be 69.6% (UN, 2009). The world is becoming increasingly urban because of economic development and job distribution. In developed countries, the population is stable and urban population is already large, but in developing countries the population is still growing and by 2050 the world population would reach about 9 billion with most of its growth being in the cities (UN, 2009).

The main effects of urbanization in poor and developing countries are: (a) income increase; (b) decrease of fertility; (c) high population density; (d) expansion of population on water source basins; (e) high concentration demand and impacts of natural resource.

The main problems related to infrastructure and urbanization in developing countries is:

a) Large population concentrations in small areas, with inadequate transportation systems; inadequate water supply and sanitation, air pollution and flooding. These unsuitable environmental situations reduce health conditions and the quality of life of the population, cause environmental impacts and are the main limitations for sustainable development;

b) Increase of the city's boundaries in an uncontrolled manner due to rural migration in search of employment;

c) Urbanization is spontaneous and urban planning is conducted for the portion of the city occupied by the middle and upper class population;

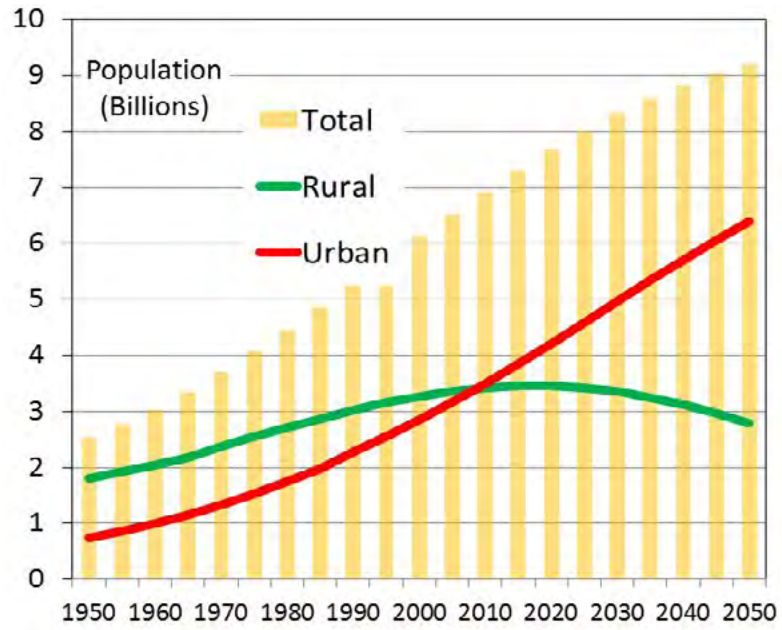


Figure 1 - Urbanization (Planning Sustainable Cities. UN Habitat. 2009)

d) Limited institutional capacity of the communities with deficiencies regarding: legislation, law enforcement, maintenance of the facilities, technical support and economical funds;

e) Lack of Integrated Urban Water Management (IUWM) – The main problems are:

- Interconnection of stormwater and sewers networks;
- lack of domestic sewage treatment or inefficient sewage treatment;
- increase of floods on the urban drainage;
- losses in the water distribution systems;
- solids in the drainage system;
- erosion and occupation of risky areas of flood plains and hill sides (which have been the main causes of deaths during storm events);
- limited garbage cleaning and education, among others.

2 URBAN WATERS HISTORIC VIEW

Until the beginning of the 20th century, one of a great challenges in the cities was to avoid the proliferation of diseases, especially those caused by sanitary conditions created by sewage, which contaminated drinking water sources, creating ideal conditions for the proliferation of infectious diseases (*pre-hygienist phase*).

The supply of water from secure sources and the collection of sewage and its release downstream (without treatment) from the city's water source, was designed to avoid diseases and their effects, but transferring the impacts downstream. This is called the *hygienist phase*. Urban growth accelerated after the Second World War, when there was a population explosion known as the "baby boom". This process is followed by accelerated urbanization, leading a high portion of the population to the cities, resulting once again in the collapse of the urban environment due to the non-treated effluents and to air pollution.

To control of these impacts, at the beginning of the 1970's, an important step was taken with the approval of the Clean Water Act in the United States, which imposed that all effluents needed to be treated with the best available technology before it was disposed in rivers. Massive investments were made in residential and industrial sewage treatment, partially allowing a recovery of the water quality in rivers, lakes, reservoirs and along the coast. These actions improved environmental conditions, avoiding the proliferation of disease and the deterioration of drinking water supplies. In this same period, it was perceived that it was not sustainable to construct stormwater structures that would increase the flow, such as the channeling of natural rivers and conduits. Attempts were made to revise procedures and use storage systems instead of channeling. This was denominated the *corrective phase* of urban waters.

Despite these actions, pollution persisted due to urban and rural flooding, called pollution from diffuse sources. Since the 1990's, developed countries have invested in sustainable urban development policy based on treatment of urban and rural pluvial waters, and tertiary treatment of effluents for the removal of nitrogen and phosphorus that cause eutrophication of lakes. This was called the *environmental sustainable phase.*

Sustainable land use is the implementation of urbanization which preserves the natural flow path and gives priority to infiltration. This phase has been received many different names in different continents such as Low Impact Development LID (NAHB, 2004). The main strategies are developed "upstream" in the planning and design of new areas, changing the traditional "end of pipe" planning and design. In this type of approach, the occupation has to take into account all the facilities and the environment, when land use is planned.

Cities in developing countries are found in various stages. Initially, when the population is small, water supply came from wells or from a nearby body of water. Sewage was released in septic tanks. When the population grew the load increased because of population density (buildings or too many people occupying the same space), and the septic tanks would spill sewage flow through stormwater network all the way to the rivers or, when the networks did not exist, through streets. It contaminated river water or groundwater, which were sources of drinking water. Usually septic tanks are not efficient for high load, low infiltration capacity or high water table, transferring its load to streets or stormwater pipes, and to the rivers. In addition, urbanization has created floods, erosion, and water quality deterioration in the stormwater due to the increase of impervious areas and the velocity of the flow by conduits, channels and impervious surfaces.

3 CHALLENGES OF DEVELOPING COUNTRIES

The main challenges for developing countries in urban areas are related to the following interconnected aspects:

- Water supply coverage: lack of safe water and competition with other uses such as irrigation has been a great challenge in major cities (for instance, Jakarta);
- Protection of water sources: pollution from point and diffuse sources in the upstream basin decreases the water availability due its quality;
- Increase sanitation coverage: it has been the main cause of contamination of water sources in urban environment together with environment degradation;
- Improve solid waste services: this is another major source of contamination due to the low quality of services and education in many metropolitan areas, with reduction of river system conveyance and pollution;
- mitigation of urbanization impact on the flow: develop source measures in order to reduce the transference of impacts in the urban basin;
- Lack of services and management, professionals, capacity building and permanent institutions;
- Develop measurable goals and indicators.

4 INTEGRATED URBAN WATER ASSESSMENT AND PLANNING

The Urban water goals are the following:

- Deliver safe water for human, animal, industrial and commercial use; Improve conservation, avoid degradation of area by erosion, treat sewage and stormwater effluents, and minimize solids in the streams from urban settlements;
- Reduce vulnerability to diseases and floods.

The main actions in order to develop a sound strategy for an integrated urban water management are:

- Sustainable urban development: Implement new urban development standard taking into account the issues of sustainability of water: (i) limits for densification and impervious areas; (ii) reserve of areas for parks and green areas; (iii) restrictions and economic incentives for conservation of urban source basins;
- Protect the water supply sources: regulate the occupation of the water supply basin;
- control the load of water supply basin; improve water quality;
- Improve water supply distribution: development of a program of investment in order toincrease the water supply network and improve the quality of water supply;
- Develop a system of waste treatment: investment on the collecting and treatment system for all urban areas;
- Flood Control Management: develop regulation for new development, controlling the future flood increase; develop flood management plan for each basin;
- Total Solids Management: develop sound services for total solids in order to decrease the amount of solids in the drainage;
- Water and environment conservation: stormwater pollution control, environment recovery of selected environment.

These targets have to be achieved by means of integrated management and interrelated actions within a region, which covers more than a basin. The development of this integrated plan requires a review of strategies over the three major water sources and the metropolitan area, together with large investments over a longer period. Every component of the plan requires specific goals and strategies.

In order to achieve these goals the following steps are necessary:

- Assessment of the urban water issues: identification of the problems in urban waters and all integrated aspects;
- Plans and Strategies: development of the planning for solution of the problems in the urban water services in the city ;

- Action Plan: implementing strategies in urban waters in a timely fashion, taking into account the needs and the economical and financial aspects of the investments.

The main plans and strategies for an urban management in the city are (figure 2):

- Urban occupation: develop or review the Urban Master Plan in order to include regulations related to urban waters;
- Water and Sanitation provide protection of water supply sources, water supply and sewer collecting and treatment;
- Total solids: a plan to improve the services and reduce the amount of solids from sediments and solid waste which reaches the drainage;
- described in chapter 4 for a sound plan for flood control;
- Environment: a plan for recovery of degraded areas in the metropolitan area and for a long term recovery of the rivers and coast environment, after the provision of other services;
- In order for these plans to be feasible in their implementation, there is a need for institutional construction of the water management in the basin and at municipal level.

The development of this integrated plan is an important challenge since most of these plans were previously developed in an independent way without connections and sometimes with conflicting conditions. The main difficulty is identifying skilled professionals to understand the overlapping aspects and issues which should be solved in an integrated way.

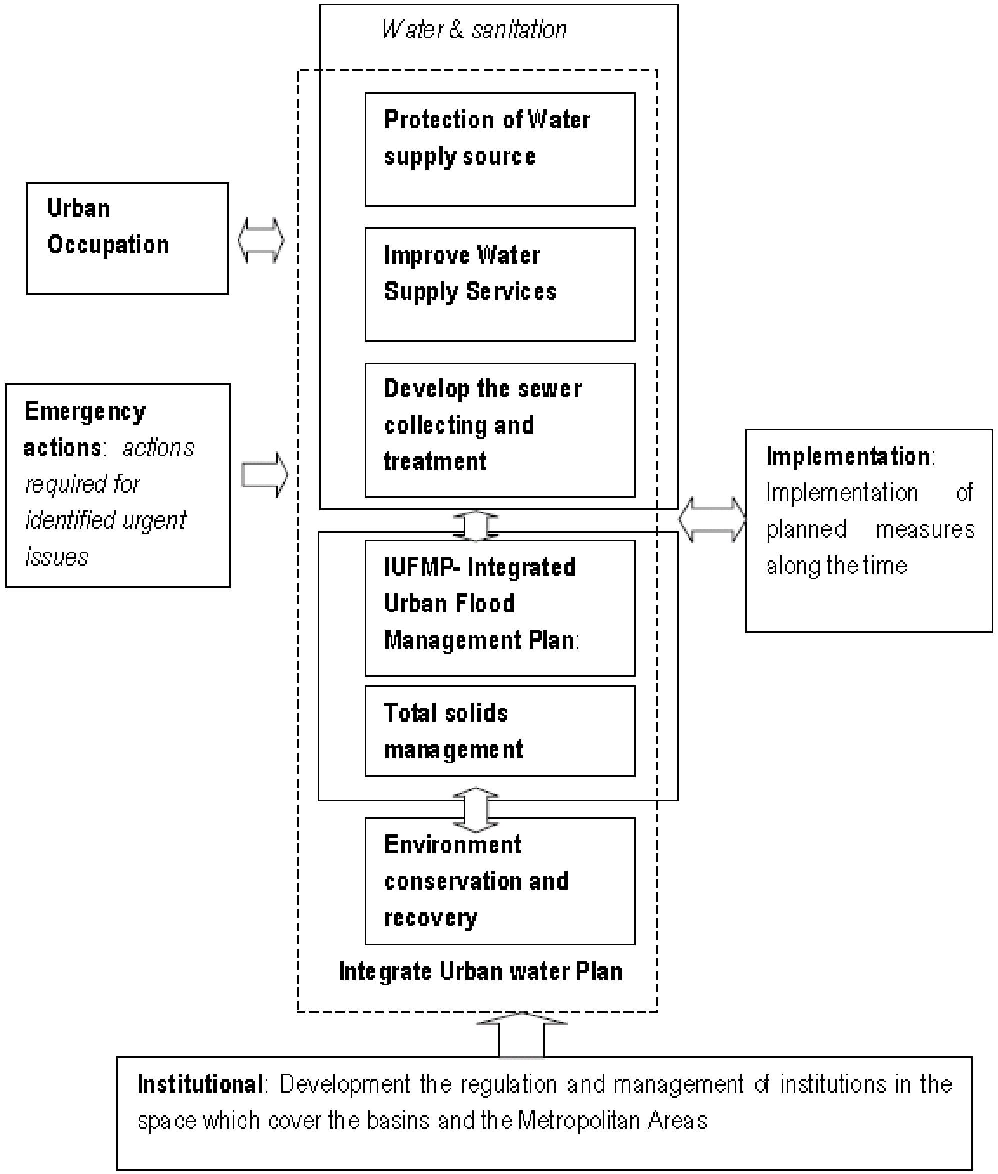


Figure 2 - IUWM Framework
Search: Tucci (2009)

REFERENCES

NAHB RESEARCH CENTER. 2004. Municipal Guide to Low Impact Development. Maryland. Available on-line at http://www.lowimpactdevelopment.org

TUCCI, C.E.M.,2009 integrated urban water management in large cities UN,2009 Urban and Rural

http://www.un.org/esa/population/publications/wup2007/2007urban_rural.htm accessed in 01/16/2009.

WORLD BANK, 2009. World Development Report 2009.Reshaping Geography Economic.World Bank.

SUMMARY

ACHIEVEMENTS AND OPPORTUNITIES: DRINKING WATER, SANITATION, AND HEALTH BEYOND 2015

Corinne J. Schuster Wallace[1]
Zafar Adeel[2]

[1] United Nations University Institute for Water, Environment and Health.
[2] United Nations University Institute for Water, Environment and Health.

ABSTRACT

Despite national and international commitments to expanding access to water, sanitation, and hygiene, scale up is slower than required, significant inequalities exist, and little attention has been paid to service levels and operation and maintenance. As we transition from the Millennium Development Goals into the 2030 Development Agenda, which is predicated on principles of sustainable development, a new approach is required. This new approach must be founded in innovative business models, evidence-informed decision-making, multi-stakeholder co-operation and co-ordination, and attention to social, economic, and environmental implications.

1 INTRODUCTION

The global water crisis – signified by hundreds of millions without access to safe water and adequate sanitation services as well as associated health implications – is one characterised and amplified through inequities. Obvious inequities include access to water and sanitation in high-income countries, where coverage is almost universal, to low-income countries where coverage is less than 70% and 50 %, respectively (WHO; UNICEF, 2015). These disparities also cut across socio-economic boundaries within low- and middle-income countries (LMICs), in which the poorest of the poor are most likely to be unserved (WHO; UNICEF, 2015) and rural inhabitant access lags significantly behind urban counterparts partly as a result of more than 80 % of aid being directed to urban areas (GLAAS, 2014). Another significant inequity pertains to gender; women and girls shoulder much of the responsibility for hauling and managing water, and disproportionately bear the adverse health and economic impacts resulting from lack of access to these basic services. And yet they possess little if any authority over, or even participation in, decision-making. Finally, an inequity manifests in the shape of investment trends in the water supply and sanitation sector. Within LMICs, government expenditure and investments in this sector fall significantly behind those for the health and education sectors. On average, less than 2 % of GDP in LMICs is invested into provisioning of water and sanitation services compared to other social services which can be as high as 10% (GLAAS, 2014). Moreover, only 50% of aid has been targeted to low income countries historically, while these countries account for 70% of the unserved population (GLAAS, 2012).

It cannot be over-emphasized that significant health benefits accrue from access to safe drinking water and adequate sanitation services (e.g. Hutton, 2012; HSBC, 2012), not the least of which are reductions in morbidity and mortality primarily through reductions in gastro-intestinal illnesses. These also directly correlated to potential reduction in public health costs in the long run. Larger "ripples" include gains in education and economic activity; in particular as local communities and entrepreneurs can be empowered to create livelihood opportunities through service provisioning. One such example is the use of anaerobic digestion to treat human, animal, and solid waste (organic materials). Sale or use of the by-products generated as a result of the breakdown (digestion) of organic materials can offset capital investments as well as operation, maintenance, and expansion. In this manner it is possible to start closing the financing gap for sanitation scale-up and realise the economic, health, and environmental benefits of biogas use for fuel and residual slurry use for agriculture (SCHUSTER-WALLACE et al., 2014).

Despite these economic and social benefits, lack of access is still costing some countries up to 7% of GDP annually (WSP Economics of Sanitation Initiative, 2012). From a regional perspective, this translates into losses of $5.5 billion per year for 18 African countries (WSP, 2012). One may, therefore, ask the question: Given that investments in drinking water and sanitation make economic, development and moral sense, why is the world struggling to achieve universal access for these basic services, let alone achieve the Millennium Development Goal (MDG) target for sanitation by the year 2015?

We argue that the barriers to achieving universal water and sanitation coverage are not technological or financial; many affordable solutions exist to obtain, treat, distribute and store drinking water, as well as to dispose of human waste hygienically. While there is always room for technological innovation and improved efficiency, these certainly do not constitute a stumbling block towards universal access. Financial investment and capital are clearly still required, but the focusing of national development policies – coupled with investment of time and expertise – is arguably more important.

Another major impediment to progress in service provisioning is correlated to lack of community empowerment, engagement, and ownership (SCHUSTER-WALLACE et al., 2015). This is further underpinned by a lack of capacity development for long-term sustainability and inappropriate solutions given physical, social, economic, and cultural contexts (SCHUSTER-WALLACE; SANDFORD, 2015). These can only be overcome by investing in the building of relationships and the understanding of community needs and strengths. An additional dimension is that of gaps in information flow and access to the economic and health issues surrounding the access to water and sanitation services; to state the obvious, reliable and reputable information is the cornerstone of decision-making and can go a long way in empowering communities. For example, community mapping in Tanzania provided not only information back to the community, but linkages to supporting institutions (GLOCKNER et al, 2004). Information opens the gate to dialogue, which leads to engagement and understanding. To take an example from the health sector, anti-malaria bed net campaigns have had considerable success in spreading information on how people are exposed to malaria and who are most vulnerable to the disease. These education campaigns have led to increased use of bednets, particularly by mothers of young children. Ironically, these mothers are putting their children's lives at risk by not paying attention to sanitation and its links to water and foodborne diseases; not through lack of interest, but ignorance of the disease transmission pathways and consequently the role they could play in ameliorating the risk of exposure. Save the Mothers, a Master's degree programme in Public Health Leadership in Uganda, takes this one step further. The programme targets representatives of specific sectors – educators, politicians, journalists and public health practitioners – to educate them on the importance of infant and maternal health and how they can use their positions to advocate for positive change. Currently, the program is rolling out a Mother Friendly Hospital initiative which is sharing knowledge with hospitals on how to improve child and maternal mortality rates through concrete steps that include access to high quality water and sanitation (CHAMBERLAIN; WATT, 2012; http://www.savethemothers.org/).

One of the largest information deficits in water supply and sanitation interventions regards the socio-cultural context in which technologies can be appropriately applied. For example, many cultures dislike the taste of chlorinated water. This often results in community members returning to traditional (untreated) water sources. Similar issues arise with boiled water; some cultures reportedly don't like the taste of 'baked' water. When asked why people practice open defecation, an individual responded that after their body has been beaten by a bout of chronic diarrhoea, they want to grab a stout branch and use it to support their weight (LEVISON et al, 2012). Why don't we design VIP toilets with handles? Tools that can be used to assess social capital, knowledge, attitudes, and practices of community members and linkages with government structures and other communities can provide important information beyond that of the physical environment and are essential for sustainable interventions (SCHUSTER-WALLACE et al., In Press).

2 ACHIEVEMENTS

Since the announcement of the Millennium Development Goals (MDGs) in the year 2000, significant progress has been made towards increasing access around the world to drinking water and sanitation facilities. Indeed, it is argued that the MDG target for cutting by half the number of people without access to safe drinking water – measured by the UN system as the access to an "improved drinking water source" – was met in 2010, some five years ahead of the 2015 deadline; others argue that the original target relates to provisioning of safe drinking water, which was in fact not measured directly or achieved. Indeed, it has been estimated that if water quality is used as an access measure, almost two billion people would still be considered unserved (ONDA et al., 2013). Still, the fact remains that some additional 2 billion people received access to an improved drinking water source over a 20-year period (1990-2010) (WHO, UNICEF, 2012) and at the end of the MDG period, almost 90% of the global population have access to improved drinking water supplies (WHO, UNICEF, 2015).

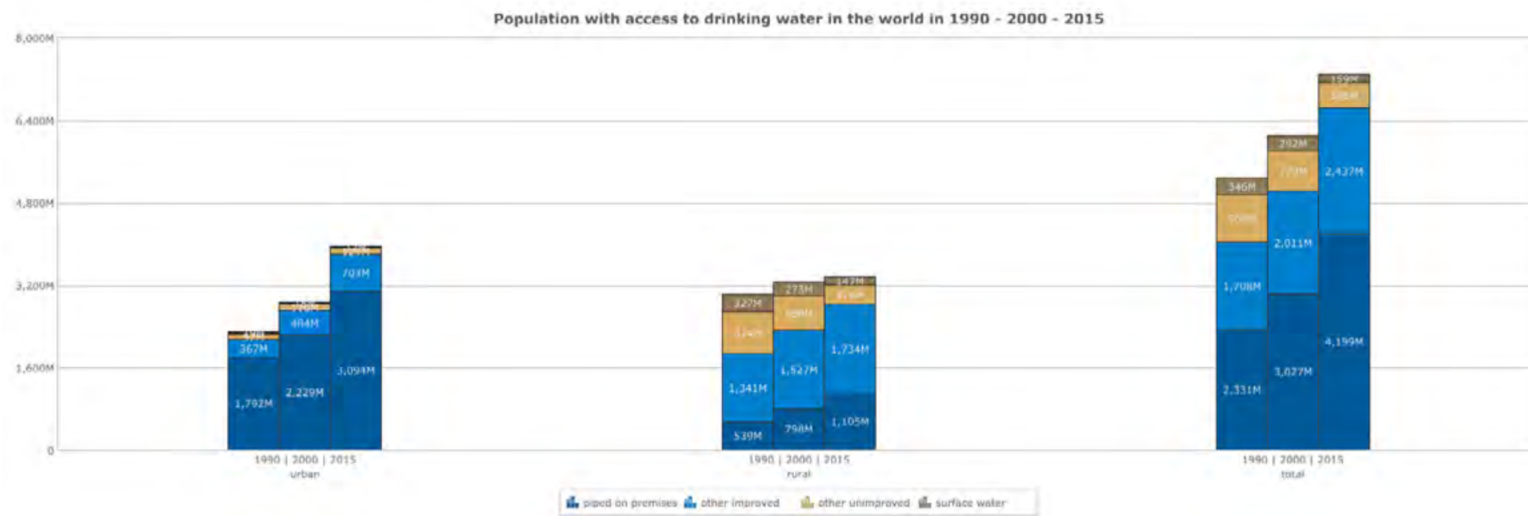


Figure 1 - Global Water Coverage, 1990-2015
Source: WHO and UNICEF (2015)

The UN General Assembly has provided significant political support to this cause by formally recognizing drinking water and sanitation as a human right in 2010 (UN General Assembly Resolution 64/292, 2010). While not everyone voted in favour at the time, abstainers such as Canada and the UK have recently acknowledged the resolution. It is understandable that while a resolution like this does not translate immediately to action on the ground, it does provide the leverage for prioritising resources, both financial and physical water supplies, as well as policy and legal mechanisms that can increase accountability and reduce discrimination (BOYD, 2012).

In 2010, financial ministers from least-developed countries were brought together with representatives of donor countries for the first high-level meeting for Sanitation and Water for All (SWA) (http://sanitationandwaterforall.org/). The second such meeting held in April 2012, resulted in national commitments to provide sanitation access to an additional 300 million people and drinking water to over 200 million people over the next few years. International donors have already been disbursing over US$7 billion to sanitation and water as a “sector” around the world. In 2014, more than 300 commitments were made by 43 countries, mainly focusing on universal access to water and sanitation, addressing inequalities, and increasing service levels.

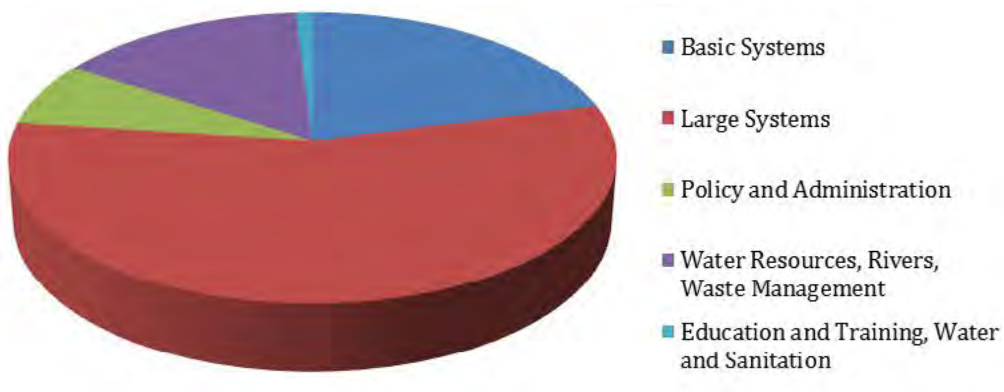


Figure 2 - 2012 Aid Commitments by Water Sector Type
Source: modified from GLAAS (2014)

SWA participants further committed to reducing the number of people practicing open defecation by over 80 million people. A reduction in the number of people practicing open defecation is critical to achieving the sanitation-related MDG target, as it is practiced by about 1.1 billion people around the world and contributes significantly to adverse health outcomes as well as causing contamination of the environment and water resources. In support of the need to eradicate open defecation as part of the sanitation MDG, the UN launched an advocacy campaign – Sanitation Drive to 2015 (www.sanitationdrive2015.org) that was augmented by the UN Deputy Secretary General's End Open Defecation Campaign (http://opendefecation.org/news/) in 2014.

Perhaps the greatest achievements are being realised at the local level. Here, engagement, empowerment, and action are making a sustainable difference. In South Asia, partly as a result of Community Led Total Sanitation (CLTS) or Community Approaches to Total Sanitation (CATS) 110 million people stopped practicing open defecation by 2010, but India accounted for 60% of those still practising (WHO and UNICEF, 2012). Global defecation rates have now fallen to 25% of global population (WHO and UNICEF, 2015). In the Lake Victoria Basin, we have observed that UNU-INWEH's projects with modest budgets – often costing less than US$15,000 per community – are able to dramatically change lives and communities. Within this UNU-INWEH initiative, one community was struggling with a good quality water source (45m borehole) that was accessed using a manual foot pump. With a missing generation of parents as a result of the HIV-AIDs epidemic in this area, the task of operating the foot pump fell to grandmothers, who were struggling to draw enough water for themselves and their grandchildren. An investment in a solar powered pump, storage container and piping has resulted in a water supply at the turn of a tap and an extended gravity-fed distribution system that now serves 4,000 people within a 2 km radius. Immediate health benefits have been significant, particularly in the reduced number of cholera cases. More important, however, are the broader societal benefits, including greater community cohesion and development of long-term plans for providing water access to local schools and a clinic with maternity centre.

3 OPPORTUNITIES

Despite significant progress over the last two decades, many opportunities exist, not only for investment of resources and capacity development, but for transdisciplinary research to develop the evidence base for appropriate solutions and mechanisms for scaling up locally successful solutions. Access to adequate sanitation services in particular requires significant attention, notably in rural communities. UNU-INWEH recognises this challenge and is focused on developing tools to help understand community needs as well as scale up proven sustainable solutions. Opportunities exist in four complementary areas: implementation of the MDGs and extrapolation to achieving universal access; monitoring and data analysis; scale up of appropriate solutions; and, developing innovative financing and business models.

While the MDGs have been criticised, for example, as distorting national priorities (UNECOSOC, 2008), they have brought global attention and resources to bear on issues of inequity. While success in keeping pace with population growth and meeting the needs of those without access has not been as timely as is ideally needed, the challenges in implementation have been identified and solutions explored. At the same time, issues have also arisen around accountability of resources already invested, selection of adequate and SMART[1]indicators, and sustainable and meaningful monitoring.

This is exemplified through the issues around indicators for Target 7c; "improved drinking water sources" are not necessarily of sufficient quality to protect health and are not necessarily available on an around-the-clock basis (a contributing factor to poor water quality). Thus, while the target has ostensibly been met according to the WHO and UNICEF Joint Monitoring Report and over 2 billion people have gained access to improved drinking water since 1990, many are still at risk for waterborne illness and unable to capitalise on the supposed benefits improved access to safe water should bring. We believe that a further factor in the absence of observed health improvements is the lack of adequate sanitation services, and in many cases, the lack of understanding around basic principles of hygiene.

While the emphasis of national and international development should remain on continued progress towards achieving the MDGs by 2015, it is now the time to look towards the future. That future must include universal access to basic services of water, sanitation and primary healthcare. Not only will this reduce the current burden on individuals, society, and national economies, it will provide the foundation blocks for resilient communities needed to cope with future uncertainties associated with global environmental change. A broad approach for developing a new set of development goals was initiated at the UN Conference on Sustainable Development (the Rio+20 Summit). The conference participants agreed that this new set of 'sustainable development goals' – or SDGs – should be "action-oriented, concise and easy to communicate, limited in number, aspirational, global in nature and universally applicable to all countries, while taking into account different national realities, capacities and levels of development and respecting national policies and priorities." In this context, they already agreed that "We commit to the progressive realization of ***access to safe and***

[1] Specific, measurable, attainable, relevant and time-bound.

affordable drinking water and basic sanitation for all, as necessary for poverty eradication, women's empowerment and to protect human health" (emphasis added).

The process for the development of the SDGs has been far more inclusive than that for the MDGs, soliciting expert and civil society inputs alongside traditional member state consultations and dialogues. Two considerations, however, remain paramount. First, the evidence-base for how any set of goals, and related targets, can be achieved at the national and international level remains largely missing. While the goals being proposed are aspirational in nature, they neither reflect well the realities and capacities at the national level, nor do they offer mechanisms through which these gaps can be addressed (SCHUSTER-WALLACE; SANDFORD, 2015). Second, the cross-linkage of the drinking water and sanitation goals to other development objectives remains difficult to visualize and quantify. Based on first principles and some anecdotal evidence, we should anticipate significant improvements in health, economic conditions, school enrolment – particularly for girls, and adaptive capacity to crises. However, no such cross-linked goals are on the table yet.

Further, as Cheng et al. (2012) have identified, water and sanitation are key elements underpinning many of the development indicators. Thus it behoves planners and decision-makers to ensure that these elements are considered in development plans. Indeed, within the context of a green economy and sustainable development goals, access to purpose-appropriate water and sanitation (wastewater treatment) cannot be ignored.

Developing indicators and related monitoring programmes must form part of this future debate. Targets have to be developed alongside appropriate quantitative indicators, the data for which are either being collected or can be collected easily and cheaply. Given the many contributing factors to be considered in any holistic approach to global sustainability, it is essential to integrate data, especially at the water-health nexus (CONFALONIERI; SCHUSTER-WALLACE, 2012). More broadly, national governments should be paying attention to and investing in monitoring and surveillance systems. While these programmes are long term and not necessarily politically lucrative, these data sets will be increasingly invaluable in contributing to informed decision-making in face of uncertainties pertaining to global changes.

4 SCALING UP SOLUTIONS

There are very few practical examples of good pilot solutions for provisioning of drinking water and adequate sanitation services that are then scaled up to a national or regional level. We need to better understand and address the roadblocks to scaling up. Scale-up of solutions requires capacity at all levels, dissemination of physically, socially and economically appropriate solutions and, investment - not only in terms of capital costs but also for long-term operation and maintenance (O&M). Resources required to achieve these elements are not mobilized mainly due to deeply embedded perceptional roadblocks in the minds of politicians, policymakers and the general public alike. These roadblocks include the notion that water, and perhaps sanitation, are a human right and thus should be provided to all free of cost. This notion impedes any efforts to mobilize capital from governments and the private sector, because there is no capital recovery possible if this notion is implemented explicitly. A related roadblock is the strong lobbying done by many NGO groups against rational water pricing, making it difficult to make the business case for international investments in water and sanitation provisioning. Yet another roadblock is the avoidance of public discussions around toilets and sanitation – which is considered taboo in many societies. This limits public engagement and interest as well as lack of any push on politicians and governments.

Let us analyze the limitations in scaling up of solutions to universal provisioning of drinking water and sanitation services.

According to GLAAS (2012; 2014), aid flow for basic water and sanitation systems remained static at approximately US$1.1 billion annually while aid flows for large systems increased by 65 % between 2000 and 2008. Since 2008, investment in basic systems increased to a high of 26% of total aid by 2010 but has since fallen back to 21%. This implies that both donor and recipient governments, for more than one reason, favour large systems. The greatest needs, however, are for smaller and remote communities that would typically require smaller systems; consequently, there appears to be a mismatch between needs and investments. Additionally, and somewhat unfortunately, sustainability is not valued in many interventions involving foreign investments. This is evidenced by the amount of money invested in infrastructure versus O&M. According to GLAAS (2012), in 11 countries, only 31% of funds were invested in O&M. This compares with current investments in the United States, which is 60 % O&M (ANDERSON, 2010). By 2012, 70% of countries reported that tariffs are insufficient to cover O&M (GLAAS, 2015).

While infrastructure is essential for service delivery, sustainable delivery can only be achieved through holistic consideration not only of the water quality and quantity, but of the capacity required to continue service provision over time. Unfortunately, lack of capacity is a negative feedback loop within a country. If capacity does not exist, then there is no capacity to train others. Therefore, the first priority must be professional development and training trainers in order to supply capacity internally. The 2012 GLAAS report made it clear that very few countries even understand the capacities – human, technological, institutional, and service delivery – required for universal coverage of drinking water and sanitation, let alone have policies in place to build that capacity over time. Despite this finding, a similar conclusion is drawn in the most recent GLAAS report (2015), highlighting not only capacity to implement, but a lack of capacity for monitoring and evaluation leading to a lack of evidence-informed decision-making.

A parallel experience is occurring in the health sector in Sub Saharan Africa. There is a shortage of physicians, especially serving rural areas. Moreover, these physicians need to be able to incorporate public health into their practices to reduce the burden of preventable (infectious) diseases in their clinics. Kenya's approach to this problem is to provide a Master's of Medicine in Family Health, a holistic approach to treating the individual rather than the disease. However, to ensure sustainability of the programme, there has to be capacity within Kenya to teach the programme before the rural positions can be filled. Of the 15 graduates from the programme to date, ten have been assigned to district hospitals. More important at the roll out is the fact that five graduates are in management positions in health facilities and one of the graduates is now Chair of the Department at Moi University and therefore well placed to start growing the programme both in terms of faculty to teach and graduates who are equipped to work in rural clinics. Two other universities in Kenya will be rolling out similar programmes over the next 12 months. The water sector can learn from this approach to building local capacity– first, capacity has to be built in training (i.e. education and institutional capacity) which can then be used to train the next generation of professionals who understand that all apexes of the WASH triangle need to be dealt with concurrently to protect health and wellbeing and environmental integrity, as well as to promote economic growth. In the meantime, it is essential to provide current practising professionals the opportunity to learn the importance of transectoral approaches within the water and sanitation sector. The UN Water Learning Centre is one approach to reaching these professionals, by delivering e-learning courses through 6 regional nodes around the world. Core content is developed by a team of international experts at UNU-INWEH and is then customized with region-specific content and case studies at each of the delivery node. In this manner, the course can be certified by UNU while content is regionally specific and appropriate.

In terms of understanding what works where and why, this is best learned from failures as well as success stories. A much greater emphasis needs to be placed on communicating experiences to others. This serves to ensure that for example, failures are not repeated; technology developers understand the constraints and implementation issues on the ground; and, governments and others are able to identify the best solutions with scale up potential. HydroSanitas (www.inweh.unu.edu/Health/SafeWaterProvisioning.htm) is one such initiative currently under development at UNU-INWEH that commits to sharing relevant and validated information within and between sectors and stakeholder groups for the purpose of improving water access in rural and remote communities.

Not all solutions need to be technologically-advanced or "modern" – particularly when one considers the immediate needs, and related humanitarian crisis triggered by them, in many developing countries. It is essential to recognise that many benefits can be realised through other types of interventions, including those that directly incorporate traditional knowledge and local customs. This is particularly important in attempting to improve use of sanitation facilities. In eradicating open defecation, for example, changes in attitudes and behaviour are far more important than the type of toilet built (although it is recognised that some are much better at securing and treating human waste than others). This is why community approaches to sanitation (CATS) has been so successful in transitioning communities to be open defecation free. In a similar vein, many communities in arid regions have centuries-old "low-tech" methods of rainwater capture and storage. These range from terracing hillsides to slow runoff for increased infiltration to using stones as mulch around fruit trees, to building large underground channels and reservoirs that reduce evaporation and channel the water to where it is needed (ADEEL et al., 2012).

Yet another major gap underlying the inability to implement large scale solutions for remote, rural areas is the lack of effective business models that can help provide the financial resources and capital. Typically, investors into such community-level projects face a high level of risk and limited return on investment, even if the community is generally willing to pay for these services. New and innovative solutions are required to serve this so-called "base of the pyramid" (BOP) element within developing countries. The Japanese International Cooperation Agency (JICA) has initiated some projects that utilize a business model in which Japanese entrepreneurs can receive initial capital funding as a long-term loan, in order to facilitate BOP implementation. Others have investigated setting up of cost-recovery schemes from sanitation-based projects, mostly through sale of waste-based manure or other related products (USHIJIMA et al., 2011).

5 CONCLUSIONS

While we should not play down the significant accomplishments achieved to date, we cannot afford, from an economic, environmental, humanitarian, or moral perspective, to stop advocating for and facilitating universal secure access to both safe drinking water and adequate sanitation. As has been observed through the establishment of the SWA and embarking on the International Year of Sanitation and launching of the 5-Year Sanitation Drive campaign, it is possible to increase global awareness and national and international commitments to drinking water and sanitation. However, more needs to be accomplished, especially given that water is the “core of sustainable development” (UN, 2012).

When looking at the distribution of those with and without access, it is very clear that key population groups have been left behind: the most vulnerable people in society, including rural and indigenous populations and the poorest of the poor. Water has been falsely prioritised over, and divorced from sanitation and hygiene, as evidenced by the woeful progress on the sanitation MDG target. This does not make sense from an epidemiological perspective – because safe drinking water in itself cannot lead to better health outcomes if unhygienic practices continue and contact with human waste is not eliminated – or from a source water protection perspective – because open defecation and unsanitary waste disposal pose a great threat to water sources and eventually to human wellbeing. A holistic community approach, including schools and clinics, is required, as is recognition of the multiple needs for water. One does not require water of potable quality to irrigate crops or water cattle, and this should be duly considered when securing community water supplies. Furthermore, this community-based approach must be situated within the national and local political context. While action has to occur at the grass roots level, this will only occur in a sustainable manner if supported within policy and legislation.

For this top-down, bottom-up approach to be successful, there is a need to continue developing assessment tools that can be used at all levels to support informed decision-making and identify gaps in understanding. This should be supported by and incorporate traditional knowledge and data collection to strengthen the evidence base. To ensure capacity and understanding, there has to be an increased commitment on the part of national governments to increase investments in “software” – human and institutional capacity – that compliments the infrastructure investments being made.

Finally, given that water is a medium that cuts across all sectors, we should be encouraging transdisciplinary research activities that engage engineers, scientists, economists, social scientists and health scientists to bring to bear their methodologies and understanding to deal with issues of water and sanitation. Further technological advancement is not the real issue; rather, tools of engagement, social capital and innovative financing are necessary to bring potable water especially to the marginalised populations that have been left behind. This in turn requires a focus not only upon water access, but on sanitation, source water protection and wastewater treatment.

REFERENCES

Adeel Z., Schuster B. and Bigas H. (Eds.) 2008. What Makes Traditional Technologies Tick - A review of traditional approaches for water management in drylands. UNU-INWEH. Available from: http://inweh.unu.edu/publications/ (Accessed August, 2015).

Anderson R.F. 2010.Trends in Local Government Expenditures on Public Water and Wastewater Services and Infrastructure: Past, Present and Future. US Conference of Mayors Available from: http://www.usmayors.org/publications/201002-mwc-trends.pdf (Accessed August, 2015)

Boyd D. 2012. The Right to Water: Moving from International Recognition to National Action In Bigas, H. (Ed.), 2012. *The Global Water Crisis: Addressing an Urgent Security Issue*. Papers for the InterAction Council, 2011-2012. Hamilton, Canada: UNU-INWEH.

Chamberlain J. and Watt S. 2012.Training Multidisciplinary Leaders for Health Promotion in Developing Countries: Lessons Learned. *Health Prom. Practice* DOI: 10.1177/1524839910384077.

Cheng J.J., Schuster-Wallace C.J., Watt S., Newbold K.B. and Mente E. 2012. An Ecological Quantification of the Relationships Between Water, Sanitation and Infant, Child, and Maternal Mortality. *Journal Env. Health*.**11**:4 doi:10.1186/1476-069X-11-4.

Confalonieri U. and Schuster-Wallace CJ. 2011. Data integration at the water–health nexus. *Current Opinion in Environmental Sustainability***3**:1–5.

Glöckner H., Mkanga M. And Ndezi T. 2004.Local empowerment through community mapping for water and sanitation in Dar es Salaam. *Environment and Urbanization*. 16(1, April):185-198.

HSBC. 2012. *Exploring the links between water and economic growth*. A report prepared for HSBC by Frontier Economics: Executive Summary. Available from: http://www.hsbc.com/~/media/HSBC-com/citizenship/sustainability/pdf/120723-hsbc-executive-summary.ashx (Accessed August, 2015).

Hutton G. 2012. *Global costs and benefits of drinking-water supply and sanitation interventions to reach the MDG target and universal coverage.* WHO. WHO/HSE/WSH/12.01. Available from: http://www.who.int/water_sanitation_health/publications/2012/globalcosts.pdf (Accessed August, 2015).

Levison M.M., Elliott S.J., Karanja D.M.S., Schuster-Wallace C.J. and Harrington D.W. 2011. “You cannot prevent a disease, you only treat diseases when they occur”: Knowledge, attitudes and practices to water-health in a rural Kenyan community. *East African Journal of Public Health* **8**(2):103-11.

Kyle Onda K., LoBuglio J. and Bartram J. 2013. Global Access to Safe Water: Accounting for Water Quality and the Resulting Impact on MDG Progress. *World Health & Population*, 14(3):32-44. doi:10.12927/whp.2013.23437.

Schuster-Wallace C.J. and Sandford B. 2015. *Water in the World We Want - Catalysing National Water-related Sustainable Development*. United Nations University Institute for Water, Environment and Health and United Nations Office for Sustainable Development. Available from: http://inweh.unu.edu/wp-content/uploads/2015/02/Water-in-the-World-We-Want.pdf (Accessed August, 2015).

Schuster-Wallace C.J., Cave K., Bouman-Dentener A. and Holle F. 2015. *Women, WaSH, and the Water for Life Decade.* United Nations University Institute for Water, Environment and Health and the Women for Water Partnership. Available from: http://inweh.unu.edu/wp-content/uploads/2015/06/Women-Wash-and-Water-for-Life-Decade_WEB.pdf (Accessed August, 2015).

Schuster-Wallace C.J., Cave K., McCormick H., Watt S. and Dickson S. In press. *The W:ISE Toolkit Handbook for Community WaSH and Wellbeing*. UNU INWEH. (www.inweh.unu.edu/publications).

Schuster-Wallace C.J., Cave K., Metcalfe C., Theodoulou M., Yargeau V. 2014. *From Waste to Wealth: Sustainable Wastewater Management in Uganda Wastewater: Management Framework*. UNU INWEH. Available from: http://inweh.unu.edu/wp-content/uploads/2014/06/Wastewater-Management-Framework_FINAL.pdf (Accessed August, 2015).

Ushijima K., Irie M., Sintawardani, N., Triastuti, J., Ishikawa, T., and Funamizu, N., 2011. *Sanitation Model for Urban Slum in Southeast Asia*, Proceedings of 2nd IWA Development Congress &Exhibition, November 21-24, 2011, Kuala Lumpur, Malaysia.

Water and Sanitation Programme. 2012. *Economics of Sanitation Initiative*. World Bank. Available from: http://www.wsp.org/content/economic-impacts-sanitation#top (Accessed August, 2015).

United Nations. 2012. *Report of the United Nations Conference on Sustainable Development*. Rio de Janeiro, Brazil 20–22 June 2012 Available from: http://www.uncsd2012.org/content/documents/814UNCSD%20REPORT%20final%20revs.pdf (Accessed August, 2015).

UNECOSOC. 2008. *Mainstreaming Global Goals into Development Strategies and Policies*. Background Study for the Development Cooperation Forum. Available from: http://www.un.org/en/ecosoc/docs/pdfs/mainstreaming_of_iadgs.pdf (Accessed August, 2015).

UNICEF and WHO. 2015. Progress on Sanitation and Drinking Water; 2015 Update and MDG Assessment. UNICEF and WHO. Available from: http://www.wssinfo.org/fileadmin/user_upload/resources/JMP-Update-report-2015_English.pdf (Accessed August, 2015).

UNICEF and WHO. 2012. *Progress on Drinking Water and Sanitation; 2012 Update*, Joint Monitoring Programme. UNICEF and WHO. Available from: http://www.wssinfo.org/fileadmin/user_upload/resources/JMP-report-2012-en.pdf (Accessed August, 2015).

UN-Water. 2014. *Investing in Water and Sanitation: Increasing Access, Reducing Inequalities*. UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water GLAAS 2014 Report. UN-Water. Available from: http://apps.who.int/iris/bitstream/10665/139735/1/9789241508087_eng.pdf?ua=1 (Accessed August, 2015).

UN-Water. 2012. *The Challenge of Sustaining and Expanding Service*. Global Annual Assessment of Sanitation and Drinking Water (GLAAS). UN-Water. Available from: http://www.unwater.org/downloads/UN-Water_GLAAS_2012_Report.pdf (Accessed August, 2015).

SESSION 2

MORE WITH LESS: MANAGING WATER FOR AGRICULTURE

SUMMARY

IWRDM AND FOOD SECURITY

Chandrakant Damodar Thatte[1]

[1] Dr. - India. E-mail: cdthatte@hotmail.com; cdthatte@yahoo.co.in.

ABSTRACT

The paper titled 'IWRDM and Food Security' addresses the Session subject: More with less – Managing Water for Agriculture from the Perspective of Developing Countries, essentially. It recognizes, that globally more than 70% of water used by mankind goes in Agriculture, while needs for other sectors to ensure economic growth increase exponentially, but are constrained due to inadequate surplus availability. Yet, need for essential agricultural products comprising nutritious food & other crops yielding cotton, sugar, oil etc keeps mounting with population and also for removal of mal-nutrition prevalent in several societies. The dilemma of meeting more needs with less and or limited water supplies continues to challenge the innovative minds. The paper describes how ensuring security of food, water and energy nexus has been fairly successful in the past century, outlining challenges and risks of the future. Amongst these, cause-effect relationship of the Climate Change threat and need for measures like a combination of Supply as well as Demand side Management conjunctively are indicated, to enable 'Adaptation' to the threatened challenge. The paper concludes that given the prudence and innovative spirit, human race in the Developing World will rise by following an Action Plan brought out in the end.

1 WATER

Water Resource (WR) a key natural gift is ill-distributed spatially and temporally. It satisfies the basic human need for drinking, for producing food, maintaining human body metabolism, and enabling activities leading to a fruitful life. It plays a crucial role in sanitation and health, besides in energy production and use for all human activities. It therefore constitutes a human right: like food, air, nutrition, health, employment, freedom of thought and action etc. Need for secured supply in right quantity, of right quality, and at required time/s (at household, national and global level) has to be ensured by Society / Governments alike. With every right, duty of one, who exercises it is paramount. Both have to be woven in Society's norms / Governance. But the WR has to be Developed (WRD) through build up of infrastructure and made available by appropriate Management (WM), both when considered together in an integrated manner can be described as Integrated Water Resource Development and Management (IWRDM). It constitutes according to the definition of IWRM adopted by Global Water Partnership (GWP) way back in 1999, both Development and Management of WR.

2 WHY AGRICULTURAL WATER IS A KEY FACTOR IN WATER MANAGEMENT (WM)

Seventy five percent area of the planet earth is covered by saline water. Humankind and many species of plants/ animals, live on the remaining 25% land because of availability of freshwater, albeit several species do live in seas. Life would not exist without water, fresh or saline – both integrated by a hydrological cycle, which is a result of incidence of solar energy on earth. Water produces food and works as its carrier for all the life forms. Mankind overcame natural vagaries of freshwater availability, devised agriculture deploying the yearly dependable WR with available land, energy and human intellect, some 10000 years ago. As a result mankind settled down in habitats. Later irrigation of agriculture by diverting dependable WR, not only helped mankind survive natural disasters, but allowed it to multiply fastest amongst all species reaching recently a huge size of 7 Billions, now showing signs of declining growth and stabilizing at about 9-10 Billions by 2050. This size of population accounting for backlog of mal-nutrition would globally need doubling of present level of food production. It would also help the global community to overcome ill-health, poverty, reduced productivity issues besides help achieve all-round supply, stability, and access for food.

An average human being requires 4-5 litres of water (lpcd) for drinking, but needs over 1500 lpcd (for producing vegetarian food) or as much as 10000 lpcd (for meat based food) for daily requirement. On conservative estimates, mankind 'eats' on an average 1000 times more water than what it 'drinks'. No wonder, agriculture utilizes a very major portion of water drawl made possible by infrastructure devised by mankind! Unfortunately, about 1 billion out of 7 billion people suffer from mal-nutrition. Paradoxically, more than another 1 billion are overfed. With economic growth & FS, former figure is declining but the latter threatens to increase!

3 ACHIEVEMENTS OF WATER SECTOR IN THE SECOND HALF OF 20TH CENTURY

Malthus' gloomy predictions made 200 years ago, about human race likely failing to produce enough food in times to come, were proven wrong in the 20th century itself, globally as well as in populous countries, which have largely remained self-sufficient and reliant on FS due to innovations such as 'green' and 'white' revolutions. India's population grew by 3.5 times in the last 60 years, yet food produced has more than kept pace and has overcome lack of self-sufficiency, production hitting an all time high of 247 M tones in last year almost 5 times that of 50 M tones produced in 1950. In good rainfall years, India can now also export grains. Presently mal-nutrition is sizeable; globally it varies from 10-12%, in developing countries it is at 20%, while Sub-Saharan Africa is at 35%.Children below five years, girls, women and the aged - constitute the vulnerable sections of society. With population stabilization in view, one can now plan confidently for the likely ultimate population. Nutrition-health-productivity (Human – HP & Water, Land both - WLP) - economy – efficiency have to be kept inter-connected. Present food basket deficit is globally about 10%. But internal inequity (availability of related Natural Resources - NRs, and products) is more difficult to narrow down, for which deficit governance is to be upgraded.

While population of the world grew, following achievements were made possible due to spectacular work carried out in the WR sector. Banishing of famines; drought-flood proofing; reversal of desertification; growth in food-milk-sugar-non food produce; substantial reduction of hunger, mal-nutrition; increase in water/ land productivity, lifting large proportion of people out of poverty trap, reduction in unemployment, immense growth in water supply (WS) for drinking, domestic, industries; growth in energy generation, better WS and sanitation with all-round health parameters etc have been achieved. Famines can still happen, but IWRDM has imparted resilience / flexibilitiy to FS. Water sharing conflicts must be defused by introducing a cadre of negotiators. Although often predicted, wars due to water will not occur as demonstrated by prudence of WR professionals / politicians during the 20th century.

4 WRD IN A RIVER BASIN – MEGA TO MICRO SCALE STORAGES / HARVESTING / WATERSHED DEVELOPMENT

The stellar role played by storages all over the world enabling huge growth in irrigated areas during the last century in mitigating age old crippling ills of societies, is well known. However presently it happens to be amongst the most criticized sector by some, on political and or other reasons, mainly because many countries of the North have built all required storages a few decades back and their populations (and hence needs) are more or less stabilized! Some of the vociferous criticisms of DAMS are amusing to say the least: **A)** They serve rich big farmers, urbanites & destroy poor- tribals - weak sections - small farmers - riparian societies - habitats - culture - forests of rural societies. **B)** They violate human rights - to develop, to habitat, to natural resources; cause involuntary displacement & relocation, are hazards to health - employment - local livelihood from resources - nature. **C)** They serve corrupt nexus of politicians - builders - engineers. **D)** They are unviable, perform poorly, are symptoms of a bad development model, should be decommissioned, because of disruption & destruction of eco-systems they cause.

In reality, out of the myriad innovations deployed by mankind, ‘Dams’ happen to be the most mis-understood! The World Commission on ‘Dams’ was the last attempt against dams, so much so that many started calling it as World Commission on ‘No Dams’. Fortunately, its recommendations were largely trashed by the Emerging / Developing (South) Countries, though vested interests in ‘North’ tried / still - of and on – try, to sell their recommendations, albeit unsuccessfully to ‘South’.

Best indicator for adequacy of available storage in a nation comes from the parameter of – yearly storage available in - cub m / capita of population and not necessarily the Annual WR (AWR) availability. A comparative picture amongst certain groups of countries is as follows: **i)** Arid Rich Countries: Australia (4733), Spain (1410), USA (>5000) cub m / capita. Carryover is provided in Hoover (also Aswan - Nile & others). **ii)** Middle income countries like Brazil (3145), Russia (6103), Turkey (1739), Mexico (1245), Morocco, China (1111), South Africa (753) cub m / capita. **iii)** India at about 200 cub m / capita is possibly lowest amongst the G.7 group of countries.

Similarly hydropower (HP) potential tapped in industrialised countries is over 80% of their economically viable size. Some European countries are totally dependant on HP. In India it is about 20%. While on the subject, it will interest the reader that India has more than 5000 large dams but needs another 2000 dams for meeting with needs in 2050. Will it be ever allowed by opponents of dams is anybody's guess.

WRD has to be river-basin specific. Maximum quantum to be developed out of the potential is really an economic choice. Water Scarcity criteria have been advocated by several researchers based on AWR availability which is vulnerable to variability, in particular in tropics. Often they don't account for potential for Development of WR in mitigation of distress. Some times, definition of closure of a river basin, restricting further development is advocated on the basis of realized proportion of development. These attempts remain seemingly oblivious of societal needs / costs the society can bear in preference to living in perpetual penury. Some people never tire of talking of Carrying Capacity of eco-system but are not bothered about people's capacity to carry poverty and deprivation.

One may still compare proportion of Water (W) / Population (P) shared by specific groups of countries listed below continent-wise, to appreciate the skew nature and variability (V) of availability worldwide. Africa : 11% W, 13% P (V- High), Asia : 36% W, 59% P (V – High), Asiana : 5% W, 1% P (V- High), Europe : 7% W, 13% P (V- Low), North & Central America: 15% W, 8% P (V-High), South America : 26% W, 6% P (V- Low).

For a hydrologist, every infrastructure intervention in a river basin amounts to 'water harvesting' or 'watershed development (WSD)'. He aims at a judicious, economic, optimum combination of scale from Mega to Micro, to enable him to meet with needs of society of the area at minimum socio-economic-ecologic cost. Activists often talk of only micro scale WSD, which is not only undependable, in particular, in face of increase in extremes due to Climate Change (CC), but also turns out to be very expensive. Another aspect often forgotten is that a larger the size of the intervention, better it serves multiple purposes, at less cost. Addition to Live Storage for example is essential in India, but progress has been retarded due to opposition by antagonists. Storages – remain a 'dirty' word even after 'WC against Dams' (WCD) was defeated. Damage is not yet undone. Need for advocacy groups like 'Friends of Dams' all round the world, is paramount.

5 FOOD PRODUCTION

Balancing of land, water, energy nexus is critical for ensuring Food Production. Land productivity is optimized / maximized as a large chunk of original rain-fed area under crops is by now irrigated, overcoming limits due to temporal variability in water availability. But a large land area remains and will continue to remain rain-fed even after harnessing all possible WRs. Solar energy through photosynthesis enables biomass growth on land in presence of rain or irrigation doses of water. Crop production under irrigated conditions typically can be as high as 5-10 times that of rain-fed agriculture, as water supply in right quantity, quality, time and place can be ensured by irrigation. But, a sizeable part of irrigation water comes from ground-water, which needs energy inputs for pumping it to surface. Crops grown on land are used for producing bio-fuels (as energy inputs) in turn used for transportation. Energy is required also for desalination of brackish/saline waters. It is also used for making industrial alcohols for a variety of industries.

With quicker urbanization and industrialization, water drawl for people sector is slated for multiplying 3-4 times the present level, but that for agriculture might grow only by 1.5 times. In absolute terms, there will be much more waste-water on hand, which will need treatment for 'safer' reuse in agriculture from health perspective or for secondary use for people sector. This activity will also involve sizeable energy inputs.

Enlargement of the present food basket for the mankind is required for the growing population, yet significantly mal-nourished society but quickly making up on the front of economic growth. It comprises: carbohydrates, proteins, fats, vitamins, minerals made available through consumption of: cereals, vegetables, pulses, fruits, nuts, roots, oilseeds, milk, meat, fish, poultry, piggery etc. Developed countries mostly use directly large proportion of cereals produced for rearing animals to produce meat and related products. Emerging countries however largely deploy crop residue in the feed, which is more economic and helps them save cereal grains for people's consumption. But, the situation is changing fast with economic growth.

The food basket caters to an average energy supply needed by a healthy human being at about 2860 kcal per capita per day. In Developed World, present use is about 3500 kcal, while in developing world it is about 2700. The gap has to be narrowed quickly. Within-country inequity in energy supply, in particular for developing world, however, is very large due to: poverty, deprivation, lack of employment etc. It constitutes their major challenge. Agriculture helps mankind grow besides food crops that are more tradable for clothing & producing goods like: cotton, sugarcane, tobacco, plantations, wines, alcohols, ethanol etc.

The inputs of bio-diversity, fertilizers / pesticides, human resources, credit, implements, economy, right governance are unquestionably critical for agriculture. Basic need for survival and healthy productive life comes from goods/services due to agriculture, as an economy sector (out of the three, viz.: agriculture, industry, services). With economic growth, output of other two sectors grows much faster, and hence proportional contribution to GDP from agriculture sector proportionately comes down, although in absolute terms it may grow.

6 FOOD SECURITY (FS)

Having considered crucial role of irrigation and other inputs for production of required food basket for the societies, FS can be considered at different levels: **i)** Household- supply, access, stability; **ii)** National – self-sufficiency, self-reliance, part of trade in goods and services; **iii)** Global – maintaining: water and land Productivity (WLP), growth rate, stocks (have to be greater than 20% of production to care for production lows) at requisite level; attend to main concerns – assess reasons for decline in these indicators and remedy them, look into: impacts of urbanization, industry, economic growth, consumption pattern, wastage, increase in meat demand.

Often production may be adequate, yet due to low buying capacity or deficient pricing mechanisms access remains limited. Governments (Govts) often determine a poverty line of income below which people's access to adequate quantum of food gets limited and hence Public Distribution System is put in place to take care of such weaker sections of society. Govts do lay down crop support prices to help farmers encourage requisite production. Govts also provide subsidy at different stages of production for needy farmers in form of low interest loans, or reduced pricing for fertilizers / pesticides / implements; besides providing crop insurance against natural disasters etc. India has recently introduced a Food Security bill for enactment in Parliament to ensure FS for those families which are 'Below Poverty Line (BPL). On the other hand, often Farmers don't get price for the production cost discouraging them from growing food crops. Or inputs for farming / growing even food crops for the family's needs are too expensive, requiring farmers to end up in debt trap, often leading to unfortunate episodes of suicides amongst such distressed farmers.

7 'MORE' (FOOD) WITH 'LESS' (WATER) – THE SESSION THEME

Production of more food with less water calls for improved water use efficiency (WUE), in particular for irrigated agriculture, although in several countries, excess of water availability calls for devising artificial systems for drainage. Excess water availability takes shape of floods also, which require a different strategy altogether. The theme thus mostly deals with Water Productivity in irrigated agriculture alone, but side-steps inadequacy in its supply. It needs to be upfront recognized that a large section of world population from emerging / least developed countries has far too less available 'water', for sustainable agriculture, but need far more 'food'. It ought to be provided through both Supply Management **(SM)** & Demand Management **(DM).** They need more water to serve un-served crop land, besides increasing WUE, using relatively less water with optimal productivity for land/crop/water. For such effective service, they need storages to hold back floods and use the waters in rest of the year. Rain-fed / Irrigated crop-lands call for different approaches; both however together ought to produce more crop per drop of WR for ensuring FS for growing population at requisite minimum of nutrition level.

SM remedies production inadequacy due to deficit in D & M of NR, increases water availability, improves Operation & Management of infrastructure including distribution system, thus looking after *'hardware'* of WM. It has to reduce wastage at all stages of production to consumption. As sizeable WR potential remains undeveloped (almost 90% as in Sub-Saharan Africa /40-60% in several emerging countries), focus has to continue on *Integrated Water Resources Development and Management (IWRDM)* which was first time enunciated in 1992 in Rio Earth Summit.

DM – aims to improve WM *'software'*, methods, processes, awareness / training of farmers receiving water through Participatory Water User Associations, soil conservation, Command Area Development and Management, Rotational Water Supply, adoption of micro and precision irrigation, conjunctive Use of Surface / Ground Waters, Water Audit, benchmarking, leading to Irrigation (Water) Management Transfer of systems set up by State to groups of farmers, recovery of water charges, automation of supplies, collection of drainage, its treatment and reuse etc.

8 WATER USE IN THREE SECTORS AND TASKS AHEAD

The World Water Vision (WWV, 1999) classified for the first time different water uses mainly into 3 sectors of: Food, People, Nature (FPN). Food sector use was considered mainly 'Consumptive' in nature (CN) through transpiration of water into vapor producing biomass, while the People sector (drinking, domestic, industry, hydro-energy use) catered to 'Non-consumptive' nature (NCN) of use retaining most of the water post-use in fluid form - albeit degraded in quality. The nature sector (plant life) deploys water of CN, whereas habitats used by nature sector remain largely require NCN. No wonder agriculture takes away more than 70% of withdrawn water (countries like India typically account for 83%). The strategy for growing enough food has then to comprise 'more' from all the water that can be utilized. It also means treating NCN water to a grade, which can be reused for agriculture. Silver lining for the dark clouds is that globally significant quantum of freshwater is still awaiting development. Objections to such a strategy from vested interests have however to be overcome.

The tasks: Removal of backlog of mal-nutrition, ill-health, under-fed population with economic growth, poverty alleviation, reduction of deprivation, etc: call for development and deployment of unused WR potential, policy reform of all the three NR sectors: water, land, energy. It also means, weaning away excess hands (and mouths) dependent on agriculture, increase land size holdings by consolidation of their fragments, reducing GDP contribution of Agriculture sector while enhancing that of Services / Manufacturing sectors, going in for overall quicker economic growth. Still, it must aim to increase agriculture sector's GDP growth to more than 5% to remain competitive.

9 CHALLENGES AND RISKS

Land under crops is globally shrinking due to urbanization, industry, habitats and sometimes, neglect. Many traditionally rural communities like India are fast getting urbanized, causing stress on WR due to pollutants, which demand easy solution of diversion of freshwater for dilution instead of treatment of the waste and recovery of chemicals. Available crop-land is fast getting converted into non-agricultural purposes, though at places deserts have been reclaimed. A global focused program for such reclamation is necessary to restore crop-land stock. On the other hand in some sub-Saharan / Latin American countries, land available in excess is considered for letting out on long term lease to incorporated farmers from abroad for growing food crops for local consumption and export. It seems that a Global rush of traders is ensuing for grabbing land and water there. A high level panel will discuss the issues threadbare at Stockholm Water Week in August 2012. It is necessary that this process is monitored by concerned Nations, in consultation with global community to avoid long term harm to the FS issues. Impacts of flood / drought like disasters are still not fully redressed. Challenges for agriculture comprise: natural disasters – drought, flood, cyclones; deficit in governance; archaic laws, lack of institutions, land fragmentation, unviable land holdings, conflicts on water sharing, co-ordination between competing uses, inequity, need for all inclusive growth so that no one is left behind; devising infrastructure projects to ensure making affected people beneficiaries / and / or providing appropriate opportunities to develop unutilised WR, honing HR talent, promotion of irrigation, drainage & reclamation of lands, S&T spread. Strategy for management of risks comprises: SM/DM, storages, providing carryover where possible, treating waste waters for agriculture, fighting neglect, discrimination, inequity on the basis of assessment of the high cost of risk and develop a prioritized action plan.

FS also calls for continuous effort at upgradation of agricultural processes and governance including – R&D, storage of seeds & products, prices, Minimum Support Prices, crop insurance, trade, economics, fertilizer / pesticide, seeds, implements costs, credits, subsidy, indebted farmers, suicides. VWT: availability, access, stability – corner stones, improving WLP in kg/cap/cubm/ha of cropped area.

10 HOW HAS THE WORLD COMMUNITY DEALT WITH FS ISSUES IN PAST

The last twenty years have indeed been momentous in the history of 'Use of Water Resources for the mankind and the 'planet earth' as the following list shows. Although Rio Earth Summit of 1992 is considered as a starting point, certain milestone events had preceded: i) in 1972, UN Conference on Human Environment was held, ii) in 1982 World Charter on Water was brought out, iii) in 1987, Brundtland Report on Environment & Development was published. As these outputs were significantly altered, Rio 1992, remains in the lead.

I. Rio, Agenda 21: The 12th Chapter dealt with WR, 18th Chapter with Freshwater. The outcome referred to 3 main targets, that have been since articulated further: Integrated Water Resources Development and Management (IWRDM), Sustainable Development (SD), and Equity. IWRDM comprises integration of - D&M, SW/GW, river basin level resources - skies to seas, goods and services, all uses by human and eco systems of CN & NCN, S&T – socioeconomic – environmental – governance issues. SD is aimed at technical viability, economically feasible inclusive growth, social acceptability, ecological sensitivity. When, it is difficult to attain all these conditions, trade-offs are considered to make a balanced assessment. *Equity* assumes rights with duties by socially strong sections for weaker ones for their upliftment out of deprivation;

II. World Water Vision sponsored by WWC / GWP and water related organisations in 1999 dealt with the subject globally in depth and identified Food, People, Nature as main sectors;

III. MDGs by UN System followed up in 2000 (aimed to reduce poverty, hunger, thirst, unemployment etc by half by 2015), monitoring of progress shows by 2012 severe slippages, require amendment to processes adopted;

IV. WEHAB program was adopted at Rio+10 at Johannesberg in 2002 ('A' related to Agriculture), and the concept of 'Virtual Water Trade' signifying need to identify and account for 'embedded water' in exchange (trade) of goods and services produced by mankind through prudent use of WRs was floated then;

V. In 2002-03, ICID floated the Country Policy Support Program (CPSP) and adopted a strategy for Member Countries for dealing with different river basins characterized by quantity and quality stress for both surface and ground water, while advocating integrated basin planning for the 3 sectors of F, P, and N;

VI. ICID adopted a specific strategy for FS in 2005 for 3 classes of countries of the world, viz. developed, emerging and least developed countries, advocating a mix of infrastructure, IWRDM and Trade in accordance with the economy of the target country;

VII. Sixth World Water Forum held at Marsaille in March 2012 adopted certain key targets (increase in productivity ranging from 15-20%, increase in use of poor quality of waters (PQWs), building more storages socially sound and environmentally sufficient for achievement during the period of 2015-2020;

VIII. An innovative, multi-stakeholder WR Group set up recently at IFC (World Bank), by WEF (Davos);

IX. Integration of all activities in shared River Basins, within and between countries yet remains a dream. UN Convention on Water Courses adopted by UNGA a decade ago after lot of effort not still ratified (10 more signatories needed);

X. Stockholm Water Week in August 2012 will focus on 'Water and Food Security'.

11 CLIMATE CHANGE (CC) AND LIKELY IMPACTS ON FS

UNFCCC has been steering global research on CC through IPCC for about two decades. It has brought out Four Action Reports so far, causing tremendous churning of world opinion as never before. Due to various well known reasons, UNGA's Kyoto Protocol on CC never entered force. COP meetings thereafter followed by Rio+20 held in 2012 (16-19 June: dialogues, 20 June - State Heads meet) aimed at formulating a new protocol to replace Kyoto Protocol seemingly without achieving the goal. Attempt was made to formulate SD Goals like MDGs adopted in the year 2000. As far as FS is considered, Climate Change - Carbon Emission Protocol was reconsidered in principle only and not on Content. It was agreed that it will be voluntary, non-binding, aspirational; responsibility will be common but differentiated. It was reported that Carbon-Credits made available to Developing Countries by the Developed Countries may no more be operative. Final word about it is not yet available.

There are serious differences about predictions made by IPCC relying on Global Circulation Models (GCMs). A Non-Governmental IPCC has brought out a report which says that anthropogenic contribution to global warming as compared to that by natural causes is insignificant! Be that as it may, for sure, the GCMs are being down-scaled to River Basin level to predict likely scenario at operative level or for that matter to address weather parameters like Monsoons / Tropics which prevail in countries of South. In the meanwhile, many of these countries are working on adopting an Action Plan, in case CC does affect IWRDM plans. In essence the plans advocate defensive measures including: building where possible – carryover storages, building quickly all possible dams to augment storage to take care of more extreme events of future, besides undertaking other essential non-structural measures. One senses that these measures are all written down in scriptures on IWRDM. Perhaps what is missing is action!

Climate Change (CC) threatens to accentuate uncertainty in water availability due to: increase in extreme events, upsetting global calendars of rainy / flood / dry seasons, rainfall intensity etc. As assessed presently, water availability may get adversely impacted due to CC. Glaciers / Snow caps might melt away faster affecting some countries. Some coastline crop-land may go under rising seas. Salinity ingress might accentuate. Crop calendars may need changes, farmers will need to be equipped with options for adaptation and adoption of resilient approaches.

One has to recognize the clear-cut divide between these two groups of countries on coping with hydro climate variability. The following summarises the present positions of the North and South to identify respectively Developed / Developing countries.

- The North and South have different realities of risk and security. The South unavoidably is busy with mobilising more water to meet with rising water demands;
- The North does not perceive immediate risk as basic needs are secured. In North, water storage per person exceeds 6000 cubic meter per year, whereas many countries belonging to South have less than 60 cubic meter storage per year;
- North therefore can afford to talk about decommissioning of dams, whereas South needs many more dams. As such, environmental concerns are perceived as a luxury.
- Positive impacts on enhancement are more visible, whereas negative impacts are more defuse;
- Water energy links are prominent. The regulation strategies have to be flexible to serve food production and energy generation.

12 CONCLUSIONS

IWRDM approach adopted globally alone can ensure SD of WR including FS. Irrigation has undoubtedly been responsible for FS; yet, it is under increasing demand / need for modernization through structural and non-structural measures. Role of storages has to be emphasized once more to all opponents to make them appreciate need for storages, in particular in view of increase in variability due to CC and accept them to develop the remaining WR potential soonest. Delay in acceptance only increases cost and makes it more difficult for implementation. For that to happen also, affected people have to be so compensated that they become beneficiaries of the schemes as has been done round the world on recent schemes.

A river-basin approach whether within national boundaries or shared between nations for IWRDM is a must, in an iterative manner: starting from the whole going to the smallest watershed and then back again to the whole basin for optimization of WLP and achieve integration of needs, demands and supplies. The approach entails a discrete combination of large to small development, none remaining unimplemented. Insistence on small WSD is counter-productive as it is hydrologically wasteful and less dependable. Such integrated approach can be useful in integrating needs of all the three user sectors of F, P, and N. In view of spectacular increase in NC water for people sector, the specter of pollution will grow and has to be tackled by treating the pollutants at source, to reduce financial load on reuse. For this purpose, zero effluent strategy has to be adopted without loss of time, causing reduction to that extent of drawl of freshwater. Integration of SW/GW and their conjunctive use is important for future FS.

Starting as a State sponsored public welfare activity, irrigation is expected to be a mainstay of social equity, people's participation at all levels, and work towards inclusive economic growth and development. FS has to be ensured for all the time in future for farming on small owners' farms, but have to increasingly go for co-operative, corporate, mechanized, automated systems for precision irrigation supported by S&T. Specific strategy is to be drawn for rainfed agriculture to ensure FS, as it will make a dent in production in a big way simply because of the large scale of rain-fed area of the world. For irrigated agriculture, lot of approaches have been articulated which concerned nations will have to adopt.

REFERENCES

United Nations, Rio Earth Summit, Environment and Development (1992), Agenda 21

Global Water Partnership 1999

Water Foot-Print

IWRD, A Plan for Action, Govt of India, Report of NCIWRD, India Food Self-Suffciciency, 1999

Peter Gleick et al, Water in Crisis (Avoided wars) 1993, UN – WWDR, 2003

World Bank & UNEP, Report of World Commission on Dams (1999)

Comments by C D Thatte on Dams and Development: A New Framework for Decision-Making (London: Earthscan) 2000

Govt of India, Planning Commission, GDP of 3 economic sectors (12th Five Year Plan) agriculture, industry, services;(2012)

Govt of India, National Water Policy (2012)/ National Agriculture Policy (2012)

Govt of India, NAPCC, Report of the National Water Mission (2012)

World Water Council, Report on World Water Vision (1999)

Stockholm International Water Institute (SIWI), Bulletin WRD 2012

United Nations, Millennium Conference, Millennium Summit Goals (2000)

United Nations Rio + 10 WEHAB, Johannesburg (2002)

International Commission on Irrigation and Drainage, Country Policy Support Programme Report (2005), www.icid.org

International Commission on Irrigation and Drainage (ICID) Strategy for Food Security (2005), www.icid.org

C. D. Thatte, Indian National Academy of Engineering (INAE) Conference on Climate Change & Water Resources Development 2007-8; National Water Academy National Seminar 2007.

SUMMARY

VIRTUAL WATER AND GLOBAL FOOD SECURITY TOWARDS 2050

Jean-Marie Fritsch[1]

[1] French Academy of Scieces

ABSTRACT

This paper was prepared as a support for a plenary discussion during session 2 of the IAP Water Symposium untitled "*More with Less: Managing Water for Agriculture*". It first recalls the concept of "virtual water" regarding food production and international exchange of food products. Then, it summarizes the findings of a special report of the Academy of Science of France "Démographie, Climat et Alimentation Mondiale", prepared under the leadership of Henri Léridon and Ghislain de Marsily (2011). The report is an assessment of the requisites for ensuring food security in 2050, when the World population would have reached 9 billion people and the impact of climate change would be significant.

1 VIRTUAL WATER AND WATER FOOTPRINTS

1.1 INTRODUCTION

You have probably been puzzled the day you learned that a small cup of water (125 ml) would turn itself into a 17 liters container if you drop a tea bag in it, or even into a large drum of 140 liters if the cup contains coffee. These figures illustrate the concept of "virtual water", i.e. the quantity of water which was necessary in the production of an agricultural product or an industrial good.

The concept of "virtual water" has been introduced by Tony Allan in the early nineties. It was thereafter extensively explored by A.K. Hoekstra and a number of associated authors. The concept was largely appropriated by the World Water Council, and in 2003 Virtual Water had joined the mainstream of water related concerns, when a special session was allocated to the issue of virtual water trade during the Third World Water Forum in Kyoto, Japan.

Among a large number of relevant literatures on the subject, one can quote as early references Allan (1993, 1994, 1997, 2001, 2002) and Hoekstra & Hung (2002), Zimmer & Renault (2003). An expert workshop held in IHE, Delft in 2002 can be considered as an important milestone on the subject, giving the state of the art at the time. The proceedings of the meeting were published in the collection "Values of Water" edited by IHE, Delft, under the auspices of IHP Unesco (HOEKSTRA, 2003). The collection hosts a number of other outstanding works in relation with virtual water issues, in which one would find assessments of the water footprints of vegetal food products, such as rice (CHAPAGAIN; HOEKSTRA, 2011), tea (CHAPAGAIN; HOEKSTRA, 2003b), coffee (CHAPAGAIN; HOEKSTRA, 2003a), animal products such as poultry, pork or beef (GERBENS-LEENES et al., 2011; MEKONNEN; HOEKSTRA, 2012b), elaborated food such as soy milk or soy burger (Ercin et al., 2011) and even pasta and pizza (ALDAYA; HOEKSTRA, 2009). The footprints of industrial goods such as paper (VAN OEL; HOEKSTRA, 2010), biofuels (GERBENS-LEENES et al., 2008), cotton (CHAPAGAIN et al., 2005) or hydroelectricity (MEKONNEN; HOEKSTRA, 2012a) have also been scrutinized. Following explicit guidelines (HOEKSTRA et al., 2011), these approaches by product have been generalized, which allowed setting up extensive data bases for the estimation of the water footprints at national level for all countries of the world and to estimate the global flows of virtual water due to the trading of commodities and manufactured goods. Several estimations have been published during the past decade, the most up-to date study being (MEKONNEN; HOEKSTRA, 2011).

Practically, the virtual water concept has two major types of application:

- Defining the water footprints of products and consequently of people consuming them

The most immediate use of the concept of virtual water is to assess the environmental impact, more precisely the impact on the water cycle, generated when producing a given product. Generally speaking, the water footprints of goods, especially agricultural products, are surprisingly high compared to the expectations of common sense. It is well known that agriculture and livestock are the most demanding sectors in terms of water consumption in the world, but the disaggregation of the consumption by primary product or processed product shows how the water is actually used. In a context where the impact of humankind on climate, biodiversity, soils and water have reached dangerous levels for the sustainability of the Planet, and facing the expectation of a 50% increase of the world population by 2050 (roughly from 6 to 9 billion people in 50 years), the virtual water content of products is a convenient tool to quantify the water which will be required to feed that population. In that respect, the composition of the diets of different population groups appears as a very sensitive driver of the pressure on the water system and shows how and where water savings could be achieved.

- Quantifying the global trade of virtual water

Most agricultural, industrial and energy products are subject to trading, most often over large distances. Massive quantities of virtual water are therefore circulating with the goods and one must consider that when a product is imported within a country, these country imports as well the virtual water content of the shipment. In this case, virtual water can be considered as an additional source of water for the importing country. The circulation of virtual water can be seen as an instrument for achieving regional water security. Such approach was developed by Allan when studying water problems in the Middle East. Virtual water exchange between nations or regions might be considered as an alternative to physical transfers of real water between river basins, the concept being there to share or to exchange the benefits of water, rather than the water itself. In that sense, from the water use perspective, stocking food harvested in humid regions shall be considered as an equivalent to the storage of water behind dam walls in dry regions.

1.2 VIRTUAL WATER CONTENT OF AGRICULTURAL PRODUCTS

It is not a trivial exercise to establish the virtual water content of a product as many factors will contribute to the result. For instance for a crop, its actual evapotranspiration depends widely on the place where it is grown, i.e. the climatic local conditions and on the season of production. If the crop is irrigated, the water efficiency at the irrigation scheme level and at the plot level will be key parameters for the water footprint. The water necessary for post-processing, cleaning, etc., which depends on the technological process of production, may also be a source of discrepancy.

Therefore it must be considered that *the virtual water content of any product is the output of a model* or even a cascade of models, and the results have always to be cautiously considered as such. In particular, the figures should not be quoted with more than 3 significant digits. However, to avoid undesired discrepancies, we have reported in this paper the values as published by the different authors.

The first estimations of virtual water content of selected farm products, made by different teams working independently, were quite close to each other (table 1).

Table 1 - Estimates of virtual water content of a selected products (m^3/ton or liter/kg)

Product	Hoekstra & Hung (2003)*	Chapagain & Hoekstra (2003)*	Zimmer & Renault (2003)**	*Mekonnen & Hoekstra (2012b)*
Wheat	1 150		1 160	*1827*
Rice	2 656		1 400	*1673*
Maize	450		710	*1222*
Potatoes	160		105	*287*
Soybean	2 300		2 750	*2145*
Beef		15 977	13 500	*15 415*
Pork		5 906	4 600	*5 988*
Poultry		2 828	4 100	*4 325*
Eggs		4 657	2 700	*3 265*
Milk		865	790	*1 020*
Cheese		5 288		*5 060*

* Global averages
** California. Egypt for soybean
Source: Hoekstra, (2003) – last column from Mekonnen and Hoeksta (2012)

They show that between 1 000 and 2 000 liters of water are required for getting 1 kg of cereals and an impressive quantity of 15 000 liters of water for 1 kg of beef. The footprints of other animal products are also impressing. The dominant proportion of the footprint (98% of it) is the footprint of the food, the water for drinking, for servicing the animal and for processing the meat representing a mere 2% of the footprint (MELKONNEN; HOEKSTRA, 2010).

These first estimates have been refined since the beginning of 2000 decade, and a more accurate and detailed assessment of animal products has been released recently (MELKONNEN; HOEKSTRA, 2012b) – see table 1 last column.. The global weighted average footprint for beef is now set at 15 415 m^3/ton (an incredibly similar value to the one given in 2003), but at this global scale, the range of the footprint would be roughly from two to one, between 21 829 if the cattle is grazing and 10 244 if it is fed with industrial concentrated food (table 2). This very large difference reflects the difference of productivity in relation to water consumption by natural ecosystems (rangelands, savanna or pastures) when the cattle is grazing and of intensive agriculture producing the animal feed, with high productivity of calories per hectare with an input of water comparable to the one used by the natural ecosystems. As previously stated, when considering different development contexts under different climates, the footprint figures vary substantially. For instance, 26 155 liters of water per kg of meat will be required in the grazing farming system in India, compared to "only" 3 856 for cattle growing under the conditions of the highly industrialized farming system of the USA (table 2).

Table 2 - The water footprint of beef, under different farming systems in selected countries (m^3/ton or liter/kg)

Farming system	China	India	Netherlands	USA	World weighted average
Grazing	16 353	26 155		20 217	21 829
Mixed	13 669	16 869	11 744	14 040	15 712
Industrial	13 159	14 749	4 508	3 856	10 244
Weighted average	13 688	16 547	6 513	14 191	15 415

Source: Mekonnen and Hoekstra (2012b)

Incidentally, such findings show that if considered out of the holistic context of sustainable development, the water footprints alone (or the carbon footprints alone, or any other single indicator) might not be relevant for defining the best practices for managing the Planet's resources, as in this case, it could be concluded that it would be more advisable to keep the cattle in stables and to feed it with grains and other high yield agricultural production instead of grazing. This would be true in a strict water accounting perspective, but many other aspects have to be considered. Intensification of agriculture has its own well known drawbacks, some pastures or rangelands in mountain areas have no other potential use as grazing, many rural societies are structured around the grazing of animals, the well-being of the animals is much higher in open field, etc.).

Whichever the breeding system might be, it is nevertheless obvious that cattle breeding requires a very large amount of water per unit of final product, and this cannot be improved as the feed efficiency of large ruminants is poor (i.e. their metabolism requires the ingestion of large weight of food per kg of meat produced). If one considers the currents diets on the planet where meat consumption is still relatively low in many regions due to poverty and to cultural habits and forecasts an evolution towards a western-style of diet for the population of the Planet in 2050, obviously the demand for water (and other resources, such as land) will not match the available resource (see further in this paper).

As far as meat is concern, table 1 shows that chicken has a much lower footprint than beef (less than 1/3 of it), but any crop product requires much less water for comparable nutritional characteristics (table 3).

The average water footprint per calorie for beef is twenty times larger than for cereals, whilst the water footprint per gram of protein from beef is 6 times larger than for pulses and the water footprint per gram of protein from milk, eggs and chicken meat is about 1.5 times larger than for pulses. Surprisingly, butter has a relatively small water footprint per gram of fat, even lower than for oil crops. However all other products from animal origin have larger water footprints per gram of fat when compared to oil crops.

The general conclusion is that from a freshwater resource perspective, it is more efficient to obtain calories, protein and fat through crop products than from animal products.

Table 3 - The water footprint of selected food products from vegetable and animal origin

Food item	Water footprint per ton (m³/ton)				Nutritional content			Water footprint per unit for nutritional value		
	Green	Blue	Grey	Total	Calorie (kcal/kg)	Protein (g/kg)	Fat (g/kg)	Calorie (litre/kcal)	Protein (litle/g protein)	Fat (litre/g fat)
Sugar crops	130	52	15	197	285	0.0	0.0	0.69	0.0	0.0
Vegetables	194	43	85	322	240	12	2.1	1.34	26	154
Starchy roots	327	16	46	387	827	13	1.7	0.47	31	226
Fruits	726	147	89	962	460	5.3	2.8	2.09	180	348
Cereals	1232	228	184	1644	3208	80	15	0.51	21	112
Oil crops	2023	220	121	2364	2908	146	209	0.81	16	11
Pulses	3180	141	734	4055	3412	215	23	1.19	19	180
Nuts	7016	1367	680	9063	2500	65	193	3.63	139	47
Milk	863	86	72	1020	560	33	31	1.82	31	33
Eggs	2592	244	429	3265	1425	111	100	2.29	29	33
Chicken meat	3545	313	467	4325	1440	127	100	3.00	34	43
Butter	4695	465	393	5553	7692	0.0	872	0.72	0.0	6.4
Pig meat	4907	459	622	5988	2786	105	259	2.15	57	23
Sheep/goat meat	8253	457	53	8763	2059	139	163	4.25	63	54
Bovine meat	14414	550	451	15415	1513	138	101	10.19	112	153

Source: Melkonnen and Hoekstra (2010)

1.3 GLOBAL WATER FOOTPRINTS

Another major improvement in the virtual water assessment during the last years was the ability developed by the research teams in differentiating the type of water which has been used for getting a product in a given country:

the “green water”, i.e. the portion of rainfall consumed by evapotranspiration of plants (and in this case by the rainfed crops) or the “blue water”, which is the liquid form of water in transit in rivers or stored in natural or artificial water bodies. This water is not only a resource, but primarily the support of aquatic ecosystems. Such distinction is of major importance in a context where a substantial growth of food production will have to be achieved to feed Humanity in the coming decades, knowing that there is already an unacceptable pressure on the blue water resource in many regions of the world. In addition, the authors have also included in the estimation the “grey water”, i.e. the polluted water generated by the considered product (MEKONNEN; HOEKSTRA, 2011).

Table 4 presents the results of the accounting.

Every year, for the food supply of its inhabitants, the World is using

- **6 684 Gm^3 (i.e. 10^9 m^3) of green water,**
- **945 Gm^3 of blue water, and**
- **733 Gm^3 of grey water**

The average footprint per capita was of 1 400 m3 per year (1383 m3 as published value) during the considered period (1996-2005), about 92% being attributed to the consumption of agricultural products while 5% was for industrial goods and 4% for domestic supplies.

Table 4 - Global water footprint of production (1996-2005)

(continua)

	Agricultural production			Industrial production	Domestic water supply	Total
	Crop produsction	Pasture	Water supply in animal raising			
Global water footprint of production (Gm^3/yr)						
- Green	5771*	912**	-	-	-	6694
- Blue	899*	-	46**	38	42	1025
- Grey	733*	-	-	363	282	1378
- Total	7404	913	46	400	324	9087

(continuação)

	Agricultural production			Industrial production	Domestic water supply	Total
	Crop produsction	Pasture	Water supply in animal raising			
Water footprint for export (Gm³/yr)	--------------------1597---------------------			165	0	1762
Water footprint for export compared to total (%)	----------------------19----------------------			41	0	19

* Mekonnen and Hoekstra (2010)
*** Mekonnen and Hoekstra (2010b)*
Source: Mekonnen and Hoekstra (2011)

1.4 GLOBAL EXCHANGE OF VIRTUAL WATER

From the information on global trade, the authors concluded that 19% of this water has virtually crossed the boundaries of the producing state countries. Almost every country both imports and exports virtual water, according to its involvement in international trade. The net balances map (Figure 1) shows that net exporting countries are typically those with industrialized agriculture and benefiting of steady rainfall or developed irrigation infrastructures. It appears also that larges countries of Central Africa (DRC, Angola) benefiting of favorable climate conditions are nevertheless net importers of water. There is obviously a large potential for rainfed agriculture in these areas, at the cost of converting natural ecosystems into cropland.

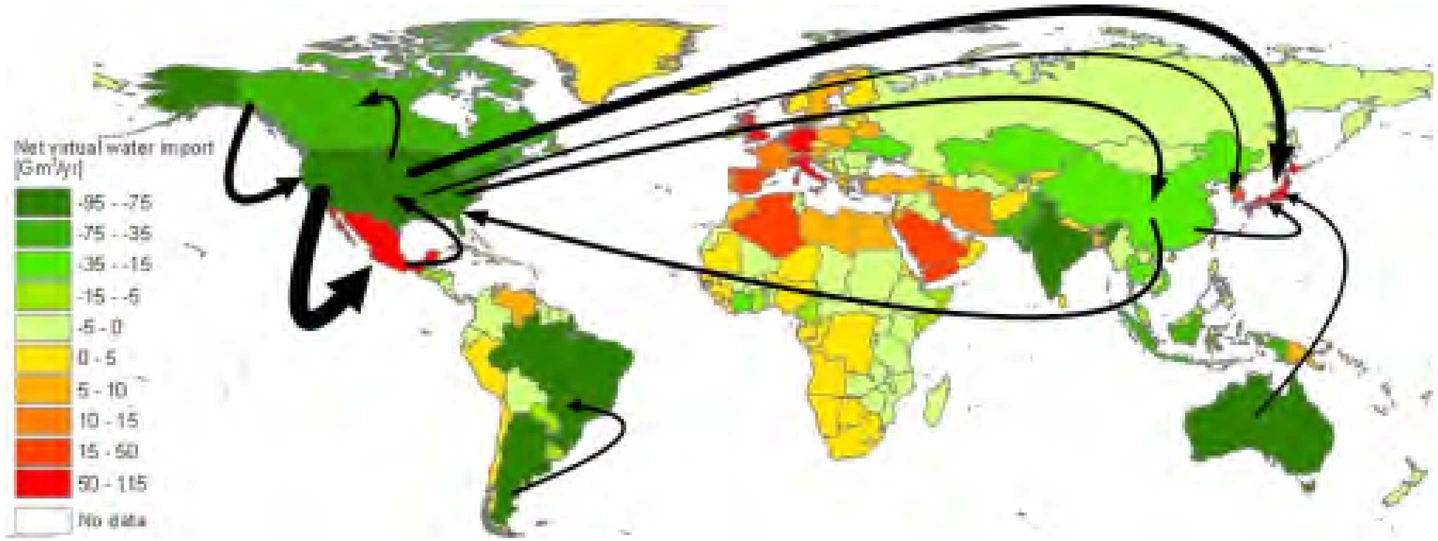


Figure 1 - Virtual water balance per country and major virtual water flows (> 15 Gm³/yr)
(Net importing countries in red and yellow. Net exporting countries in green)
Source: Mekonnen and Hoekstra (2011)

If the importing country of a given agricultural product would have grown it within its own boundaries (provided this would be feasible in terms of land and water resources), this would have required a certain amount of water according to local climate conditions and local agriculture practices. As far as water consumption is concerned, if the balance of conditions is in favor of the exporting country, the result is not only a transfer of water, but at global scale, this can be considered as a “water saving” (producing the same quantity of food with less water). Figure 2 shows the magnitude of the savings in terms of blue, green and grey water from the perspective of several receiving countries. For instance, the map shows that Mexico or Morocco have made substantial savings of blue water by importing agricultural products from the US, as Egypt has done with its imports from the EU.

The concept of global water savings allows us to conveniently introduce the issues of feeding the world at the horizon of 2050.

Figure 2 - Water savings associated with trade of agricultural products (1996-2005) - Only savings > 5 Gm3/year are shown Source: Mekonnen and Hoekstra (2011)

2 PERSPECTIVE ON GLOBAL FOOD SECURITY IN 2050

Major global changes in different domains such as climate, biodiversity, water, energy, industry, trade, demography, health, economy are currently taking place on the Planet. The forecasted increase of the population is probably going to drive the most important changes and the question arises on how it will be possible to feed the world at the horizon of 2050.

2.1 THE DEMOGRAPHY CONSTRAINT

They were 1,5 billion of people on the Earth in 1900. The number was 6,2 billion in 2000 and the forecast is 9,2 billion in 2050, according to the a medium fertility rate scenario, i.e. supposing a reduction of grow rate by this time everywhere, but in Africa. (Figure 3).

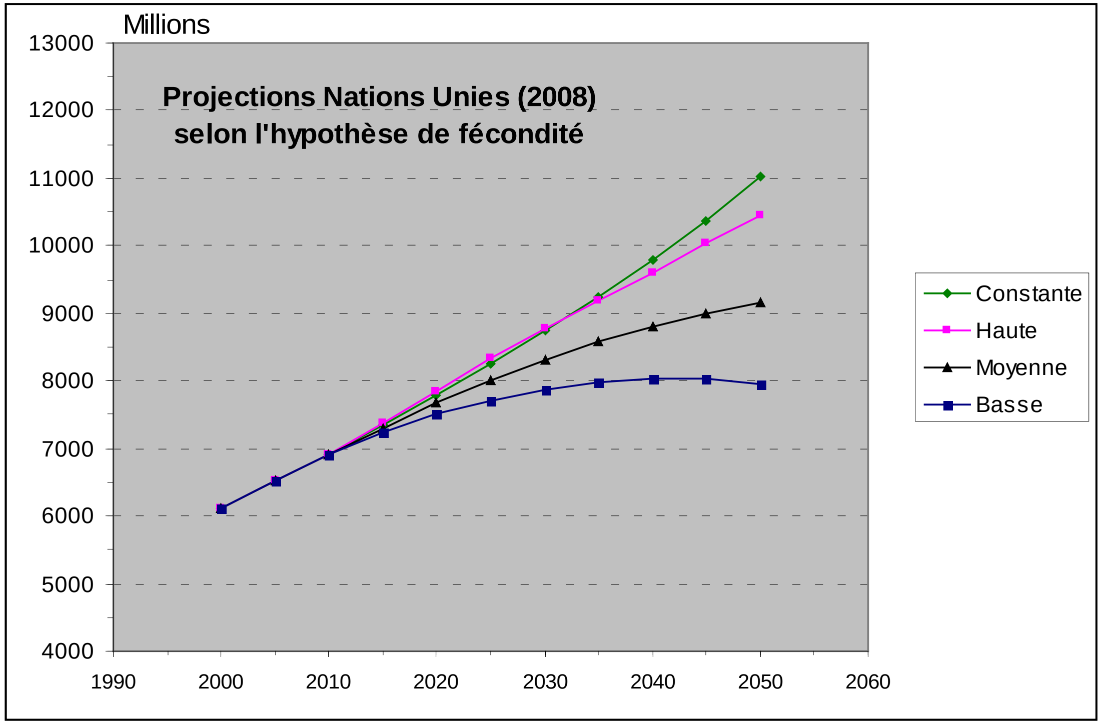


Figure 3 - Evolution of World population (2000-2050)
Source: UN (2008)

The absolute major increase of population will be felt in Asia (+1,5 billion), in Africa (+1,2 billion), followed by more modest increase in Latin America (+210 million) and North America (+130 million). The population of Europe would stabilize ore even decrease slightly (-36 million). (Figure 4).

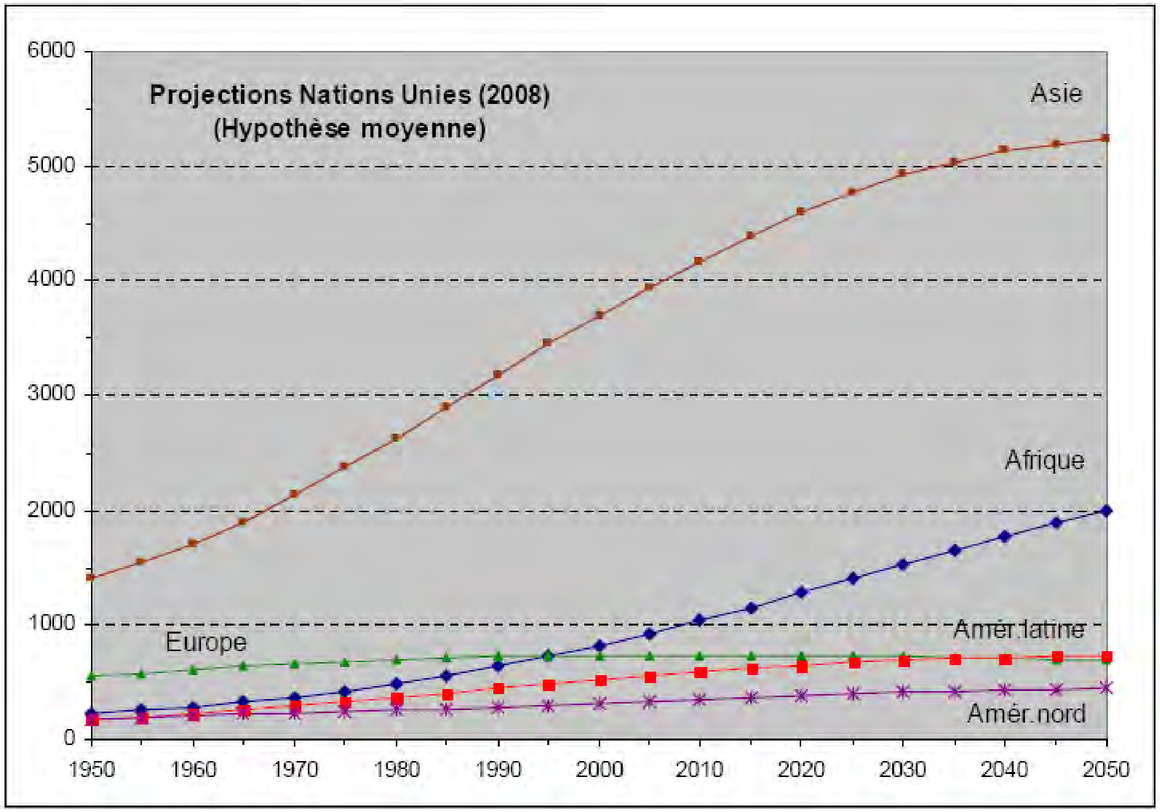


Figure 4 - Evolution of World population by continent (1950-2050)
Source: UN (2008)

It is forecasted that the majority of the additional population will live in towns. If currently the ratio urban/rural is around 50/50, it should be 70/30 in 2050. Important migrations should take place, mostly for economic reasons (which include the degradation of the living environment of the migrants). According to the UN estimations, about 123 million of people would move between continents (63 million leaving Asia, 37 million leaving Latin America and 23 million leaving Africa for Europe and North America). In comparison, migrations having climate change as first cause (such as people displaced by increase of sea-level) would displace much smaller numbers of people.

2.2 FOOD AVAILABILITY

The food consumption figures presented are “apparent food consumption” and refer to the amount of food available for human consumption as estimated by the FAO Food Balance Sheets. However the actual food consumption by people is always lower than the quantity shown, as food actually consumed depends on the magnitude of waste and losses during storage, during preparation and cooking, as plate-waste, thrown away or used to feed domestic animals and pets.

Currently, very large discrepancies affect apparent food consumption, according to regions and stages of development. The availability of food (expressed in kcal per day) is shown in Table 5. Extremes low values would be found in Sub Saharan countries (less than1 900 kcal/day in Angola, Zambia, Ethiopia, Burundi or Central African Republic), while in developed countries, such as USA, the availability is about 3 800 Kcal/day. To ensure food security, i.e. having less than 5% people undernourished, WHO considers that at the macro scale of countries, the food availability should be 3 000 kcal/capita/day, of which 500 should be of animal origin (meat, dairy product, eggs, fish).

Table 5 - Apparent food consumption (2006-2008)

Food consumption (period 2006-2008)		
Country groups *MDG/UN regional classification*	(kcal/person/day)	% of undernourished
WORLD	2 790	13
Developed regions	3 430	—
Developing Regions	2 640	15
Least Developed Countries	2 120	33
Landlocked Developing Countries	2 280	26
Small Island Developing States	2 550	21

Source: FAO_Stat

The proportion of undernourished persons has declined from 26% to 13% between 1970 and 2008. However, according to the last report on food security released by FAO in 2008, 923 million were still undernourished in 2007 and the number has crossed the barrier of 1 billion in 2009, as a consequence of the global food crisis and of the rocketing prices of food products. In the same time, 1.3 billion adult people are considered as being overweighed (1/3 of adult population), of which 400 million are obese (10% of adult population).

More than a decade ago, it has been estimated that total crop production at field level would produce a global average of 4 600 kcal/capita/day (SMIL, 2000). Post-harvest losses (600 kcal) and losses and wastage in distribution and households (800 kcal) would reduce the availability to 3 200 kcal/day (30% losses as shown in Figure 5). In addition a large fraction of food products are used as animal feed (more than 1/3 of the cereals). From the strict energy point of view, as it is necessary to consume about 10 vegetal kcal to get 1 beef meat kcal, this is equivalent to a loss of 1 700 kcal. In return, the animal chain returns 500 kcal of products in the form of meat, eggs and dairy products, which makes a net loss of 1 200 kcal in the animal food chain. Eventually, about 2 000 kcal are really ingested from the consumer plate.

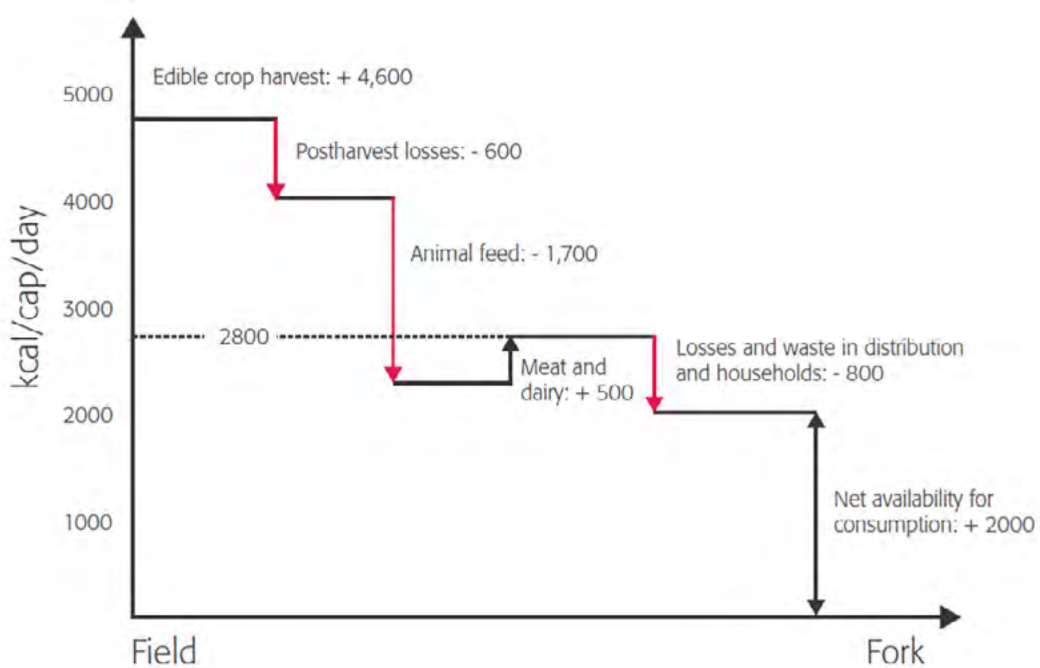


Figure 5 - Losses and wastage in the food chain
Source: Smil (2000) - Graph in Lundqvist et al. (2008)

These figures might probably not be exactly up-to date in 2012, but they show that large gains in food availability could be obtained in limiting losses and wastage. There is an additional large saving potential by reducing, even moderately, the meat content of the diets in Western-style eating countries or by no increasing it immoderately elsewhere. However, it might be politically incorrect to question cultural behavior, especially when many undernourished people in the world still have an insufficient proportion of protein in their diet. Therefore; the official predictions of FAO still forecast a global increase of meat in the diet, at global level, even if a slow down or even a reduction is currently taking place in some OECD countries.

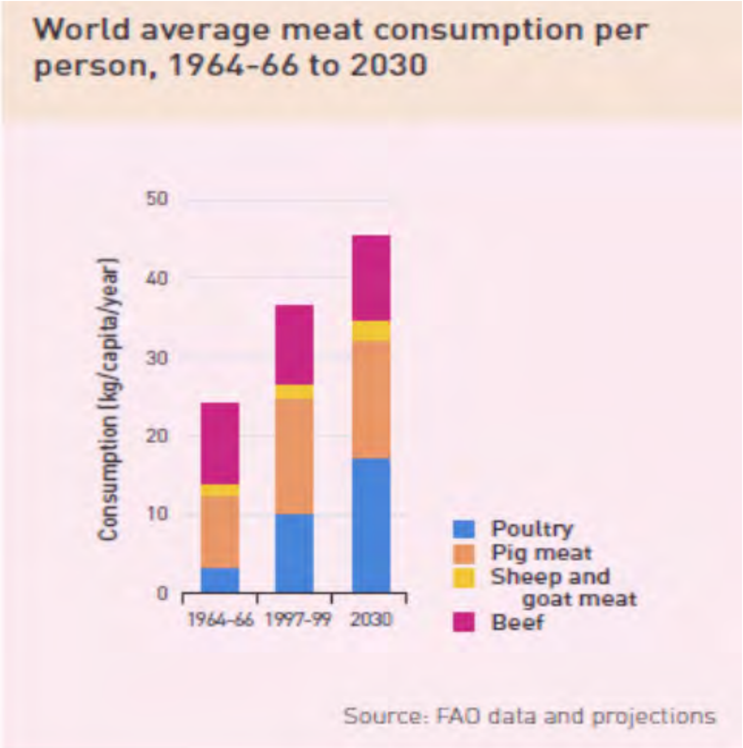


Figure 6 - World average meat consumption per capita (1964-66, 1997-99, 2030)

2.3 THE REQUIRED INCREASE OF FOOD PRODUCTION

Taking a population increase to 9,2 billion as a very likely hypothesis (1.47 times the population of 2002), one understands from the previous considerations that the quantity of kcal to be produced in 2050 to feed that population will highly depends on the composition of the average diet of the human being at this time. Not surprisingly, a large panel of scenario has been issued on that respect by different UN agencies, national research systems and NGO's. To be consistent, the scenarios have to embed the nutritional behavior in a much broader scope of development and way of life. How mankind will eat at the mid-term of the XXI century will depend on the moral, political, economic, environmental and social values of the people.

The UN FAO official production scenario, which is largely derived from the underlying trend, but calls for a responsible management of the Planet, assumes that the required growth in food availability should be of about 70% compared to the 2002 level.

The increase of production would come from 2 sources:

- Increase of yield

Even aiming at a model of "green" sustainable agriculture, spectacular increase of yields are nevertheless still possible in many regions of the world where productivity is extremely low. If very higher yields are neither expectable, nor desirable in several OECD countries, there is however room for improvement in Sub-Saharan Africa and in countries of former Soviet Union for instance (Figures 7 and 8).

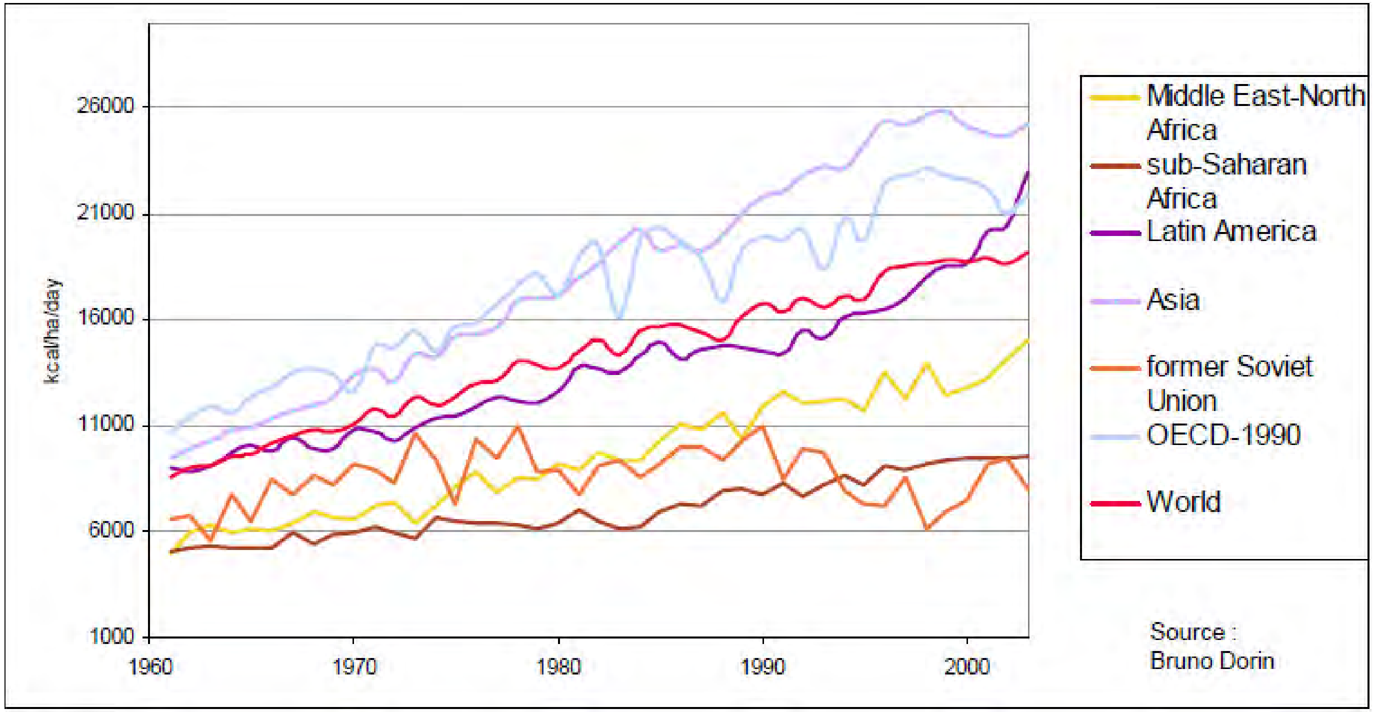


Figure 7 - Yield of agricultural production (1960-2003) expressed in kcal/ha/day
Source: Treyer (2010)

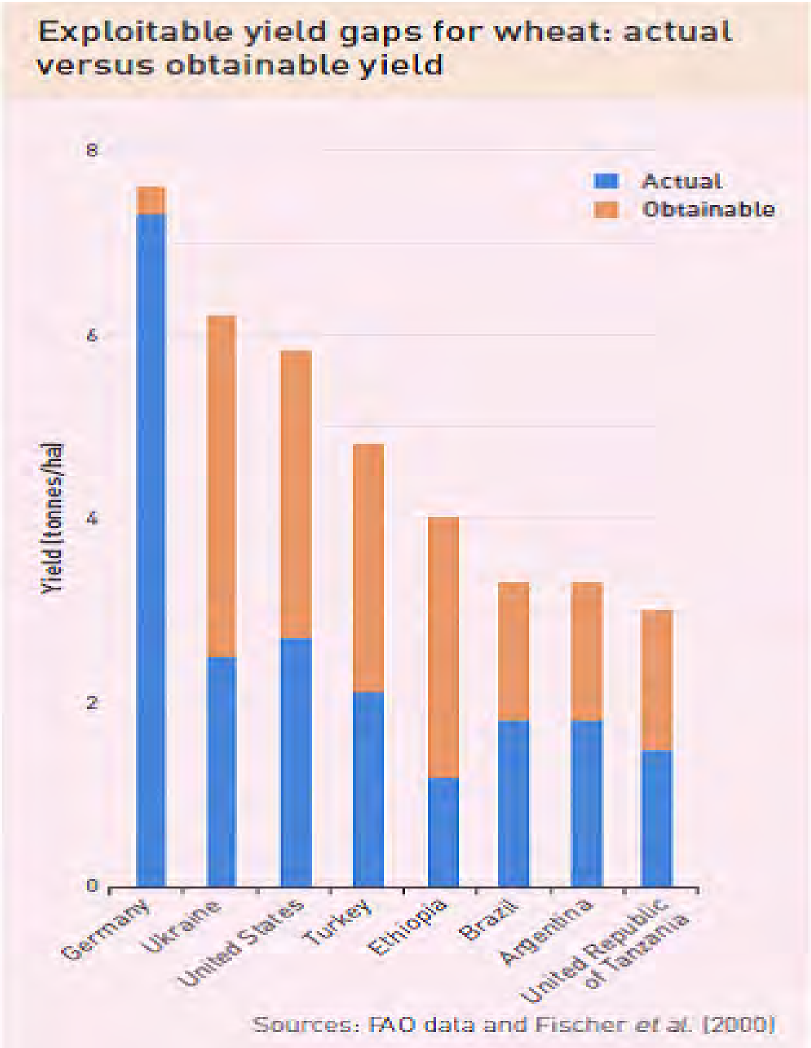


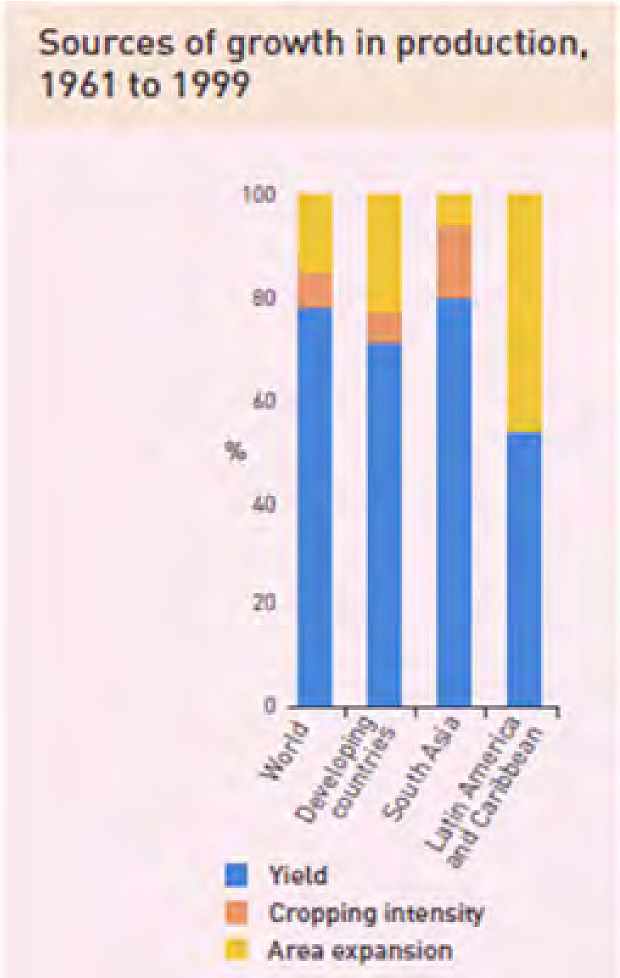
Figure 8 - Potential for yield increase of wheat (actual versus obtainable yield)

However, one must be cautious on the promises of "potential obtainable yields" as a number of examples have shown that industrialized agriculture with high inputs is not environmentally sustainable and socially desirable.

- Increase of cultivated area

The increase of cultivated area will be done at the expense of agricultural land not yet cultivated (rangelands and pastures) or by encroaching natural ecosystems (savanna, forests). Thus, there will be a thoughtful tradeoff at country level, between intensification of production on existing farm land (and selection of the process of intensification to be followed) and the destruction of the remaining natural ecosystems. However, provided the economic system in place in 2050 will allow small and medium farmers to still exist, numerous studies and practical experiences have already shown that sound agriculture can be done in good intelligence with Nature and that cultivated areas are not necessarily dead ecosystems.

According to the FAO forecast, the processes underlying the production increase by 2050 would not be drastically different from those which have been experienced by now : most of the required increase would come from higher yields, which is how it had worked in the past (Figure 9). Increase in yield would be responsible for 71% of the production growth, while new agricultural land would only produce 21% of the gain. Cropping intensity, which consists in having several cultural cycles per year on the same plot, generally thanks to irrigation, would have a share of 8% in the production growth.



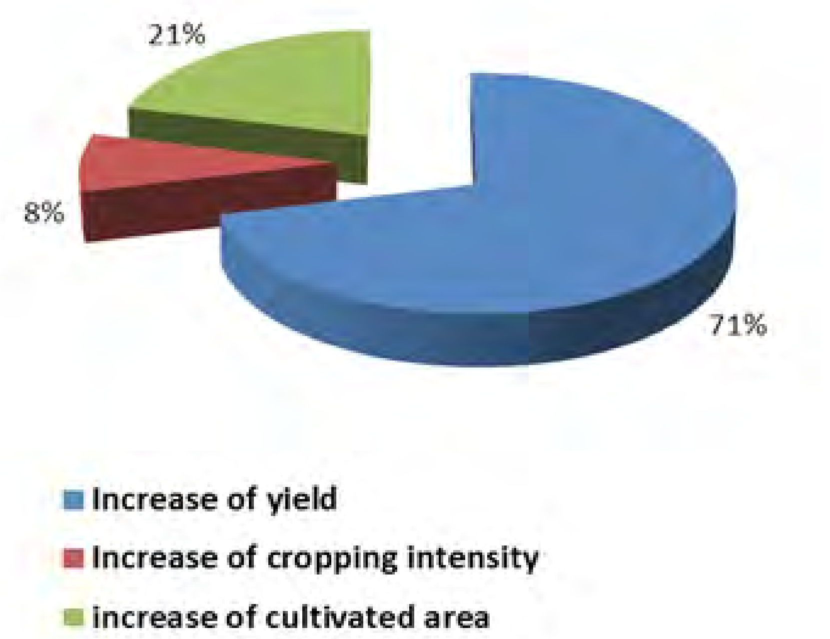


Figure 9
Source: of production increase (1961-1999) (2050)
Credit: FAO Global Perspective Studies Unit

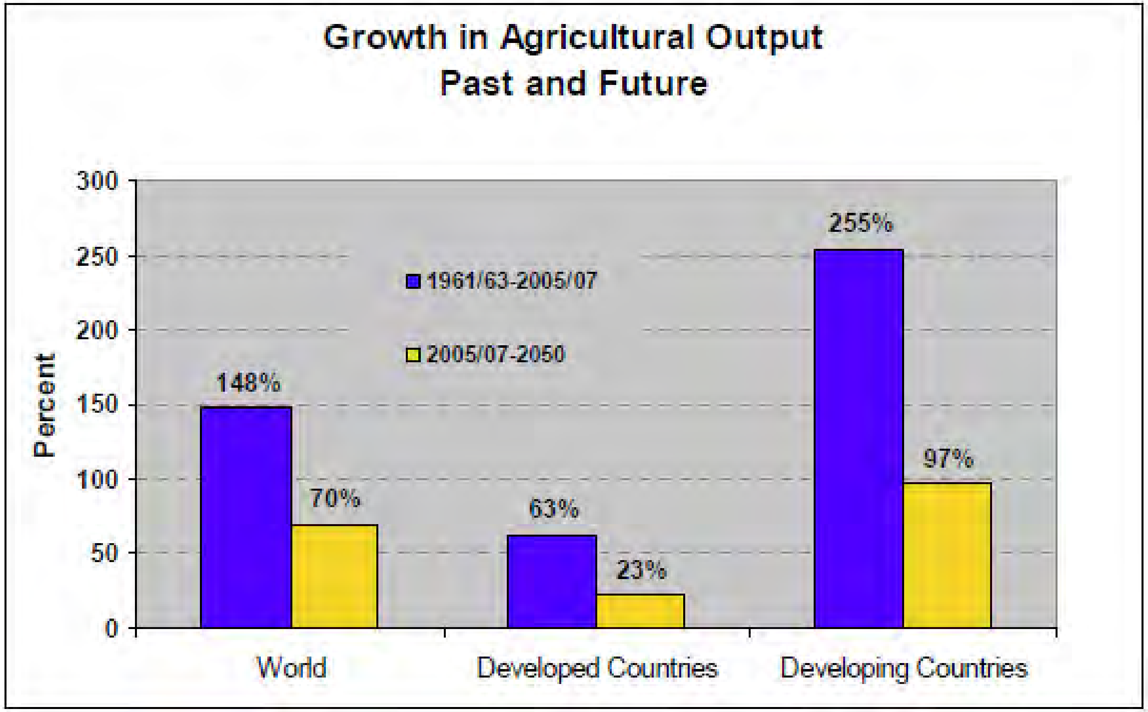


Figure 10 - Past (1960-2005) and future (2005-2050) agricultural production growths
Source: FAO Global Perspectives Studies Unit

The FAO predictions require that the global production will have to grow by about 70% between 2005 and 2050, but almost by 100% in developing countries (Figure 10).

This would be less than half of what has been achieved between 1961 and 2007, but as it has been observed in regions where yields are already substantial, such forecast might be optimistic as yield increases start leveling since they reach 70% of maximum potential yield (CASSMAN, 2010, Figure 11).

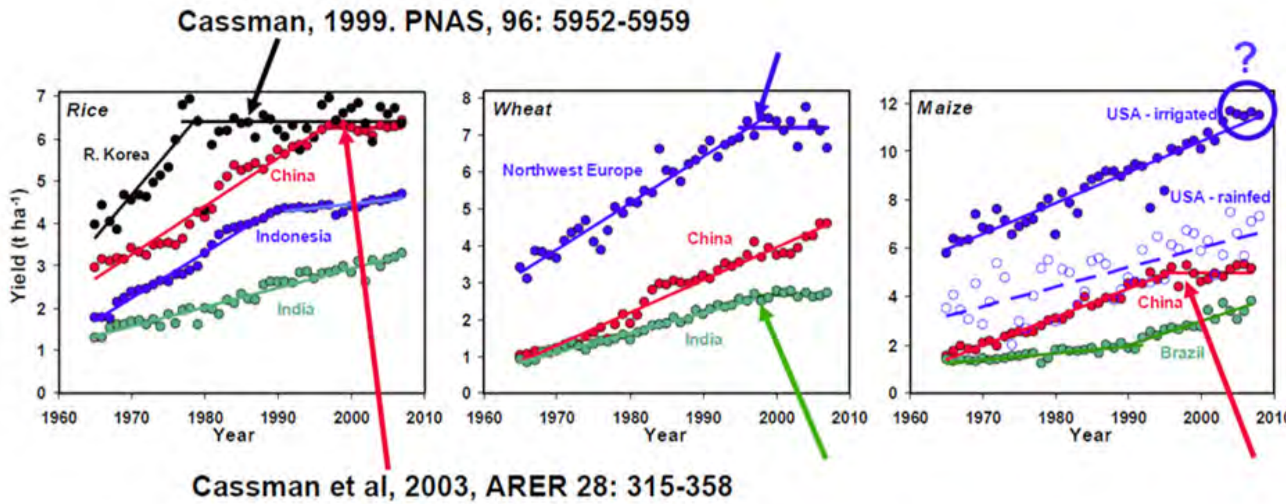


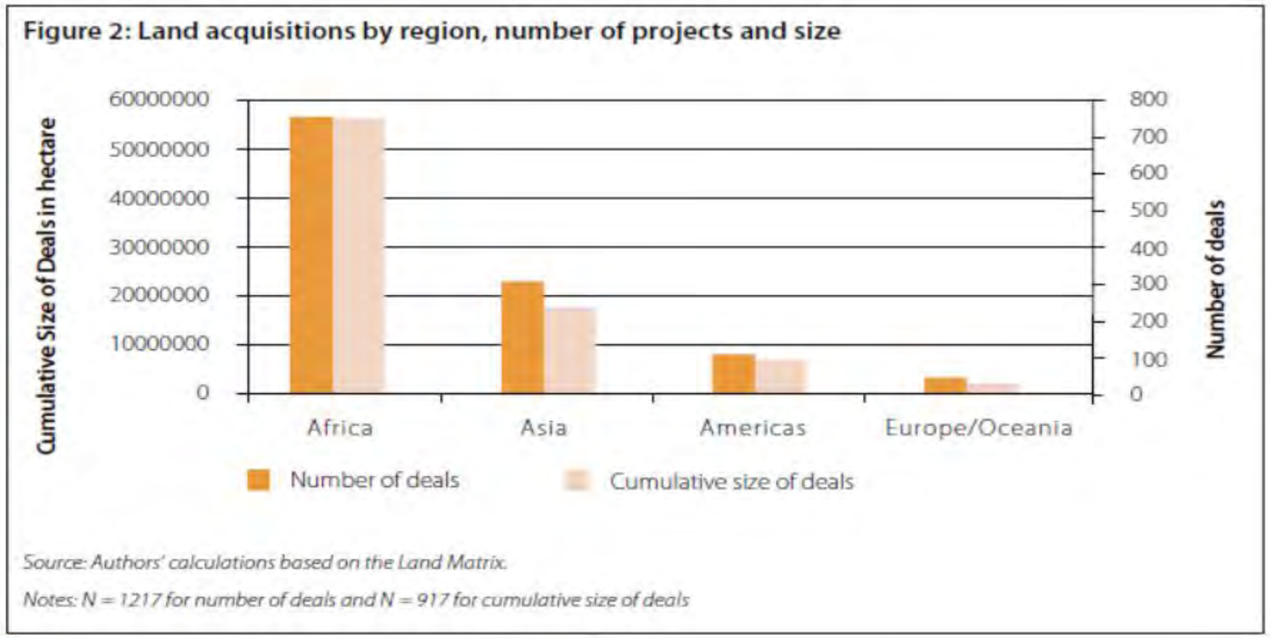
Figure 11 - Average national yields begin to plateau after 70-80% of maximum potential
Source: Cassman (2010)

Note : Yield plateau in Korea and China for rice, in northwest Europe and India for wheat, in China for maize and … perhaps for irrigated maize in the USA

According to FAO projections, the largest expansions of agricultural land are expected to occur in Brazil, Nigeria, India, Indonesia, Mexico, Congo DRC, Sudan, Iran, and Myanmar.

Such predictions are already on track, as a number of lands deals (acquisition or long term lease) are currently taking place. According to a recent survey (ANSEEUW et al., 2012), Africa is the most targeted region as 56.2 million ha are located on this continent. In addition, 17.7 million ha are in Asia and 7 million ha in Latin America (Figure 12). Eleven countries concentrate 70% of the surface concerned by the deals. Among them, 7 are in Africa (Sudan, Ethiopia, Mozambique, Tanzania, Madagascar, Zambia and Congo DRC Congo). Other targeted countries are in South-East Asia, such as the Philippines, Indonesia, and Laos. Investment originates from three groups of countries : emerging countries (Brazil, South Africa, China, India, Malaysia, Korea); Gulf States; and for a lesser extent, countries from the “North” (USA, European countries) (Figure 13).

One can express some doubt regarding the FAO predictions on modest encroachments on natural space in the future, as according to the mentioned land deal assessment, forested areas represent 31% of the total surface of land acquisitions. Converging evidence is given by Jacquet et al. (2012), and Gibbs et al (2010) as between 1980 and 2000, 83% of new agricultural land has been gained on forests, half of it on undisturbed natural forests (Figure14).



[2] Source: http://faostat.fao.org/

Figure 12 - Surface and number of land acquisition deals by region
Source: Anseeuw et al. (2012)

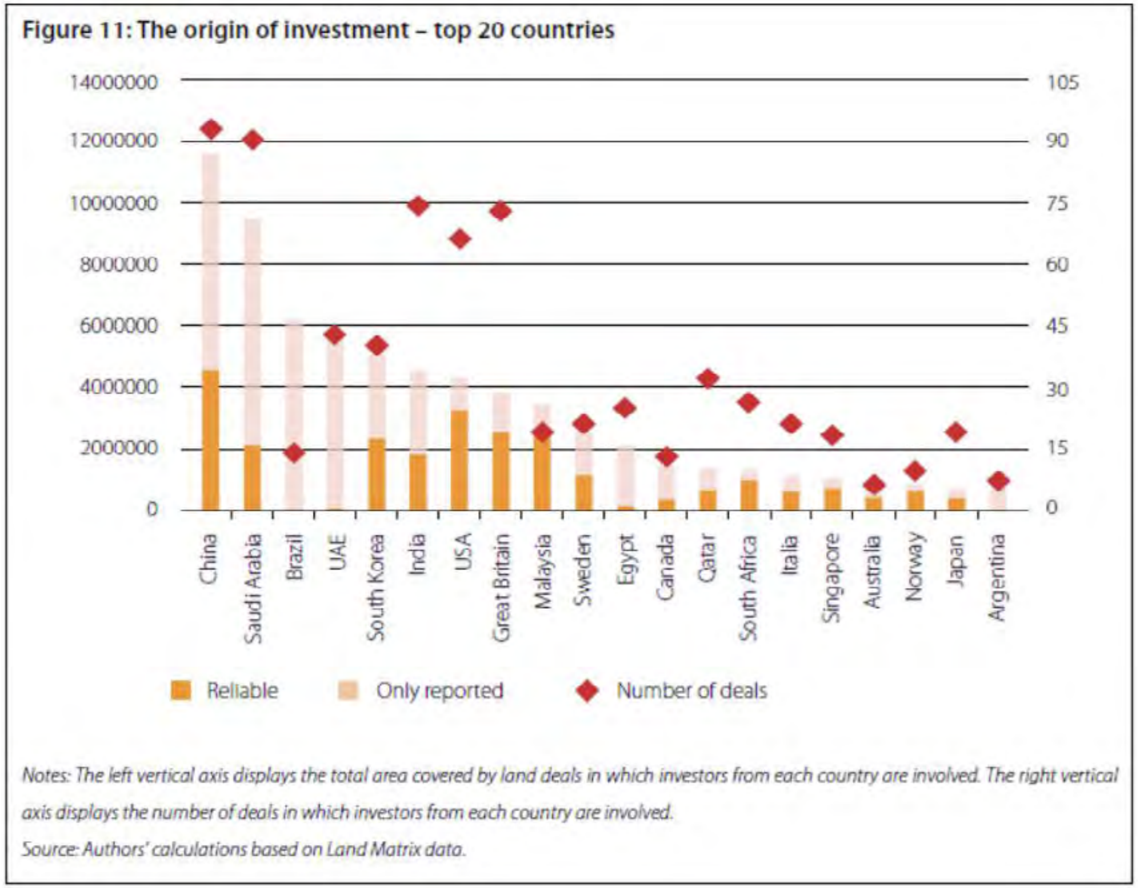
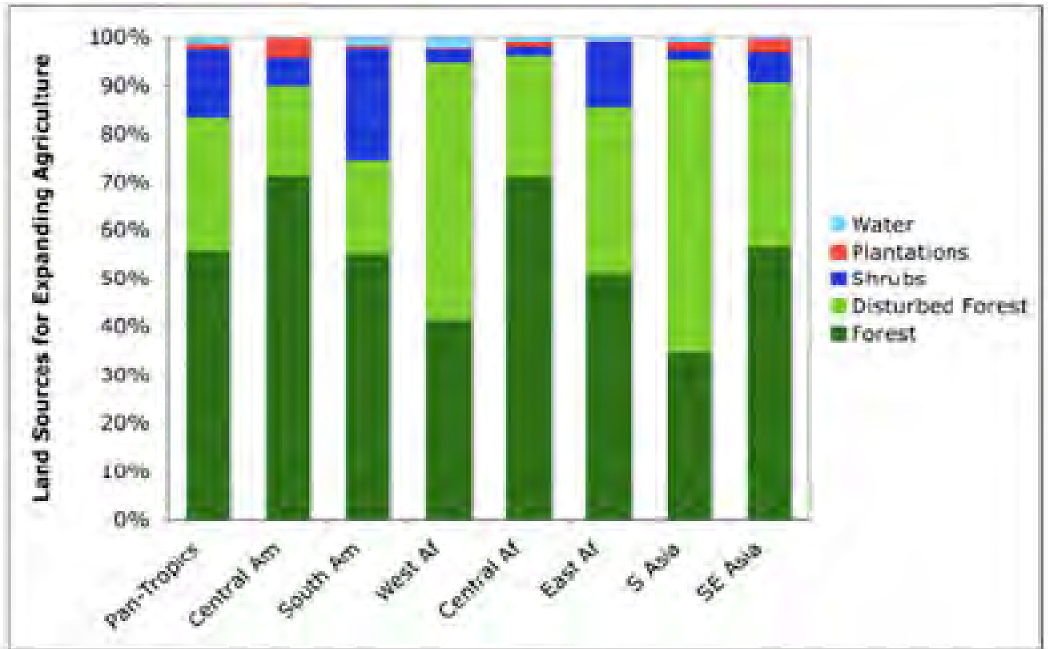


Figure 13 - Origin of investment for land acquisition (top 20 countries)
Source: Anseeuw et al. (2012)



The origins of new agricultural land, 1980–2000. Bars show the average proportion of land sources comprising new agricultural land in major tropical regions. Caption and image courtesy of Gibbs et al 2010.

Figure 14 - Origin of new agricultural land in major tropical regions (1980-2000)
Source: Gibbs et al. (2010)

2.4 WATER FOR FOOD BY 2050

Traditionally, water use in agriculture has been linked with the availability and use of "blue water", withdrawn from wells, rivers, underground water tables, natural and artificial water bodies, which is conveniently manageable trough canals and pipes. Since the earliest antiquity, rural societies have developed skills to manage water for agriculture, which allowed societies to develop in harsh environment which would not have been able to ensure food security under rainfed conditions. Using the power of highly mechanized technology, large water works have been implemented after the after the Second World War and reached a peak in the 1970s (Figure 15). Irrigation currently provides 40% of the world's food from just 20% of the cultivated area and underpins food supplies in densely populated countries such as Pakistan, China and India. Almost half of the total area under irrigation in the world is located in these three countries and covers 80% of the cultivated area in Pakistan, 35% in China and 34% in India (FAO, 2010). If it is unlikely that the world would retreat from such production system, the room for expending it considerably, which implies to withdraw more blue water, does not exist anymore and since the 90's, storage of water in artificial reservoir has not anymore significantly increased (Figure 15).

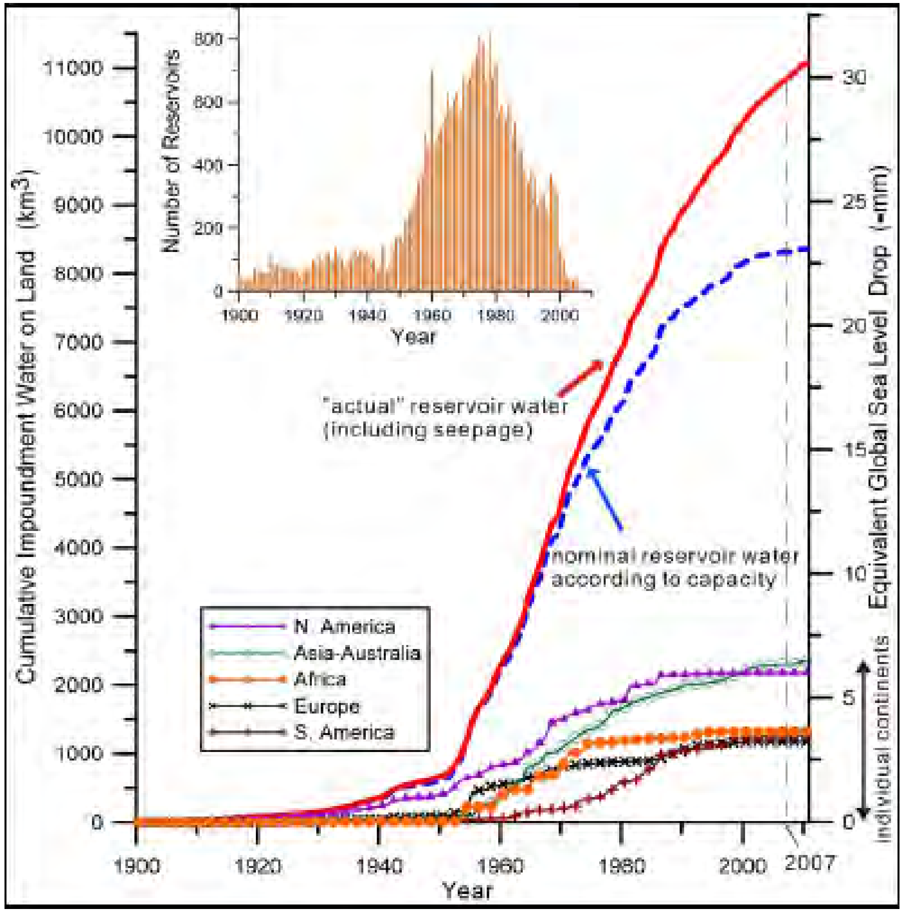


Figure 15 - Development of dam construction during the XX century
Source: Chao et al. (2008)

FAO is forecasting modest news developments of irrigation, which would nevertheless lead to increase of global withdrawals of about 11% in 2050, compared to 2005. The percentage of the increase of irrigated surfaces would be higher, due to improvements in water efficiency. However FAO's objectives are rather modest (or may be realistic !) as far as efficiency is concerned (Table 6).

Table 6 - Water Withdrawals for irrigation by 2050 according to FAO forecast

	Rainfall	Renewable water resources *	Water efficiency ratio		Blue water withdrawal for irrigation		Increase of Withdrawal 2005 -> 2050
			2005-07	2050	2005-07	2050	
	mm/yr	km³	%	%	km³	km³	%
Developing countries	990	28 000	44	47	2 115	2 413	14.1
Sub Saharan Africa	850	3500	22	25	55	87	58.2
Latin America/Caribbean	1 530	13 500	35	35	181	253	39.8
Near East / North Africa	160	600	51	61	347	374	7.8
South Asia	1 050	2 300	54	57	819	906	10.6
East Asia	1 140	8 600	33	35	714	793	11.1
Developed countries	540	14 000	42	43	505	493	-2.4
WORLD	800	42 000	44	46	2 620	2 906	10.9

Significant development of water withdrawals should mostly occur in Africa (+58% compared to present) and Latin America (+40%), where some areas have a potential of untapped resources of blue water. Surprisingly, an 8% progress of withdrawals is expected in the WANA region (Northern Africa and Near East), while practices in several countries are already unsustainable (such as mining fossil ground water). Withdrawals would be reduced in the developed countries. Even if the FAO scenario will be feasible, irrigation will not be able to supply the required food and the bulk of the required additional production would come from rain fed agriculture.

Assuming a projected high level of average food supply of 3 000 kcal/capita/day, with 80% from plant food and 20% from animal origin, the consumptive water use in 2050 will be about 1 300 m^3/capita/year (FALKENMARK; ROCKSTRÖM, 2004), which corresponds to water requirements of about 11 900 km^3/year. The per-capita figure is compatible with the previously quoted estimation made by Mekonnen & Hoekstra (2011) using the methodology of virtual water (1 400 m^3/capita/year including the "grey water not taken into account here). A graphical sketch on how to address the problem in the future is given in Figure 16 (SIWI, IFPRI, IUCN, IWMI, 2005). According to this graph, in 2005 the world was using 5 000 km^3 of green water and 1 800 km^3 of blue water (total 6 800 km^3) for food production. For the average period 1996-2005, Mekonnen and Hoekstra (2011), found a comparable result : 5 771 km^3 for crop production trough rainfed agriculture, butt adding water used by pastures (913 km^3), the total consumption of green water would have been of 6 684 km^3. Applying the virtual water methodology, these same authors estimated at 945 km^3 the blue water consumed by the irrigated crops, which is half of the SIWI estimation. The latest probably includes water lost because of the generally poor efficiency of large irrigation schemes. Considering the withdrawals (and not only the consumption) of blue water for irrigation, the FAO estimation is of 2 600 km^3/year (Table 6). According to Figure 16, the additional water (5 600 km^3) required by 2050 will be found by improving the efficiency of irrigation and by a slight increase of irrigated areas, by improving rainfed efficiency (i.e. increasing of yield) and by the expansion of rainfed agriculture over new areas.

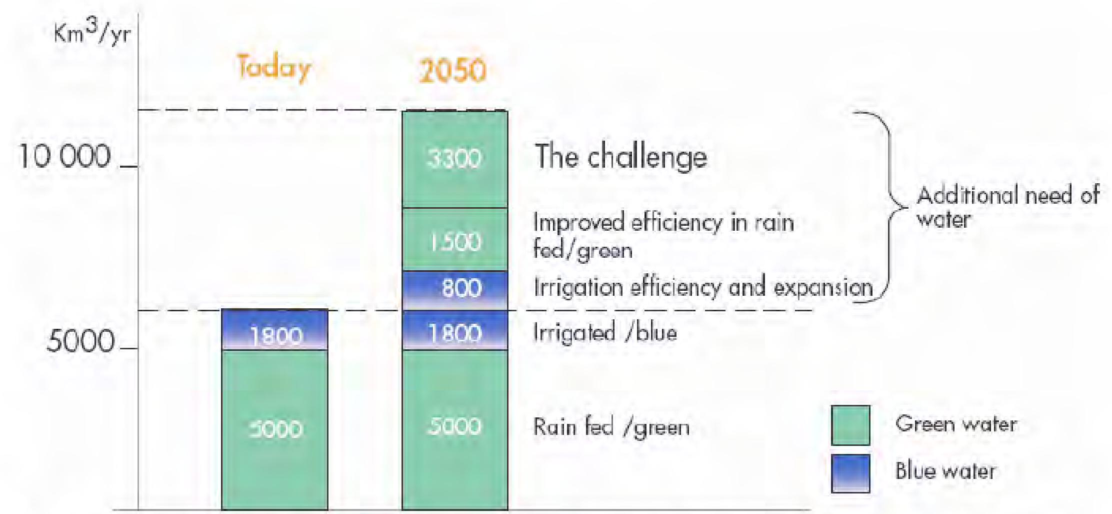


Fig. 2. Today's food production involves a consumptive water use of altogether 6800 km3/yr (out of which 1800 are supplied from blue water resources). To feed humanity by 2050 on 3000 kcal per person per day will require an additional 5600 km3/yr, out of which a maximum of 800 will come from blue water resources. The 2050 column shows that the remaining 4800 have to be contributed from new green water resources (e.g. horizontal expansion) or from turning evaporation into transpiration (vapour shift).
Source: SIWI, IFPRI, IUCN, IWMI (2005)

Figure 16 - Origin of water for food production in 2050
Source: SIWI, IFPRI, IUCN, IWMI, (2005)

Thus, it is not surprising that the recent expansion of croplands and the land deals which have been earlier mentioned, have affected mostly forest regions, as these regions are the most suitable for ensuring secure rainfed agriculture.

A number of other scenarios have been produced, simulating the conditions of food security by 2050. The most crucial conclusion of all the forecasts is that the required quantity of food can be produced at the global level, but national or even regional food security will not be achievable in large regions of the Planet, as land and water availability on one hand and the geographical distribution of population on the other, will not match in space. Therefore, countries and regions will be food producers, while others will be consumers, i.e. the unbalanced situation would be more contrasted in 2050 than nowadays (Table 7). West Asia, Northern Africa, Sub-Saharan Africa and Asia will see their current deficit increased, while Latin America, Russia/CIS States and the OECD countries will supply the deficit. The equilibrium between regions will rely on increased international trade.

When considering the processes of the food crisis of 2008, one may express concerns on the fact that trade will smoothly solve the food crisis (as some have argued that trading was indeed the cause of the crisis, and not the shortage of supply). Therefore, food security will not depend only on availability of land and water, but on the political and economic order which will prevail in 2050 and which must be able to control and to mitigate the oscillations induced by the “offer and demand” process.

Table 7 - Deficits/Surplus of food production by regions (2003; 2050)

Region	Agrimonde 2003	Scenario Agrimonde GO 2050	Scenario Agrimonde 1 2050
West Asia / North Africa	- 32 %	- 52 %	- 63 %
Sub-Saharian Africa	- 12 %	- 18 %	- 53 %
Latin America	+ 11 %	+ 26 %	+32 %
Asia	- 2 %	- 4 %	- 19 %
Russia and CIS	- 2 %	+ 10 %	+ 77%
OECD-1990	+ 6 %	+ 19 %	+ 46 %

Source: Léridon and Marsily (2011)

Agrimonde predictions made by the French research institutions (CIRAD; INRA, 2009).

Scenario Agrimonde GO is derived from for Global Orchestration scenario of the Millennium Ecosystem Assessment. Agrimonde 1 is a more innovative scenario, aiming at balanced diets and reducing as much as possible the pressure on the ecosystems.

2.5 FOOD PRODUCTION AND BIOFUELS

The rocketing developments of biofuels during the very last years raise the question of the competition of limited resources of land and water to produce food or to produce energy. For instance, in the USA, the World major producer of bioethanol, the production of maize for biofuels has grown from 18 million tons during the 2001-02 harvest to 76 million tons in 2007-08. While 7.4% of the maize production was dedicated to biofuels in 2001-02, the proportion has grown to 22.9% in 2007-08 (Figure 17). The influence of biofuels crop on the building up of the food prices during the 2008 crisis is a matter of controversy between experts, but most of them consider that the influence is far from negligible (Table 8). While the effects of the drought are compromising the harvest of cereals during the summer of 2012 in the US, it is not surprising that the Director General of FAO stated that "Much of the reduced crop will be claimed by biofuel production in line with U.S. federal mandates, leaving even less for food and feed markets" and called for "An immediate, temporary suspension of that mandate which would give some respite to the market and allow more of the crop to be channeled towards food and feed uses" (FINANCIAL TIMES, August 9, 2012).

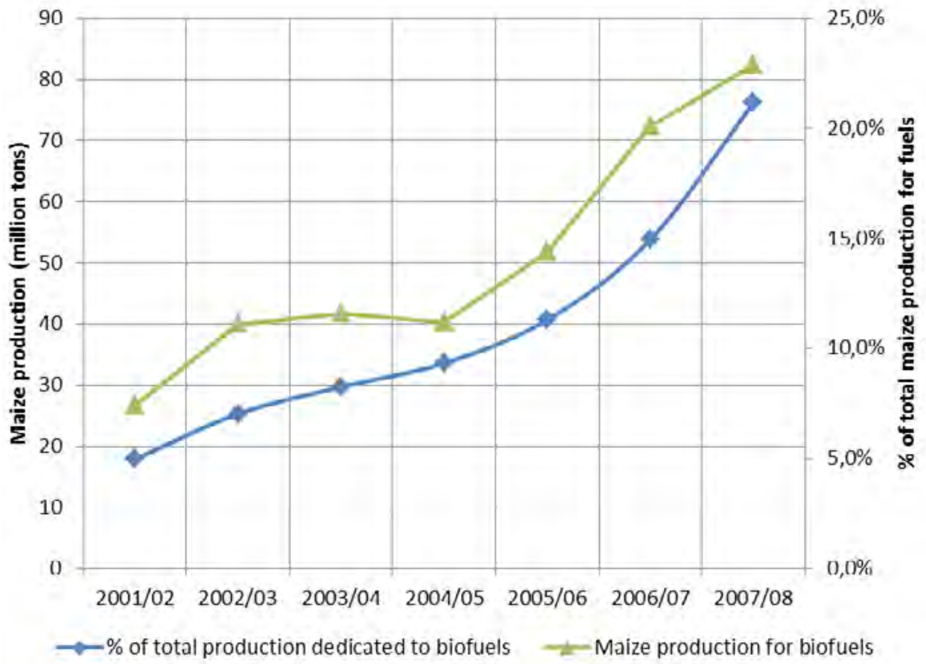


Figure 17 - Production of maize for biofuels in the USA
Source: http://www.ers.usda.gov/data/feedgrains/standard/reports/YBtable4.htm

Table 8 - Role of biofuels in the increase of cereals prices

Authors	Role of biofuels in the price increase
Lipsky (2008)	70% for Maize
	40% for Soya
Collins (2008)	60% for Maize
Rosengrant et al. (2008)	47 % for Maize
	26% for Wheat
	25 % for Rice

Source: Voituriez (2010)

As far as bioethanol is concerned, the USA (27 million tons) and Brazil (19 million tons) where the world's biggest producers in 2008, followed by the EU (2.2 million tons) and China (1.5 million tons).

While it is evident that the development of biofuels will cause major instability in food prices and land use in the coming years, the long term forecast of its influence and the situation around 20050 is hazardous. Some authors argue that by this date, biofuels of first generation (made from cereals, oil crops or sugarcane) will have been replaced by products of the second generation, using any form of cellulose from the vegetal reign, including agricultural residues, leaves and wood, while others believe that this technology would only be a share in the production. The third generation of biofuels, based on algae bred and transformed thanks to new biotechnologies, is even more promising.

REFERENCES

Anseeuw, W.; Boche, M.; Breu, T. ; Giger, M.; Lay, J.; Messerli, P. and K. Nolte. (2012) Transnational Land Deals for Agriculture in the Global South. Analytical Report based on the Land Matrix Database. CDE/CIRAD/GIGA, Bern/ Montpellier/Hamburg.

Bruinsma J. (2009) The Resource Outlook to 2050. By how much do land, water and crop yield need to increase by 2050. FAO Expert Meeting on “How to Feed the World in 2050”, 24-26 June 2009

Cassman K.G. (2010). Yield Gap Analysis: Implications for Research and Policy. Presentation at AGRO 2010. August 29 to September 03, 2010, Montpellier France

Chao B.F, Wu Y. H.and Li Y. S. (2008) Impact of Artificial Reservoir Water Impoundment on Global Sea Level. Science: Vol. 320 no.5873, pp. 212-214.

Collins K. (2008) The role of biofuels and other factors in increasing farm and food prices: a review of recent developments with a focus on feed grain markets and market prospect. Expert report to the review by Kraft Foods Global Inc. on the situation in farm and food market. June 19, 20008.

FAO. 2010. AQUASTAT database. http://www.fao.org/nr/water/aquastat/main/index.stm

Gibbs H. K., Ruesch A. S., Achard F., Clayton M. K., Holmgren P., Ramankutty N. and Foley J. A.. Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. PNAS www.pnas.org/cgi/doi/ 10.1073/ pnas.0910275107

Jacquet P., Pachauri K. and Tubiana L. (2012) Regards sur la terre. Armand Colin.

Lipsky J. (2008) Commodity Prices and Global Inflation. Council on Foreign Relations, New York City, May 8, 2008

Lundqvist,. de Fraiture J., C and Molden D. Saving Water: From Field to Fork – Curbing Losses and Wastage in the Food Chain. SIWI Policy Brief. SIWI, 2008.

Rosengrant M. (2008) Biofuels and grain prices: Impacts and policy responses. Testimony for the US Senate Committee on Homeland Security and Governmental Affairs, 7 May 2008, IFPRI, Washington D.C.

SIWI, IFRI, IUCN,IWMI (2005) Let it Reign : the new water paradigm for global food security. Final report to CSD-13. Stockholm Water Institute.

Smil, V. 2000. Feeding the World: A Challenge for the Twenty-First Century. MIT Press, Cambridge, MA, USA.

Treyer, S. (2010) Agriculture et alimentation du monde ne 2050. Scenarios et défis pour un développement durable. Oral Presentation, Saint Hyacinte, 27/04/2010

Voituriez T. (2010) Energy prices increase, farming prices increase: Which connections and implications on the mid and long term? Sud Sciences & Technologies, N° 19 & 20, p 21-37

SUMMARY

TROPICAL AGRICULTURE, FOOD PRODUCTION AND WATER RESOURCES: CHALLENGES IN SCIENCE AND TECHNOLOGY AND OPPORTUNITIES FOR INTERNATIONAL COOPERATION

Silvio Crestana[1]

[1] Member of Hassan II Academy of Science and Technology.

ABSTRACT

This paper provides, in a concise way, an overview on water, agriculture and food production based on OECD´s (Organization for Economic Co-operation and Development), FAO´s (United Nations Food and Agriculture Organization) and ANA´s (Brazilian Water Agency) information data systems and visions. In addition, it provides a compilation of some articles published by the author and collaborators to illustrate the potential for international cooperation concerning to agriculture and water resources, giving emphasis to the tropics and Brazil. Of the 1.5 billion hectares cultivated worldwide about 270 million undergoes irrigation, which corresponds to 18% of the total land cultivated, half of the world´s food production comes from irrigated land.

1 INTRODUCTION

Different international forecasts agree that, for the period 2000-2030:

- The world's population will rise from 6 billion to 8 billion (33%);
- Demand for food will increase by 50%;
- Demand for energy will increase by 50%;
- Demand for water will increase by 30%.

Figure 1 represents the water resources world map concerning the water available, in million of liters per habitant, per year, by 2020, according to the Centre for Environmental Systems Research, at University of Kassel, Germany (http://news.bbc.co.uk/nol/shared/bsp/hi/dhtml_slides/09/water_stress/img/slide02.gif). It is very clear that several regions of the globe will be under water stress, some of them very severe.

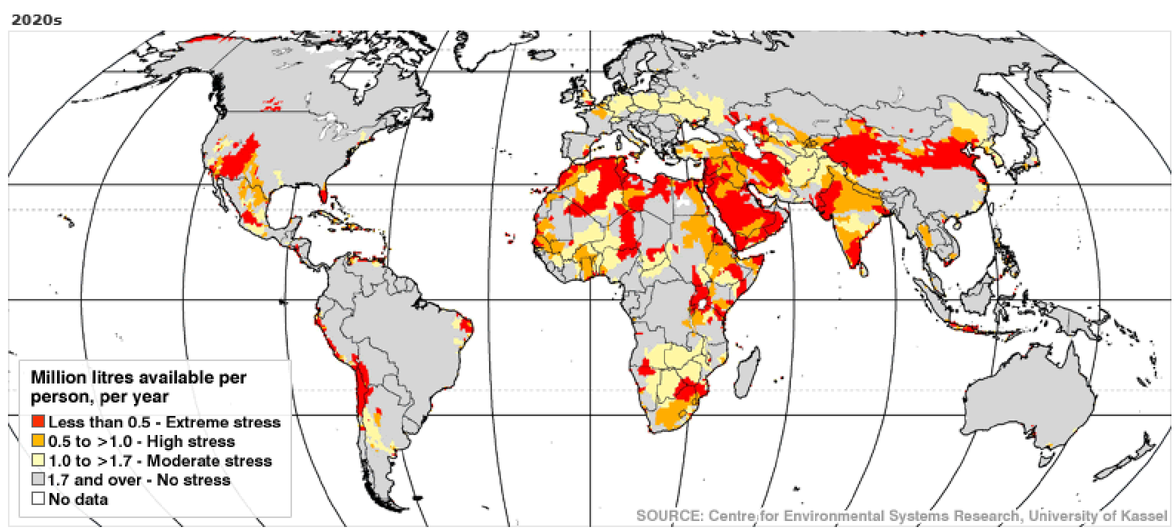


Figure 1 - World map representing the water distribution with emphasis to the water scarcity in millions litres available per habitant, per year, as estimated for the year 2020 Source: Centre for Environmental Systems Research, at University of Kassel, Germany

As a consequence, it is quite easy to figure out how tensioned are and, will continue to be in the coming years, the natural resources essential for agriculture, food and energy production as land, water and biodiversity (ROCKSTROM et al., 2009; SAYER et al., 2013). This paper provides, briefly, an overview of water, agriculture and food production based on OECD (Organization for Economic Co-operation and Development), FAO (United Nations Food and Agriculture Organization) and ANA (Brazilian Water Agency) information data systems and visions. As well, it is provided a compilation of some articles published by the author and collaborators to illustrate the potential for international cooperation regarding some agricultural and water resources research challenges, mainly in the tropics and with Brazil. According to OECD, Brazil is the principal country to meet the world food demand over the next ten years, a demand which will grow by 20%, largely to meet the growth in population and per capita income in the emerging countries. The increase in supply will have to come from various regions. The European Union will contribute with growth of 4%, Australia with 7%, the United States and Canada with a maximum of 15%, Russia, China, India and Ukraine with something around 27%. The largest part must come from Brazil, with 40% of the increase in production. Another important issue that deserves consideration is the importance of irrigation for food production. Out of 1,5 billion hectares cultivated worldwide about 270 millions are under irrigation corresponding to 18% of the total land cultivated. Recently, important global water resources modeling and calculations published by Pokhrel et al, 2012 establishes a straight relation between the water withdrawal from ground water and the increase of sea level, explaining the difference not accounted by previous climate change calculations. Important part of the water withdrawal from the groundwater is for irrigation purposes. Half of the world food production comes from the irrigated land. World Bank estimates that 175 mi indians and 130 mi chineses depend on grains produced through over pumping water from the ground water. This leads to a “buble” of food production. It will blow up by the time ground water is depleted. As following, it is selected some OECD, FAO and ANA data and visions, for the present and coming years, directly related to the issues addressed in this paper.

1.1 OECD’S VISION

Agriculture is a major user of water resources and, important contributor to water pollution from excess nutrients, pesticides and other pollutants. But, the competition for water is increasing and the costs of water pollution can be high. Sustainable management of water in agriculture is critical to increase agricultural production, ensure water can be shared with other users and maintain the environmental and social benefits of water systems. According to OECD's data and projections farming accounts for around 70% of water used in the world today and 47% of the world's population could be living under severe water stress by 2050, an increase from 44% in 2005. Increased pressure from urbanization, industrialization and climate change will provide agriculture with more competition for water resources. Climate change could affect water supply and agriculture through changes in the seasonal timing of rainfall and snow pack melt, as well as higher incidence and severity of floods and droughts.

Future policies to address the management of water resources in agriculture will be influenced by many and diverse drivers. For OECD countries farm management and technology; climate change and climate variability; and energy costs for pumping water are particularly important. In *Sustainable Management of Water Resources in Agriculture*, OECD analyses the challenges of moving towards more efficient management of water resources in agriculture and responding to growing food demands and the impacts of climate change. The OECD report suggests that it will be important for policy makers to:

1. Recognize the complexity and diversity of water resource management in agriculture, in the context of varying regional and national water resource supply and demand balances;
2. Strengthen institutions and property rights for water management in agriculture;
3. Ensure charges for water supplied to agriculture at least reflect full supply costs;
4. Improve policy integration and coherence between agriculture, water, energy and environmental policies;
5. Enhance agriculture's resilience to climate change and climate variability impacts;
6. Address knowledge and information deficiencies to better guide water resource management.

1.2 FAO'S VISION

Farmers are at the centre of any process of change and need to be encouraged and guided, through appropriate incentives and governance practices, to conserve natural ecosystems and their biodiversity and minimize their negative impact, a goal that will only be achieved if the appropriate policies are in place. Irrigation institutions must respond to the needs of farmers, ensuring more and reliable delivery of water, increasing transparency in its management and balancing efficiency and equity in access to water. This will not only require changes in attitudes, but also well targeted investments in infrastructure modernization, institutional restructuring and upgrading of the technical capacities of farmers and water managers. The agriculture sector faces a complex challenge: producing more food of better quality while using less water per unit of output and providing rural people with resources and opportunities to live a healthy and productive life. Also, applying clean technologies that ensure environmental sustainability and contributing in a productive way to the local and national economy. Today, agriculture is often unable to compete economically for scarce water. Cities and industries can afford to pay more for water and earn a higher economic rate of return from a unit of water than does agriculture. For the first time in many countries, agriculture is being obliged to give up water for higher-value uses in cities and industries. Irrigators in some areas are now asked to pay for the water they receive, including the full cost of water delivery. In other areas, new regulations require farmers to pay for polluting streams, lakes and aquifers. The irony is that irrigated agriculture is expected to produce much more in the future while using less water than it uses today. At present, 2.4 billion people depend on irrigated agriculture for jobs, food and income (some 55 percent of all wheat and rice output is irrigated). Over the next 30 years, an estimated 80 percent of the additional food supplies required to feed the world will depend on irrigation (INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE, 1992). These developments are placing enormous pressure on agricultural policy-makers and farmers. Throughout the world, governments assume the prime responsibility for ensuring food security and, because food depends increasingly on irrigation, food security is closely linked with water security. Between 30 and 40 percent of the world's food comes from the irrigated 16 percent of the total cultivated land; around one-fifth of the total value of fish production comes from freshwater aquaculture; and current global livestock drinking-water requirements are 60 billion litres per day (forecasts estimate an increase of 0.4 billion litres per year). Food security in the next century will be closely allied to success in irrigation. Irrigation can help make yield-increasing innovations a more attractive investment proposition but it does not guarantee crop yield increases. The overall performance of many irrigation projects has been disappointing because of poor scheme conception, inadequate construction and implementation or ineffective management. The mediocre performance of the irrigation sector is also contributing to many socio-economic and environmental problems, but these problems are neither inherent in the technology nor inevitable, as is sometimes argued. Irrigation projects can contribute greatly to increased incomes and agricultural production compared with rain-fed agriculture. In addition, irrigation is more reliable and allows for a wider and more diversified choice of cropping patterns as well as the production of higher-value crops. Irrigation's contribution to food security in China, Egypt, India, Morocco and Pakistan is widely recognized. For example, in India, 55 percent of agricultural output is from irrigated land. Moreover, average farm incomes have increased from 80 to 100 percent as a result of irrigation, while yields have doubled compared with those achieved under the former rain-fed conditions; incremental labour days used per hectare have increased by 50 to 100 percent. In Mexico, half the value of agriculture production and two-thirds of the value of agricultural exports is from the one-third of arable land that is irrigated. Irrigation is a key component of the technical package needed to achieve productivity gains. In the future, as high levels of costly inputs are added to cropland to sustain yield increases, the security and efficiency of irrigated production will become even more important to world farming. Water will no longer be plentiful and cheap. It will be scarce, expensive to develop and maintain and valuable in use. The prospect of high-cost water may at first seem to be another problem looming for low-income economies. However, the high cost will be an incentive to use water more efficiently. The single most important factor limiting the adoption of proven irrigation and drainage technology is the low cost of water. Moreover, if farmers have opportunities for higher-value uses and can make profits, both governments and farmers will invest in irrigation. This water dilemma - to produce more in a sustainable way with less water - points to the need for demand management mechanisms to reallocate existing supplies, encourage more efficient use and promote more equitable access. Policy-makers need to establish a structure of incentives, regulations, permits, restrictions and penalties that will help guide, influence and coordinate how people use water while encouraging innovations in water-saving technologies. In the past, supply-side approaches dominated water resource management practices. Water itself was physically managed through technical and engineering means that captured, stored, delivered and treated water. However, the era of meeting growing demand by developing new supplies is ending. In our present-day water economy, resource management is shifting away from the goal of capturing more water towards that of designing demand- and user-focused approaches that influence behavior. The development of "irrigated crop calendars" for each country, based on FAO's knowledge of the countries' agriculture is probably one of the most sophisticated ways to ensure reliable assessment of irrigation water requirements. The modeling approach FAO employs combine data from the AQUASTAT FAO database, such as harvested irrigated areas and crops, cropping patterns and intensity, as well as different elements of the climate in order to assess the amount of water diverted and required for irrigation. The robustness of this model is now well recognized and it has been used for a number of significant FAO exercises, such as the World agriculture: towards 2015/2030; an FAO perspective, the World agriculture: towards 2030/2050, the "World agriculture: towards 2050/2080", and more recently the State of the world's land and water resources for food and agriculture (FAO, 2013). The accuracy of the approach has also been validated by national statistics that became available in the meantime. This review however has the additional benefits of updated data as well as a handmade meticulous selection and correction of individual data, based on expert judgment. More details can be seen at http://www.fao.org/nr/water/aquastat/water_use_agr/index6.stm. Worldwide, over 307 million hectares are currently equipped for irrigation, of which 304 million hectares are equipped for full control irrigation and 261 million hectares are equipped for full control and actually irrigated. From these actually irrigated areas and thanks to the higher cropping intensity (CI) permitted by irrigation, over 346 million hectares of irrigated crops are harvested (meaning a global CI of 133 percent), the total irrigation water requirements of which account for 1 500 km^3. To meet these requirements, 2 673 km^3 are withdrawn (from primary and secondary renewable water resources, fossil groundwater and non-conventional sources of water), resulting in a water requirement ratio of 56 percent. However, both the methodology's improvement and the geographical coverage expansion since the previous modelling exercise (from 90 to 167 countries) prevent from attributing the progress of this ratio (which was 38 percent in 2000, the previous exercise) to refined irrigation or water management. Brazil´s irrigation and drainage development according to FAO data can be found at: <http://www.fao.org/nr/water/aquastat/data/query/results.html>.

2.3 WATER USE AND DEMAND FOR THE BRAZILIAN AGRICULTURE, ACCORDING TO ANA

Figure 2 provides a view of one of the most important areas of irrigation in Brazil, at San Francisco River, in the semi-arid region, northern part of Brazil. Thanks to the adoption of irrigation practices a truly green technological revolution had occurred at that region.

Figure 2 - Codevasf (São Francisco and Parnaíba Valley Development Company) perimeter of irrigation, São Francisco River, in the Northern of Brazil. Source: Photo by Anna Paola MichelanoBubel (from ANA image data bank)

Considering the water capacity stored per capita in the world (m3/habitant), Brazil with its 3.607 m3 in artificial reservoirs per habitant, is in a privileged position compared to several other countries and even, continents. Adding to that, 12% of the total surface water of the planet is located in Brazil. According to the 2012 ANA report on water resources (http://arquivos.ana.gov.br/imprensa/arquivos/Conjuntura2012.pdf), taking into account data and estimates from 2010, a total of 2373 m3/s was withdrawal and 1212 m3/s effectively consumed, corresponding to 51% of the total withdrawal outflow. The demands for type of consumption use shows that the biggest withdrawal outflow is for irrigation purposes, i.e., 1,270 m3/s, corresponding to 54% of the total, followed by urban human supplying, equal to 522 m3/s. With regard to the outflow effectively consumed, 72% corresponds to the irrigation demand, followed by animal use (11%), urban supplying (9%), industrial supplying (7%) and rural population use (1%). Hence, 84% of the total consumption occurs in the rural area! Even though, today, only 5.4 mi hectares (value 20% superior for 2006) are under irrigation considering the potential of 29.6 mi hectares for irrigation. One important research and public issue is the impact of agricultural activities on the soil, water and biodiversity resources. Runoff, soil loss and leaching of agrochemicals are particularly of great concern considering the tropical climate with its high intensity rainfalls in areas of agricultural production under fragile soils and inadequate management practices. Although most of the Brazilian area occupied with grain production is already employing conservation methods and systems, like no-tillage ones, the potential for groundwater contamination, eutrophication and silting up of waterways is high. Nowadays, concerning water chemical contamination from non-point sources, as the agriculture sources, it is important to highlight that Brazilian market for pesticides is already the world largest one. The business related to the commerce of pesticides accounted for US$ 9.71 billion dollars, according to 2012 data, referring to 823,226 tons of commercial product and 346,583 tons of active ingredient applied for agricultural production. Regarding to the data available for the commerce of fertilizers, it was sold in 2012, a total of 29.53 million tons.

2 THE BRAZILIAN AGRICULTURAL RESEARCH SYSTEM AND OPPORTUNITIES FOR INTERNATIONAL COOPERATION IN WATER RESOURCES AND FOOD PRODUCTION

The Brazilian Corporation for Agricultural Research (Embrapa) linked to the Ministry of Agriculture, Livestock and Food Supply, was established on April 26th, 1973.The Embrapa's mission is to design solutions that enable the research, development and innovation to the sustainable agriculture in order to benefit the Brazilian society. Embrapa organization encompasses 47 research and service units and 14 administrative units, spread out all over the country, with research and service actions covering all the six Brazilian biomes. To help Brazil in the construction of its leadership in tropical agriculture, the corporation invested, over all, in training of its human resources. Nowadays, Embrapa has 9,600 employees, of which 2,700 are researchers - more than 80% with PhD. The budget of the Company in 2012 was about US$ 1 billion. One of the previous missions of Embrapa was to coordinate the NARS (National Agricultural Research System), comprising federal and state public institutions to develop, in a cooperative way, research in the different geographic areas of the country and fields of scientific interest. Technologies generated by NARS and Embrapa had changed the Brazilian agriculture (THE ECONOMIST, 2010). The use of technologies made available by NARS and Embrapa, for the Brazilian savanas (cerrados), added 67.8 million of tons, i.e., 48.5% of the Brazilian production as 2008 data. Soybean was adapted to the cerrados conditions and today the country is the second largest world producer. Regarding to bovine and swine meat the production was increased by 5 times whereas chicken by 21 times (period 1975/2008). The milk production increased of 7.9 billion liters in 1975 to 27 billion liters, in 2008 and the Brazilian production of vegetables has raised from 9 million tons, in an area of 771.36 thousand hectares, to 17.5 million tons, in 806.8 thousand hectares, in 2006. In 2012, Brazil's annual grain production was 185 millions of tons and the total meat production reached more than 25 millions of tons.In the last decade the contribution of agriculture to the country's economy has been essential. In 2011, 22.15% of GDP, almost 40% of labour and 45% of exports came from the agribusiness sector. Moreover, it is worth to highlight the Brazilian leadership in the world production of coffee, in which it is the main producer of arabian and conilon coffee. Beyond coffee Brazil is the world largest exporter of orange juice, sugar, etanol, bovine meat and chicken. Thanks to the progress the country performed in exporting markets, today it is occupying the third world position as exporter (US$95.6 billions, in 2012) only behind U.S.A. and European Union, generating a trade surplus to the Brazilian economy of US$ 80billions, in 2012. Equally important is to mention the role NARS and Embrapa plays regarding to the generation of tropical knowledge and technologies. The tropical region encompasses the region of the globe between 23°27´ latitude north and 23°27´ latitude south, located between the Tropics of Cancer and Capricorn. The tropics span four continents – America, Africa, Asia and Oceania. There is a surplus of solar radiation up to 35° latitude North and South, while the opposite phenomenon occurs in the higher latitudes. The region's tremendous genetic diversity is what makes tropical agriculture so remarkable. More details concerning tropical agriculture can be found in Crestana and Souza, 2008.

The achievements and contributions of Embrapa and NARS allowed the country to detain the best "technological package" related to tropical agriculture. Just to date some technological examples made viable by the Brazilian science: fibers and wood (cotton, eucalyptus), tropical grasses (Brachiaria), agriculture in the Cerrados, biological pest control and nitrogen fixation and no-tillage system. Also, animals and plants production under tropical conditions, tropical and temperate horticulture, zebu cattle development, aviculture, soybean production (photo-periodism), integrated crop-livestock-forest-systems (ICLFS), and double cropping allowing at least two harvests per year, without irrigation. Moreover, specific programs of research provided by NARS and Embrapa had made available technologies and production systems that helped to increase the efficiency of family agriculture and to incorporate small producers to the market, improving its incoming and well-being. Family farming plays a very important role in assuring food safety to the country and, it is socially and economically important. Its farming area occupies 106.8 million hectares corresponding to 24% of Brazilian agricultural area, responds for 84% of land owners and has 12 million producers (1/3 of them are women). According to the Ministry of Agrarian Development, family farming is responsible for 87% of cassava, 58% of milk, 70% of bean, 30% of cattle, 50% of poultry, 46% of maize, 59% of swine and 34% of rice Brazilian production. In regards to Embrapa's international cooperation, the corporation holds 78 bilateral agreements of technical cooperation with 56 countries, 89 institutions, mainly of agricultural research, keeping multilateral agreements with 20 international organizations, involving partnerships in research and technology transfer. Adding to the effort of improving international cooperation, Embrapa established partnerships with laboratories in the United States and the Europe (France, Holland, England and Germany) for the development of strategic research and technologies of mutual interest. These "Virtual Laboratories Abroad" (Labex' s) count on with the physical basis of the Agricultural Research Service (ARS) of the United States, in Beltsville (Maryland), of the Agrópolis, in Montpellier, in France, of the University of Wageningen, in Holland, of the Institute of Research of Rothamsted, in England and of Julich Institute, in Germany . More recently, Labex-Korea was installed in Swon, in the South Korea and Labex-China, in Beijing. With those initiatives Embrapa researchers and the ones from these other countries have accessed to the highest technologies in areas of natural resources, biotechnology, computer science, precision agriculture, agro-energy, amongst others. In the sphere of the technology transfer for developing countries (Cooperation South-South) it is highlighted the establishment of Embrapa technology transfer projects in the African Continent (Embrapa Africa, in Ghana, Mozambique, Mali and Senegal), in the South American Continent (Embrapa Venezuela), and in Central America and the Caribbean (Embrapa Americas, in Panama). That effort has allowed to a bigger dissemination of the technologies and innovations of tropical agriculture developed by Embrapa and NARS, and, at the same time, helping Embrapa to better attending to the demands from the countries of those continents with the purpose of contributing to their respective agricultural development agendas.

3 SOME OPPORTUNITIES FOR INTERNATIONAL COOPERATION IN SCIENCE AND TECHNOLOGY RELATED TO AGRICULTURE AND WATER RESOURCES

In this section some environmental studies of agricultural interest and vice-versa are presented. Catchment has been used as the management unity with multipurpose tasks as to subsidize public policies, characterize, integrate studies and establish strategies for management of terrestrial, aquatic ecosystems and production systems and to assess the impact of agricultural activities on water resources, as one example. Balances of mass and energy are the basic science and conceptual basis behind the scenes. The concept and application of gauged and ungauged catchments is in the forefront (WAGENER et al., 2008). Simulation and modelling using models such as USLE, SWAT and Clue-S have been applied to predict soil loss, run-off and leaching of agricultural inputs. One case study of land use change and its environmental impacts is presented, as the case of São Carlos-SP county and neighborhood (MINOTTI et al., 2011). More recently, Embrapa is supporting and leading a research project and network named AgroHidro with opportunities for international cooperation. AgroHidro is a network of researchers aimed to develop studies, generate knowledge and technologies related to the interactions of agriculture, concerning its different activities, with the water resources. Coordinated by Embrapa the network aggregates professionals from various institutions interested in finding alternatives for the sustainable development of agriculture, taking into account a scenario of increasing water demand, risk of water scarcity and need to prevent from the impacts caused by extreme climate events. Converging technologies and complex systems, agricultural instrumentation, adaptation and implementation of models and instrumentation to simulate scenarios of agricultural impacts on water and soil resources as well simulation of flow and sediments are presented as good opportunities for technical cooperation, as following.

3.1 CONVERGING TECHNOLOGIES AND COMPLEX SYSTEMS

The vision of Galileo Galilei (1564-1642) about water science is intriguing: *"I had less difficulty in the discovery of motion of heavenly bodies in spite of their astonishing distances than in the investigation of the movement of water before our very eyes".* On the other hand, at the dawn of this new century, science and technology is providing concepts and tools, including computer capacity, laboratory and field instrumentation to deal with complex systems in a more appropriate and realistic way, as the ones related to soil-water-plant-atmosphere studies and agricultural production systems submitted to intensive pressure. It is worthwhile to point out that since the end of the 20th century various alternatives have arisen to underline or modify concepts of intense agriculture. The so-called advanced biological, information and communication technologies are examples. Precision Agriculture is another concept that has appeared in order to deal with questions not only of yield but also of environmental variables. Today, in substitution to the green revolution, it is needed a new green revolution, only this time greener and socially more inclusive. In other words, the goals of the so-called sustainability need to be reached. The progress using Science and Technology obtained in the last two centuries was based on the isolation of the different disciplines. None of the disciplines of chemistry, biology, genetics and machine engineering responsible for the success of green revolution were applied to agriculture in an integrated way. This time the basic ingredient of the new revolution will be integration between disciplines through inter-disciplinary and trans-disciplinary work. In this context, new opportunities coming from the convergence of physical sciences, life sciences, engineering and human sciences as well the science, engineering and management of complex systems are very exciting (CRESTANA; FRAGALLE, 2011; BEDDINGTON, 2009; FERREIRA et al., 2012; FOLEY et al., 2011; SAYER; CASSMAN, 2013). For the first time in the history, mankind are able to manipulate, simultaneously, atoms, molecules, genes, bits and neurons by technologies stemming from information, the cognitive sciences, bio-technology and nano-technology. That means to manipulate matter and life, for example, by producing new materials, plants, animals and engineering new agricultural production systems. Strictly speaking, these sciences and technologies could interact themselves, communicating, converging and producing synergies potentially unprecedented in the whole history of Science, Technology and Innovation. At their core they possess the revolutionary capacity to change paradigms which could alter the relationship of man to man and his relantionship with nature. Which take us on to the management of complex systems, in which decision-making needs the integration of systemic and non-linear approaches, including, besides technological problems, questions of ethics, of law, and of individual and collective well-being.

3.2 AGRICULTURAL INSTRUMENTATION

Agricultural instrumentation is the use of advanced techniques and knowledge, methods, systems, and instruments to develop equipment, methodologies, processes, sensors, measuring and control devices, drivers, and signal transmitters and processors applied to agriculture. Also, to simulate, model, monitor and manage agricultural production systems to generate new knowledge and technology from basic sciences as Physics, Biology and Mathematics as well as from the different areas of Engineering. In Brazil, one of the responsibilities of Embrapa is to carry out research in agricultural instrumentation. Since 1984, Embrapa started its activities in this research area throughout its national research center called Embrapa Agricultural Instrumentation. Today, Embrapa Agricultural Instrumentation is one of the 45 research centers of Embrapa. Embrapa Instrumentation plays an important role in increasing productivity and quality of products, with the purpose of ensuring the sustainability and competitiveness of Brazilian agriculture. Some of Embrapa Agricultural Instrumentation lines of research are applied to agro-energy, family agriculture, soil and water resources management, precision farming, quality evaluation of products, environment, rapid diagnosis and early detection of diseases, nanotechnology, post-harvest and agricultural wastes. Nowadays, the converging technologies and sciences as Information Technology, Biotechnology, Nanotechnology and Cognitive Sciences became essential for managing agricultural systems and agribusiness in a sustainable way. IT and Biotech are already present in the day by day of the Brazilian agricultural activities in the lab and field as well as in the innovation agenda of the private sector. The next coming wave of innovation and development in agriculture will be implemented by the use of Nanotechnology and Cognitive Sciences. Not only but added to the Management and Engineering of Complex Systems and possible synergies coming from the converging technologies. In this context, agricultural instrumentation is receiving great attention concerning to the management of land, advanced automation, development of embedded systems like unmanned aerial vehicles (drones), imaging techniques, robotics, and artificial intelligence just to mention some of them. It is important to notice that researcher time has become increasingly scarce. The manpower cost increases exponentially and its availability for field work is decreasing. Hence, work-saving machines are very much in demand. Taking all into account, the public and private research and educational system are under strong pressure to redefine their roles at local, regional, national and international level. Mainly, regarding to the preparation of new professionals and entrepreneurship actions to reach the new challenges demanded by the markets, public policies and “mega tendencies” foreseen for the next years. The growth or disappearing of such institutions seems to be directly conditioned to the immediate construction of strategies in order to establish planning, commitments and actions not only in the short term, but principally in the long term. International cooperation is one of the essential strategies and tools. One example, under discussion and implementation regarding to cooperation in Science and Technology applied to agriculture and water resources is already in place between Embrapa Instrumentation, in Brazil and Hassan II Academy of Science and Technology, in Morocco.

3.3 ADAPTATION AND IMPLEMENTATION OF MODELS AND INSTRUMENTATION TO SIMULATE SCENARIOS OF AGRICULTURAL IMPACTS ON WATER AND SOIL RESOURCES

The instrumentation and monitoring of watersheds is a worthy task. One of the reasons is the generation of reliable data in order to take the best decisions regarding to the management of soil and water resources. From the scientific point of view the generation of a huge amount of data not only for assessing the quality of soil and water in these regions but also as input for theoretical and empirical models for prediction of environmental impacts of scenarios for different land uses and soil management is a must. Therefore, the use of widely known models such as CLUE-S, SWAT, WEPP, AnnAGNPS, CENTURY, and CQESTR is welcome but they need to be adapted to the tropical and subtropical ecosystems and develop others if necessary. CLUE-S (Conversion of Land Use and Its Effects at Small Extent) is a forecasting model for use and occupation of space and land covers and is useful to predict possible changes in the planting of crops in the watersheds being studied (VERBURG; KONING, 1999; VERBURG et al., 2002). SWAT (Soil and Water Assessment Tool) is a simulation model of the hydrological cycle in complex watersheds and evaluates the impact of different land uses and management (ARNOLD; FOHRER, 2005; GASSMAN et al., 2007). Once properly adjusted and calibrated, the SWAT model allows to forecast future impacts on soil and water quality from the current agricultural activities, and other possible scenarios, for example, increasing or decreasing the areas of environmental preservation. WEPP (Water Erosion Prediction Project) is similar to SWAT, but it is more accurate and only estimates the loss of soil (FLANAGAN; NEARING 1995; LAFLEN et al., 1997). AnnAGNPS (Annualized Agricultural Non-Point Source Pollution Model) has applications similar to SWAT, but is more focused on the simulation of pollutants (THEURER; CRONSHEY, 1998; BINGNER; THEURER, 2005; USDA-ARS, 2006). CENTURY is a complex model of plant-soil nutrient cycling which simulates the long-term dynamics of carbon, nitrogen, phosphorus, and sulfur for different types of ecosystems (PARTON et al., 1987, 1994). CQESTR is a soil carbon balance model that simulates biological decomposition of vegetal and animal residues into soil organic matter (LIANG et al., 2008, 2009; GOLLANY et al., 2010). As required, other models may be developed to better match the weather conditions, land use, management, and plant species of the watersheds of interest. In the last two decades our research team, in collaboration with other scientists in the country and abroad, had made important investment and progress in developing and applying conventional and advanced instrumentation, modeling and simulation to Brazilian real conditions, at watershed scale. Presently, one of the main purposes of the team work is to monitor and assess the impact of land use and land cover change on soil-water quality taking into account different agricultural management practices. Nowadays, as well known, a great challenge is to deal with the concept of gauged and ungauged catchments, depending on the availability and quality of data (WAGENER et al., 2008). Complex systems mainly related to the soil-water-plant–atmosphere system have been investigated employing advanced analyses tools and instrumentation such as multi-fractal analyses, pedotransfer functions, percolation theory, artificial neural networks, imaging reconstruction, tomography and other non-invasive methods and techniques. In the last twenty years, several projects and capacity building were implemented producing a large number of peer reviewed publications, Master dissertations, PhD thesis and innovative technologies. To be more precise, some examples are given, as following: AGNPS (SOUTO, 1998), SWAT (MINOTI, 2006, NEVES, 2005; GALHARTE, 2011), CLUE-S (GALHARTE, 2011), LEACHM-P (GIULIANO, 1995). At watershed scale, research straightly related to simulation: Giuliano, 1995, Souto (1998), Eskes (1998), Neves (2005), Minoti (2006), and Galharte (2011), to instrumentation and measurements: Ferreira (1999), Bramorski (2007), Netto (2007), Vaz (1989; 1994), Posadas (1990; 1993), Cassaro (1994), Naime (1994; 2001) and Silva (1997) and to soil-water impact of agricultural practices: Galharte (2007) and Stopelli(2005) were performed. Also, other published matter can be verified: Bramorski et al., 2012; Minoti et al., 2011; Crestana et al., 2010; Galharte and Crestana, 2010; Silva et al., 2010; Posadas et al., 2009; Pedrotti et al., 2005; Stopelli et al., 2005 and Tomasella et al., 2003.

3.4 SIMULATION OF FLOW AND SEDIMENTS

One of the study areas of our interest is located in the central region of São Paulo, southeastern Brazil (MINOTI et al., 2011), near to São Carlos county, place where Embrapa Agricultural Instrumentation Research Center is located. The two study units (basins Jataí and Guabirobas) drain into opposite sides of the Mogi Guaçu, a tributary of the Parana River (La Plata basin) (Figure 3). Elevations in the Jataí basin range from 529 to 851 m a.s.l. and in the Guabirobas basin range from 530 to 718 m a.s.l. The Jataí basin (80 km^2) is occupied by sugarcane (39%), eucalyptus (25%) and the Ecological Station of Jataí (36%), which is a preservation area. The Guabirobas basin (51 km^2) (Figure 4) is used for agricultural production with its area occupied mainly by sugarcane (60%), eucalyptus (6%), orange (18%), pasture (6%) and natural vegetation (9%). With the application of the SWAT model for the studied basins it was possible to simulate the basin outlet flow and sediment loads generated annually in both sub-basins, and calculate the loads exported to the Mogi Guaçu River.

Figure 3 - The Mogi Guaçu river (in brown) divides the picture in two main areas: the area preserved (Ecological Station of Jataí), on the right margin and the area exploited by human activities (farming, livestock, forest, leisure and others), on the left margin. Taking the river and the watershed as reference this scenario provides an exceptional environment for research related to land use and land cover change and its impacts on soil and water resources

Figure 4 - Views of Guabirobas basin, as part of the Mogi Guaçu river watershed, showing typical agricultural land use occupied by pasture, sugarcane and citrus. In the sugarcane corridors, used mainly for traffic of heavy-duty vehicles, the process of erosion is underway

Source: Photos by Minoti, R. T. (2006)

SUMMARY

The model outputs for the ungauged basins, as simulated by the SWAT model were compared with observed data from a monitored basin, which is also part of the River Mogi Guaçu catchment, but about 70 km downstream from the area studied here, and an area about 10 times the areas of the simulated basins.The location of the watersheds and land use are shown in Figure 5.

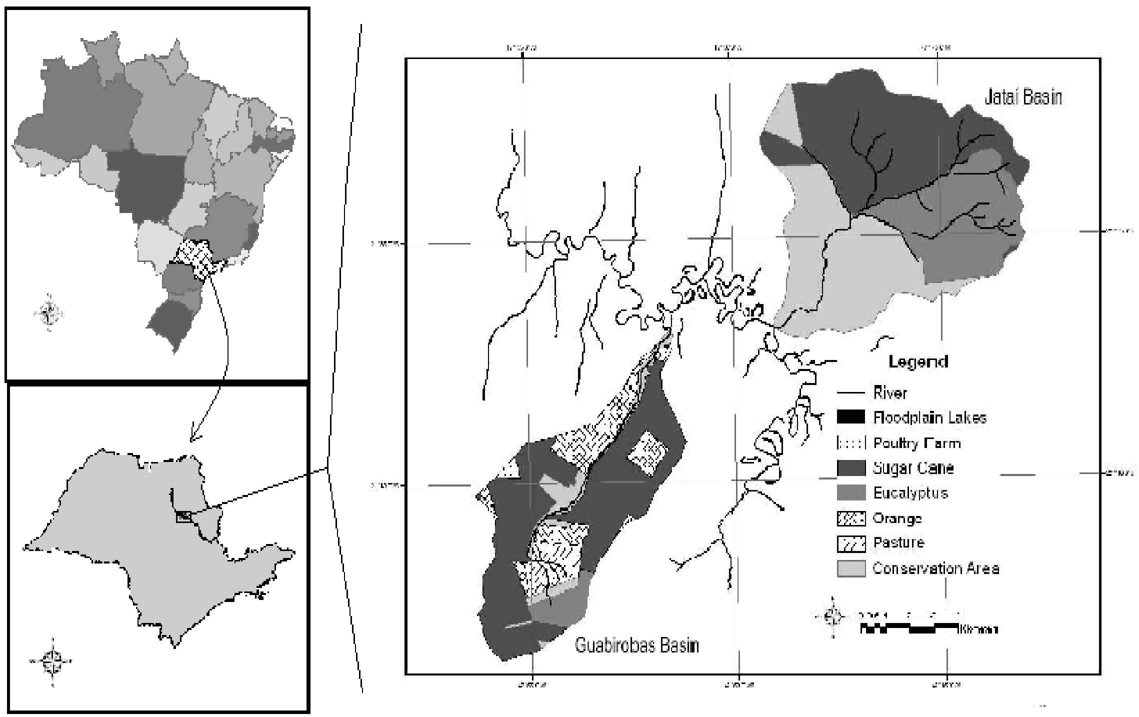


Figure 5 - Map showing the location of Jataí and Guabirobas river basins and land use

The focus of the study was to identify areas of greatest vulnerability to erosion and sediment production in the studied ungauged basins. In order to achieve this, the USLE and SWAT models were jointly applied. The purpose of using the USLE model was to compare results of this traditional model, widely used in Brazil, with studies of different scales, including river basins, with the results generated by the more complex SWAT model, developed for use in areas with scarce data. The USLE model, traditionally used in studies of rural planning in the State of São Paulo (Brazil), led to results expected for the region. The qualitative interpretation of the results generated by the SWAT model has been consistent with the results obtained by applying the USLE; both indicating the most critical areas of the basins. The SWAT model was sensitive to changes in land use scenarios and to the set of available data related to the study area. However, due to difficulties in conducting studies in the selected basins, flow and sediment loads are not monitored, and thus model calibration and verification is very difficult in these cases.The distributed approach, both by the USLE as well as by the SWAT model, helped to identify the most critical areas related to erosion and sediment yield. The prospect of developing scenarios confirmed the identification of critical areas and created information related to the risks of extensive cultivation of sugarcane in this region. The results obtained using these models could be used in the identification of more appropriate land uses and management practices best suited to the most vulnerable sectors of the basins. Further studies must be carried out to improve the application of SWAT model in these areas.Sediment generation for the preserved scenario was low and for the sugarcane scenario, mainly to Jataí basin, was very high.

In order to develop a cooperative national and international agenda on water resources, tropical agriculture and food production some opportunities, are suggested, as following:

- Develop and evaluate sustainable systems for recuperation of degraded areas, especially by livestock grazing;
- Develop and exploit second generation technologies;
- Take a stand on water footprint: blue, green and grey water and taking advantage of AgroHidro initiative establish a Brazilian and possibly, an international research, development and innovation network concerned to water resources and agriculture;
- Measure life cycle (water, energy, greenhouse gases, rate of loss or gain of biodiversity ...) of agricultural products;
- Establish quality indicators, measure them and monitor them (the metrics of sustainability);
- Measure the vulnerability and resilience of agricultural systems;
- Simulate and model agricultural systems seeking to establish scenarios and forecasts;
- Establish partnerships with *International Institute for Ecology, AgroHidro network* and *Embrapa Agricultural Instrumentation*, in São Carlos, SP and other national and international institutions of research and funding to implement the *International Center on Water and Watershed Research (figure 6),* for:
- Development and use of instrumentation, methods, simulation and modelling like multifractal analysis, imaging techniques, sensors, precision farming, converging technologies and complex systems approach;

- Calibration, sensitivity, modification and validation of the models in use and
- Evaluation of agricultural land use and land cover change considering its impacts on soil and water resources.

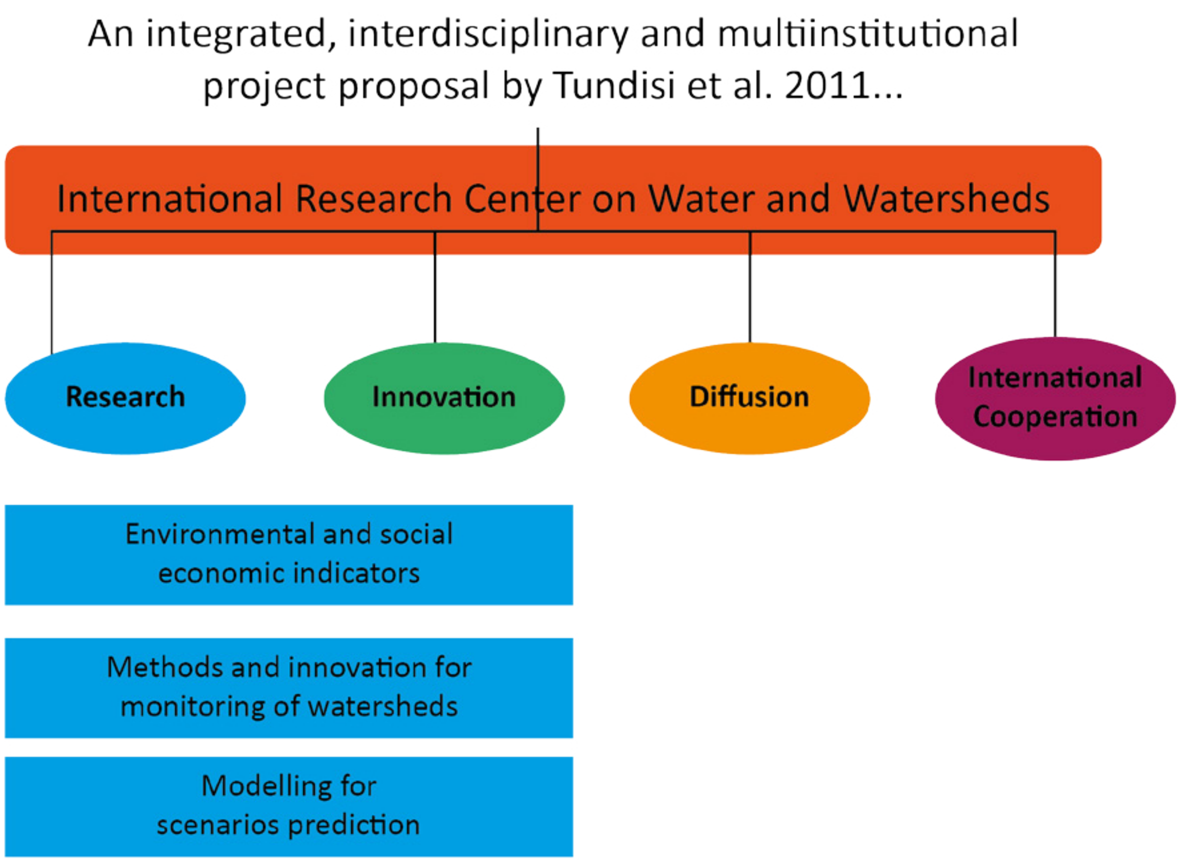


Figure 6 - Proposal of an International Research Center on Water and Watersheds elaborated by Tundisi et al., 2011, based on four legs: research, innovation, diffusion and international cooperation

Finally, it is worth to remember Confucius (551BC-479BC): “if you have goals for one year, plant rice; if you have goals for 10 years, plant a tree; if you have goals for 100 years, then educate a child; but if you have goals for 1000 years, then preserve the environment”. It makes sense: if the environment is not preserved, there is no chance of raising a child, of growing a tree and of cultivating rice. As country or institution, are we cultivating rice, planting trees, educating children or preserving the environment? Brazil is a fortunate country: looking at the horizon for a period of 1000 years, we have the gift of having conserved 60% of our native forests, of having 12% of all the world surface water, the biggest tropical biodiversity of the planet and is one of the world largest food production countries. Therefore, it is necessary to conserve such treasures at the same time Brazil contributes for supplying the food the country and the world population demands. In order to achieve that endeavor science and technology stand high. Moreover, national and international cooperation is not only an opportunity but one of the most important tools mankind has at hands for reaching such achievement.

REFERENCES

Arnold, J. G., Fohrer N. 2005. SWAT2000: Current Capabilities and Research Opportunities in Applied Watershed Modelling, Hydrol. Process., 19 563.

Beddington, J. 2009. Food security: contributions from science to a new and greener revolution. Phil. Trans. R. Soc. B 2010 365, 61-71.

Bingner, R. L., Theurer, F. D. 2005. AnnAGNPStechnicalprocessesdocumentation: Version 3.2. Oxford, Miss.: USDA-ARS National Sedimentation Laboratory. Available at: www.ars.usda.gov/SP2UserFiles/Place/64080510/AGNPS/PLModel/Document/Tech_Doc.PDF. Accessed December 2011.

Bramorski, Julieta. Evaluation of soil loss and nitrogen fertilizers by erosion in agricultural sites: an integrated and experimental approach of the factors influencing the process. 2007 Thesis (PhD Program in Sciencesof Environmental Engineering) - Universidade de São Paulo (in Portuguese)

Bramorski, J.; I. C. De Maria; R. Lemos e Silva and S. Crestana. 2012. Relations between soil surface roughness, tortuosity, tillage treatments, rainfall intensity, soil and water losses from a red yellow latosol. R. Bras. Ci. Solo, 36:1291-1297

Cássaro, Fábio Augusto Meira. Double energy tomography for physical and hydrological characterization of expansive porous media under diverse degrees of hydration. 1994. Dissertation (Master Program in Physics) - Universidade de São Paulo (in Portuguese).

CRESTANA, S.; Sousa, I. S. F. de. 2008. Agricultura tropical no Brasil, vol. 1, 41-65. In: Albuquerque, A. C. S.; SILVA, A. G. da. (Ed.). Agricultura tropical: quatro décadas de inovações tecnológicas, institucionais e políticas. Brasília, DF: Embrapa Informação Tecnológica.

Crestana, S.; Minoti, R.T.; Neves, F. F.; Modeling and simulation applied to the evaluation of the impacts of soil loss and swine dejects in water quality at microbasin scale. In: Gomes, M.A.F.; Pessoa, M.C.P.Y. (Ed.). Environmental planning of rural space focused on microbasins: management of water resources, computational tools and environmental education. Brasília, DF: Embrapa Informação Tecnológica; Jaguariúna: Embrapa Meio Ambiente, 2010. p.167-199.

Crestana, S. and E. P. Fragalle. 2011. Tropical agriculture in Brazil: competitiveness and sustainability based on science and innovation. Cadernos FGV Projetos. Year 6, no. 17, 76-89.

Eskes, Sander Jacobus Titus. Application of stochastic modeling techniques to quantify the leaching and pesticide persistence in the soil at watershed scale. 1998. Thesis (PhD Program in Sciences of Environmental Engineering) Universidade de São Paulo (in Portuguese)
FAO The State of Food and Agriculture 2013 (available at http://www.fao.org/docrep/018/i3301e/i3301e.pdf)

Ferreira, J.; R.Pardini; J.P. Metzger; C.R. Fonseca; P.S. Pompeu; G. Sparovekand J. Louzada. 2012. Towards environmentally sustainable agriculture in Brazil: challenges and opportunities for applied ecological research. Journal of Applied Ecology. British Ecological Society. 1-7

Ferreira, Sávio José Filgueiras. Influence of the forest management on the water cycle and nutrients in a forest area of Central Amazôniaunder terrafirme. 1998 Thesis (PhD Program in Sciencesof Environmental Engineering) - Universidade de São Paulo (in Portuguese).

Flanagan, D.C., Nearing, M.A, 1995. USDA-Water Erosion Prediction Project: Hillslope Profile and Watershed Model Documentation. NSERL Report No. 10. USDA-ARS National Soil Erosion Res. Lab., West Lafayette, IN, USA.
Foley, J. A.; N. Ramankutty; K.A. Brauman; E.S. Cassidy;J.S. Gerber; M. Johnston; N. D. Mueller; C. O'Connell; D.K. Ray; P. C. West; C. Balzer; E.M. Bennett; S.R. Carpenter; J. Hill; C. Monfreda; S. Polasky; J. Rockstrom; J.Sheehan; S. Siebert;

D. Tilman and D. P. M. Zaks. 2011. Solutions for a cultivated planet. Nature, Vol. 478, 337-342.

Galharte, Caroline Alves. Assessment of environmental impacts related to farming-livestock integration system: a case study of Embrapa technological innovation. 2007. Dissertation (Master Program in Science of Environmental Engineering) - Universidade de São Paulo(in Portuguese)

Galharte, C. A.; CRESTANA, S. Farming-livestock production system in Brazilian savanas: assessment of environmental impact under soil conservation aspect. Revista Brasileira de Engenharia Agrícola e Ambiental, Campina Grande, v.14, n.11, p. 1202–1209, nov., 2010.

Galharte, Caroline Alves. Prediction of runoff and sediments production in areas of farming-livestock and forest activities, in São Paulo State, as a function of land use and land cover change. 2011. Thesis (PhD Program in Sciences of Environmental Engineering) - Universidade de São Paulo (in Portuguese).

Gassman, P., Reyes, M., Green, C., Arnold, J. 2007. The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions. Trans. ASABE, 50 (4), 1211.

Giuliano, Antonio Donizetti. Development and validation, in lab, of a model for prediction and fate of organic solutes in non-saturated porous media and transient condition. 1995 Dissertation (Master Program in Science of Environmental Engineering) - Universidade de São Paulo(in Portuguese)

Gollany, H. T., J. M. Novak, Y. Liang, S. L. Albrecht, R. W. Rickman, R. F. Follett, W. W. Wilhelm, and P. G. Hunt. 2010. Simulating soil organic carbon dynamics with residue removal using the CQESTR Model. Soil Sci. Soc. Am. J. 74:372&150; 383.

International Irrigation Management Institute. 1992. Developing environmentally sound and lasting improvements in irrigation management: the role of international research. Colombo, Sri Lanka, IIM

Laflen, J. M., Elliot, W. J., Flanagan, D. C., Meyer, C. R., Nearing, M. A. 1997. WEPP predicting water erosion using a process-based model. Journal of Soil and Water Conservation, 52 96-102.

Liang, Y, H.T. Gollany, R.W. Rickman, S.L. Albrecht, R.F. Follett, W.W. Wilhelm, J. M. Novak, and C.L. Douglas, Jr. 2008. CQESTR simulation of management practice effects on long-term soil organic carbon. Soil Sci. Soc. Am. J. 72:1486-1492.

Liang, Y, H.T. Gollany, R.W. Rickman, S.L. Albrecht, R.F. Follett, W.W. Wilhelm, J. M. Novak, and C.L. Douglas, Jr. 2009. Simulating soil organic matter with CQESTR (v. 2.0): Model description and validation against long-term experiments across North America. Ecol. Model.220:568-581.

Minoti, Ricardo T. Qualitative and quantitative approach for studying microbasin and flooded areas pertaining to the Médio Mogi-Superior SP river taking into account the loss of soil by erosion. 2006 Thesis (PhD Program in Sciences of Environmental Engineering) - Universidade de São Paulo (in Portuguese)

Minoti, R. T.; Silva, F.; LombardiNeto, F.; Koide, S.; CRESTANA, S. 2011. Application of models to estimate erosion, sediment production and future scenarios in two Brazilian tropical watersheds. Red Book Series, IAHS Publ., n. 345, p. 99-105. ISSN: 0144-7815.

Naime, João de Mendonça. A new method for dynamical studies, in situ, of water infiltration in the vadose zone. 2001 Thesis (PhD Program in Sciencesof Environmental Engineering) - Universidade de São Paulo (in Portuguese).

Naime, João de Mendonça. Design and construction of a portable tomograph for soil and plants studies, in the field. 1994. Dissertation (Master Program in Electric Engineering) - Universidade de São Paulo (in Portuguese)

Netto, Antonio Angelotti. Estimating soil water retention based on the use of non-conventional instruments, artificial neural networks and pedo-transfer functions. 2007. Thesis (PhD Program in Sciencesof Environmental Engineering) - Universidade de São Paulo (in Portuguese).

Neves, Fernando F. Risk assessment referred to erosion at Rio Bonito (Descalvado - SP) microbasin potentially affected by contamination of poultry dejects. 2005. Dissertation (Master Program in Science of Environmental Engineering) - Universidade de São Paulo (in Portuguese)

Parton, W.J., Schimel, D.S., Cole, C.V., Ojima, D.S. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Sci. Soc. Am. J., 51 1173-1179.

Parton WJ, Schimel DS, Ojima DS, Cole CV. 1994. A general model for soil organic matter dynamics: sensitivity to litter chemistry, texture and management. In: Bryant RB, Arnold RW (eds) Quantitative modeling of soil forming processes. SSSA Spec. Pub. 39. ASA, CSSA and SSSA, Madison, 147-167.

Pedrotti, A ;Pauletto, E A; Crestana, S. ; Holanda, S F R ; Cruvinel, P e ;Vaz, C M P . Evaluation of bulk density of Albaqualf soil under different tillage systems using the volumetric ring and computadorized tomography methods. Soil & Tillage Research, NY, USA, v. 80, n. 12, p. 115-123, 2005.

Posadas, Adolfo Durand. Kinetics of thawing and freezing of water in a non-saturated porous medium: experimentation and simulation. 1990. Dissertation (Master Program in Physics) - Universidade de São Paulo (in Portuguese).

Posadas, Adolfo Durand. Theoretical modeling and experimental validation for the problem of instability of water and solute infiltration in non-saturated double layer soils: fingering phenomenum. 1993. Thesis (PhD Program in Physics) - Universidade de São Paulo (in Portuguese).

Posadas, A. ;Quiroz, R. ; Tannús, A ; CRESTANA, Silvio ; Vaz, C. M. P.. Characterizing water fingering phenomena in soils using magnetic resonance imaging and multifractal theory. Nonlinear Processes in Geophysics, v. 16, p. 159-168, 2009.

Pokhrel,Y.N., N. Hanasaki, P. J-F. Yeh, T. J. Yamada, S. Kanae and T. Oki. 2012. Model estimates of sea-level change due to anthropogenic impacts on terrestrial water storage. Nature Geoscience, vol 5,389-392.

Rockström, J;W. Steffen; K. Noone; Å. Persson; F. S. Chapin;E. F. Lambin; T. M. Lenton; M. Scheffer; C. Folke; H. J. Schellnhuber; B. Nykvist; C. A. de Wit; T.Hughes; S. van der Leeuw; H. Rodhe; S. Sörlin; P. K.Snyder; R. Costanza; U. Svedin, M. Falkenmark; L. Karlberg; R. W. Corell; V.J. Fabry; J.Hansen , B. Walker; D. Liverman; K. Richardson; P. Crutzen and J. A. Foley. 2009. A safe operating space for humanity. Nature, Vol. 461, 472-475.

Sayer, J. and K.G. Cassman. 2013. Agricultural innovation to protect the environment. PNAS, vol. 110, no. 21, 8345-8348.

Sayer, J., T. Sunderland, J. Ghazoul, J-L Pfund, D. Sheil, E. Meijaard, M. Venter, A.K. Boedhihartono, M. Day, C. Garcia, C. van Oosten and L.E. Buck. 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. PNAS, vol.110, no.2, 8349-8456.

Silva, Alvaro Macedo da. Design, construction and use of a microtomograph dedicated to soil science studies. 1997 Thesis (PhD Program in Sciences of Environmental Engineering) - Universidade de São Paulo (in Portuguese).

Silva, F. das G. B. da; Minotti, R. T.; Lombardi Neto, F.; Primavesi, O.; CRESTANA, S. Prediction of soil loss at Canchim Farm-SP (Embrapa) using geo-processing and USLE 2D. Engenharia Sanitária e Ambiental, Rio de Janeiro, v. 15, n. 2, p. 141-148, 2010.

Souto, Adriano Rausch. Modeling studies for evaluation of environmental impacts in rural microbasins. 1998 Dissertation (Master Program in Science of Environmental Engineering) - Universidade de São Paulo (in Portuguese)

Stopelli, I M de B S ; CRESTANA, S.2005.Pesticide exposure and cancer among rural workers from Bariri, São Paulo State, Brazil. Environment International, New York, v. 31, p. 731-738.

Stopelli, Illona M de Brito Sá. Agriculture, environment and health: an approach about the risk of contact with agrochemicals using hospital data of regional reference. 2005. Thesis (PhD Program in Sciencesof Environmental Engineering) - Universidade de São Paulo (in Portuguese).

The Economist The miracle of cerrado Aug 26th, 2010 The Economist Newspaper Limited, London, 1-7.

Theurer, F.D., Cronshey, R.G. 1998. AnnAGNPS – Reach routing processes. In Proc. 1st Federal Interagency Hydrologic Modeling Conf., 1-25 to 1-32. Washington, D.C.: Interagency Advisory Committee on Water Data, Subcommittee on Hydrology.

Tomasella, J.; Pachepsky, Ya.; CRESTANA, S.; Rawls, W.J..Comparison of two techniques to develop pedotransfer functions for water retention. Soil Science Society of AmericaJournal, V. 67, p. 1085-1092, 2003.

Tundisi et al, 2011. International Research Center on Water and Watersheds. Proposal to Fapesp.

USDA-ARS. 2006. AnnAGNPS - Annualized Agricultural Nonpoint Source Pollution model. Oxford, Miss: USDA-ARS National Sedimentation Laboratory. Available at: www.wsi.nrcs.usda.gov/products/w2q/h&h/tools_models/agnps/index.html. Accessed December 2011

Vaz, Carlos Manoel Pedro. Computerized tomography applied to soil compaction studies. 1989. Dissertation (Master Program in Sciences (Nuclear Energy in Agriculture)) - Universidade de São Paulo (in Portuguese).

Vaz, Carlos Manoel Pedro. Electroanalytical methodology for measuring atrazine in water and soil solution. 1994. Thesis (PhD Program in Sciences (Nuclear Energy in Agriculture)) - Universidade de São Paulo (in Portuguese).

Verburg, P.H., Koning, G.D. A spatial explicit allocation procedure for modeling the pattern of land use change based upon actual land use. 1999. Ecological modeling, 116(1) 45-61.

Verburg, P.H., Soepboer, W., Limpiada, R., Espaldon, M., Sharifa, M., Veldkamp, A. 2002. Land use change modeling at the regional scale: the CLUE-S model. Environmental Management, 30(3) 391-405.

Wagener, T; H. S. Wheater and H. V. Gupta. 2008. Rainfall-runoff modeling in gauged and ungauged catchments. 306pgs, Imperial College Press, London, UK.

SESSION 3

WATER GOVERNANCE FOR DEVELOPMENT AND SUSTAINABILITY

PROMOTING INTEGRATED LAKE BASIN MANAGEMENT (ILBM): THE INITIAL GLOBAL EXPERIENCE, 2008-2012

Masahisa Nakamura[1]
Walter Rast[2]

[1] Research Center for Sustainability and Environment, Shiga University, Japan. International Lake Environment Committee (ILEC), Japan.
[2] Meadows Center for Water and the Environment, Texas State University, USA. International Lake Environment Committee (ILEC), Japan.

ABSTRACT

In September, 2015, a set of global goals will be adopted in the United National General Assembly to end poverty, protect the planet, and ensure prosperity for all as part of a new sustainable development agenda. Among the seventeen goals is Goal 6, "Ensure access to water and sanitation for all" (UNITED NATIONS GENERAL ASSEMBLY, 2015). Under this Goal, there are seven targets toward 2030, i.e., achievement of universal and equitable access to safe and affordable drinking water; achievement of access to adequate and equitable sanitation and hygiene; improvement of water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials; substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity; implement integrated water resources management at all levels, including through transboundary cooperation as appropriate; protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes; expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies; and support and strengthen the participation of local communities in improving water and sanitation management. With the above in the background in mind, and based on the authors' more comprehensive treaties of the subject (NAKAMURA; RAST, 2014), this paper addresses the need for greater awareness and concern about the state of lentic water systems on the globe and about their management challenges, with specific reference to the importance of the concept of Integrated Lake Basin Management (ILBM). It presents an overview of the experiences and outcomes of ILBM application between 2008 and 2012, with a categorization of the cases and an interpretive discussion of the results. It also discusses the challenges faced in promoting ILBM as a comprehensive mechanism for addressing lakes and reservoirs, their basins and the sustainable use of their resources, including the importance of the development of support mechanisms.

1 LAKES AS LENTIC WATERS

Lakes and reservoirs, consisting more than ninety percent of the liquid freshwater on the surface of the earth (SHIKLOMANOV, I. 1993), are broadly considered to be "standing" or "static" water systems. They can be viewed as "hydrostatic" systems as contrasted to "hydrodynamic" systems to which rivers and other channeled water courses belong. The synonymous terms to hydrostatic and hydrodynamic systems in the ecology literature are "lentic" and "lotic" systems. The meaning of "lentic" is basically the same as for hydrostatic, while the meaning of "lotic" is the same as for hydrodynamic. However, the lentic and lotic expressions have the additional connotation of their imbedded ecological functions. Ecologically the lentic waters, either fresh or saline/brackish, have a particularly vulnerable and fragile property due in large part to their unique bio-chemico-physical features transcending to complex management challenges, i.e., *an integrating nature* (it receives all forms of stress from almost every direction)*, long water residence time* (the received stresses remain long and persistently)*;* and *complex response dynamics* (the stresses change their form from one state to another within the water body, often not being readily noticed since they take place in small increments)*.* Thus, the natural basin water systems, such as lake-river systems, pond-stream systems, wetland-spring systems, and even constructed, but naturalized, dam-river systems are hydrostatic-hydrodynamic systems, as well as being lentic-lotic systems, because of the historically-fostered ecosystem functions they have acquired over long periods of time. The natural lake-river systems, pond-stream systems, and wetland-feeder spring systems are strongly lentic-lotic in character. Managing a basin that consists mostly of a strongly lentic-lotic regime, for example, requires a different management approach than that for a basin consisting primarily of man-made hydraulic systems with little historically-fostered ecosystem functions.

2 INTEGRATED LAKE BASIN MANAGEMENT (ILBM)

Managing a water system (lakes, wetlands, rivers, aquifers) for sustainable use is a complex challenge involving a range of interconnected scientific, socioeconomic, political and environmental issues, sometimes even with conflicting or contradictory goals. Integrated Lake Basin Management (ILBM) is an approach for achieving sustainable management of lakes and reservoirs through gradual, continuous and holistic improvement of basin governance, including sustained efforts for integration of institutional responsibilities, policy directions, stakeholder participation, scientific and traditional knowledge, technological possibilities, and funding prospects and constraints. It has been conceptualized on the basis of the premise that achievement in managing lakes, reservoirs and their basins so that they can continue to provide their wide range of life-supporting ecosystem services is facing a serious global challenge. ILBM also takes the position that even the problems facing individual lakes cannot be properly addressed unless the fundamental issue of sustainable resource development, use and conservation facing the lakes is address globally, and with strong, long-term political commitment. The ILBM process also is designed for lake basin stakeholders collectively to fill the gaps between what has already been achieved, and what remains to be achieved realistically in continuing governance improvements over time. As discussed further below, the ILBM 'Platform' is a virtual stage for collective stakeholder actions for improving the basin governance through ILBM, as a strategic means of facilitating the gradual and continuous improvement of basin governance, conveniently termed as an ILBM Platform Process, over a long time period. The concept of ILBM, while having been derived from the term Integrated "Lake" Basin Management, is in fact a concept for lentic waters of all kind, and they are generally complexly intertwined with lotic waters, implying that ILBM is a budding concept of Integrated Lentic and Lotic Basin Management (ILLBM or IL^2BM).

3 ECOSYSTEM SERVICES: A USEFUL CONCEPTUAL FRAMEWORK

The overall degrading trend of the world's lakes suggests that, regardless of the form of ownership, their management is generally far from adequate. The Millennium Ecosystem Assessment (World Resources Institute. 2005) proposes that ecosystems provide a wide range of benefits, in the form of life-supporting services to humanity, services that nature provides essentially free-of-charge monetarily, although not strictly without other costs. Virtually all ecosystems provide services essential for human health and economic well-being. The four classes of ecosystem service components are:

a) Resources Provision Services – These represent the products people obtain from ecosystems, including water supplies; fish; crop irrigation; wood and fiber; fuel; hydropower generation;

b) Regulating Services – These refer to the benefits people obtain from the regulation of ecosystem processes, including flood and drought mitigation; self-purification capacity; health provision; navigation routes; climate mediation; aquatic habitats; diverse food-chains; fertile lands; coastal ecotone buffer capacity;

c) ***Cultural Services*** **–** These refer to the non-material benefits people obtain from ecosystems, including aesthetic and scenic values; religious and spiritual values; historic sites; educational resources; and

d) ***Supporting Services*** – These refer to the services necessary for sustainability of all other ecosystem services, including heat energy; geological formation; nutrient cycling; primary production; physical formation.

The main challenge for humans is to gradually attain a balance between the *resource provision services* and the *regulating services* comprising major components of the overall *ecosystem services*, and which require a much longer timeframe and much broader spatial implications than the conventional notion of lake basin management. Consistent with the Millennium Ecosystem Assessment, ecosystem services represent the benefits people obtain from ecosystems. In defining ecosystem services in this manner, it is noted that resource provision services are typically valued in monetary terms. The other three classes of services, however, are more difficult to evaluate in an economic context. As a result, degradation of the latter services is often neglected in management efforts. Increasing use of lake resources can have profound negative impacts on the environmental status of lake systems. The progress of degradation within a lake and its basin often takes place on a wider, deeper scale than may be readily apparent. Of particular interest within the context of lake basin management is that increasing human use of lake-specific resource provision services can result in degraded ecosystem regulating services. Even more important, however, is that increasing loss of regulating services can, in turn, also result in decreasing provision services, as well as the loss of cultural and support services. This reality highlights the need to transform unsustainable resource development to sustainable resource use.

4 PLANNING VS. GOVERNANCE

4.1 MEETING THE MANAGEMENT NEEDS: SCOPES AND APPROACHES IN PLANNING

The possible reasons for, and purposes of, lake basin management would necessitate development of suitable frameworks for planning, with the goal of fulfilling the respective management requirements. For example, **a)** ***resource development*** plans would be required for the sectoral agencies in charge of water supplies and fisheries. The **b)** ***resource value enhancement*** plans would be required, for example, for promoting tourism and recreational facilities. There will soon be a need, however, for plans to **c) *decongest resource use*** in such a way that undue pressures would be alleviated by, for example, reducing the number of fish catches through both statutory and non-statutory means. In the case of **d) *resolving resource use conflicts***, introduced plans may involve compensatory payments, or the creation of a new resource base to ease the resource use competition. Most well-known plans in lake basin management are those for **e) *reducing environmental stress***, particularly in relation to the quality of lake water. The plans usually stipulate structural means (e.g., construction of sewerage systems), as well as nonstructural means (e.g., enhancement of regulatory activities such as compliance monitoring of the quality of discharged effluents; public education programs to change human behaviors). There is a wide range of stress reduction measures, including removal of noxious sediments form the lake bottom, promotion of agricultural Best Management Practices (BMPs), introduction of local eco-labeling, etc., which could all be categorized under **e)** above. There also are other types of plans that play important roles in lake basin management, such as those for **f) *rehabilitation and restoration*** of degraded riparian ecosystems, an example being sanding the lake bottom after sediment removal to restore shellfish habitat, as well as those for **g) *resource value protection***, such as delineation of reed bed protection zones for maintaining and enhancing ecosystem integrity. Planning for **h) *precautionary actions*** is rare, but there are cases where a precautionary decision could be made to forgo the planned construction of lake basin facilities that could have potentially irreversibly adverse impacts on its ecosystem. The plans mentioned above are all related in various ways to addressing **i) *overall ecosystem maintenance*** with a long-term comprehensive plan.

The plans developed for the various reasons and purposes, however, may not necessarily produce the desired outcomes, typically because of a lack of harmony regarding their timing or scale. The resource development and resource conservations plans individually introduced, for example, could result in a conflicting outcome. The temporal and spatial scopes of plans can prove inconsistent with the manner in which a lake ecosystem responds, despite significant financial, technological and manpower investments. Improved lake water quality could prove to be a very erratic goal over the short planning horizon. Above all, the plans being developed and implemented by the responsible bodies with different mandates (e.g., multiple resource development agencies vs. regulatory and coordinating agency) may not necessarily always be implemented in coordination, and there is no standard approach that will always work well in such cases. In summary, there is a need for more than planning and implementation activities alone to ensure inconsistencies among individual reasons and purposes would gradually be harmonized. The individual plans would complement each other over time, with the overall outcome of these plans being consistent with sustainable development, use and conservation of lake basin resources. This suggested approach defines "Integrated Lake Basin Management," or ILBM, a concept described in the following section.

4.2 SIX PILLARS OF GOVERNANCE

The adequacies and inadequacies of lake basin management for individual lake basins may be determined by reviewing and assessing the existing management activities and practices. Based on the comprehensive surveys of the state of world's lakes conducted over the past decades, relevant review questions have been categorized into six thematic domains, including: **(1) Institutions** to manage a lake and its basin for the benefit of all lake basin resource users; **(2) Policies** to govern people's use of lake resources, and its impacts on lakes; (**3) Involvement of people** to facilitate all aspects of lake basin management; **(4) Technological possibilities and limitations** that often dictate long-term decisions; **(5) Knowledge** of both traditional and modern scientific origin as the basis for informed decisions; and (**6) Sustainable finances** to support implementation of all of the above-noted activities. Relevant questions regarding these domains include:

<Institutions>

Is there a focal-point institution in charge? Are the relevant capacity building and training programs effective? Is the institution focusing on priority skills? Is it inclusive and open to cooperating agencies, community groups, etc.? Are any mid- course corrections needed?

<Policies>

Is there a management plan with a realistic implementation scope? Does an adequate management plan already exist, or should the existing plan be updated? Are the relevant priorities and phasing clear? Does strong political will exist to support sustainable management? Is sustaining and building political will and commitment appropriately incorporated as part of the management program?

<Involvement of people>

Do effective mechanisms exist for participatory implementation? Does the existing management plan include all relevant stakeholders for its implementation? What changes have occurred in regard to awareness and understanding of the problems, and their linkages to stakeholder activities? What are the perceptions of program stakeholders?

<Technological possibilities and limitations>

Are the existing technologies working well? If yes, could their performance be further improved? If no, what are the reasons for their not working properly? Have there been unexpected adverse impacts of technology applications? If yes, have the adverse effects been appropriately mediated? If no, should the applications be further replicated? Have either technology options or costs changed, and are such changes reflected in the management plan?

<Knowledge and Information>

Is there a common, shared knowledge base about the priority management challenges? Does a monitoring system exist to measure changes in key governance and other relevant indicators? Is the data base sufficient? What are the remaining key gaps? Are information management tools adequate to be effectively deployed?

<Finances>

Are the currently available financial resources adequate? How can access to financial resources other than those currently available be improved?

These six major topics comprise the essential governance ingredients that collectively form the management regime for the integrated approach for lake basin management encompassed within Integrated Lake Basin Management (ILBM), referred to hereafter as the Six Pillars of Governance in ILBM (**Figure 1**).

Figure 1 - Conceptual Illustrations of ILBM Platform Structure with Six Pillars of Governance

3 LAKE BRIEF AND ILBM PLATFORM PROCESS

3.1 PREPARATION OF A LAKE BRIEF

Box 1. General Outline a Lake Brief

The general structure of a Lake Brief is as follows:

I. Introduction
II. Description of the Lake (supplemented by Annex A below)
III. Management of the Lake and Its Basin
IV. Major "Impact Stories" of the Lake
V. Major Lake Basin Governance Issues (supplemented by Annex B below)
VI. Key Challenges to Lake Governance (supplemented by Annex B below)
VII. References

Annex A. Lake Questionnaire (Checklist of data and information on biophysical and managerial issues facing the lake basin)

Annex B. Six Pillars of Governance (Check list flowchart of the governance issues facing the lake basin)

The ILBM Platform Process begins with the preparation of a 'Lake Brief' **(Box 1**). In a practical sense, preparation of the essential part of a Lake Brief may be facilitated by first identifying the 'Impact Stories,' or the past incidents of success and failure, the management implications surrounding the unique physico-chemical characteristics, limitations and prospects facing the basin community, etc., that feature the lake basin environment and its community (**Section IV**). The remaining sections can then be developed around these elements, particularly with regard to the issues and challenges to be described (**Sections V and IV)**. Useful inputs, in the form of reviews and suggested refinements, can be obtained effectively through an iterative process by such means as collaborative workshops. Inclusion of appropriate figures, tables, illustrations, maps and other visual materials will obviously increase the usefulness of a Lake Brief. A guideline document is available for preparing a Lake Brief, which contain questionnaire elements that include the bio-geophysical features of a lake basin, its socio-economic and governance features, and impairments to its sustainable use, including its ecosystem regulating services.

This Lake Brief forms a knowledge base for what is called the ILBM Platform Process, to be described later, and which conceptually transforms the existing state of lake basin governance exhibiting very weak or non-existent governance pillars into a sound state after expending much effort for governance improvement by strengthening of the Six Pillars of Governance, as shown in **Figure 2**, through the ILBM Platform Process.

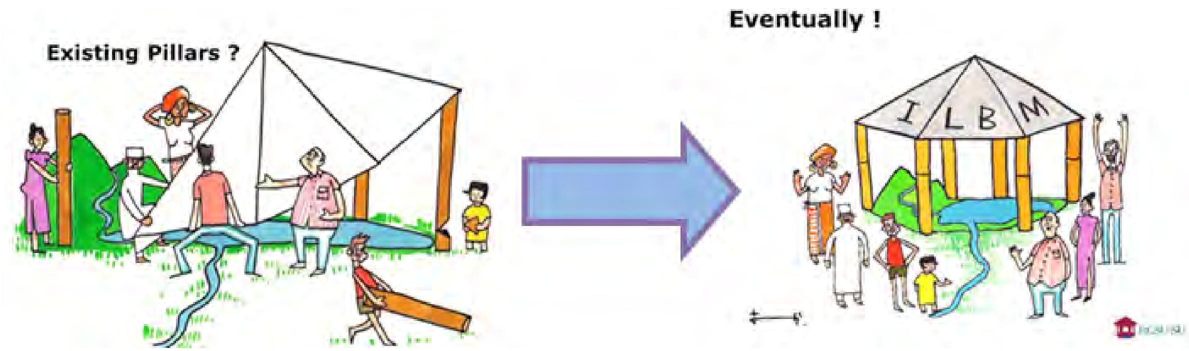


Figure 2 - Strengthening Six Pillars of Governance for the ILBM Platform Structure

5.2 DEVELOPMENT OF ILBM PLATFORM PROCESS

The ILBM Platform Process takes the form of either a basic (i.e., 'once-through') process (**Figure 3**) or a cyclic process (**Figure 4**). Because of its fewer steps, the basic process may often be the initially-utilized approach, with the more comprehensive cyclic process to be subsequently developed with further experience. Based on most cases of lake basin management in developing countries conducted to date, the basin stakeholders usually find ILBM Platform Process useful regardless of whether they use the basic or cyclic process. This observation is based on the experience that the conventional approach in planning for lake basin management is primarily a government-driven activity, thereby often exhibiting a very 'top-down,' as well as 'expert-driven,' management approach. This approach often deprives a broad range of stakeholders from being involved in the planning process in any significant manner, despite the fact that they are usually the ones most directly and indirectly affected by the implementation of such plans. A basic process may, or may not, subsequently be transformed into a cyclic process, depending on the interests and capabilities of the members developing the Platform. In many cases, however, the need to transform the basic process into a cyclic process will become apparent over time, with the collective aspiration to do so also growing over time.

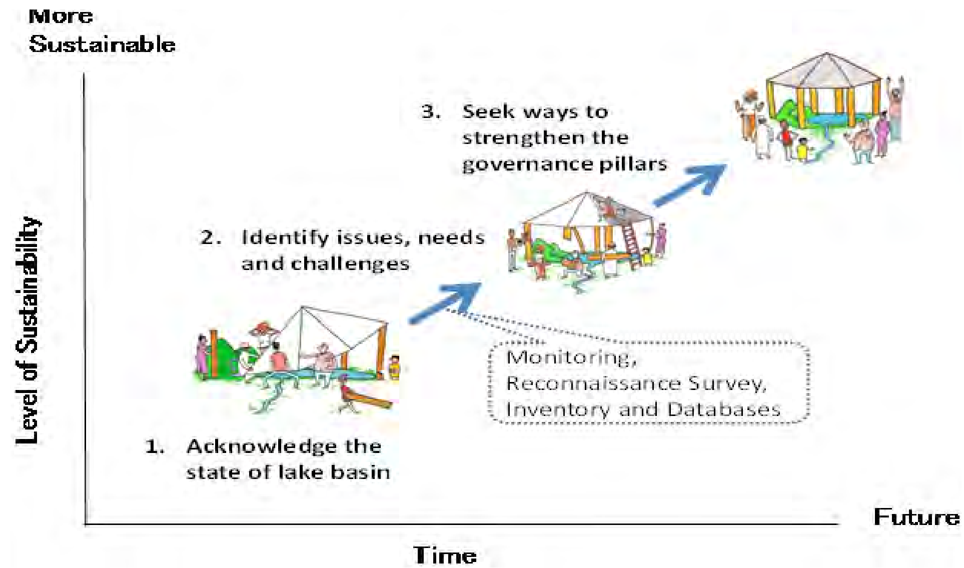


Figure 3 - Conceptual Image of a Basic ILBM Platform Process

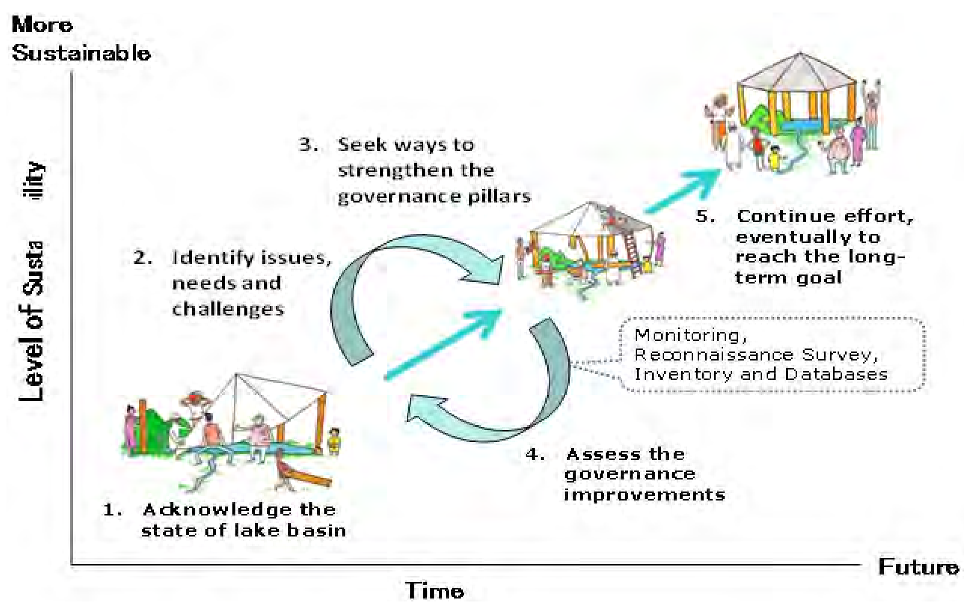


Figure 4 - Conceptual Image of a Cyclic ILBM Platform Process

Figure 5 is a diagrammatic presentation of the Cyclic ILBM Platform Process. It begins with **Step 1)**, "Description of the State of Lake Basin Management," for which the information and data gained in preparing the Lake Brief for a given lake and its basin play a key role. The analysis of "Issues," "Needs," and "Challenges" regarding the Six ILBM Governance Pillars identified in Sections V and VI of the Lake Brief will take place in **Step 2)** of the Platform Process. The **Step 2)** can be elaborated in some depth as follows: a) The "Issues" identified in Section V of the Lake Brief should include those identified by individual stakeholder groups, as well as collectively by multiple stakeholder groups; b) Some of the "Challenges" identified in Section VI of Lake Brief may be clear and straightforward, and the approaches to address them may become clear rather quickly through a constructive consultative process among the concerned stakeholders. Other "Challenges" may be more complicated to address, requiring much time and collective efforts on the part of multiple stakeholder groups. They also may be left for consideration in subsequent rounds of analysis in the cyclic process. For **Step 3)** of the Platform Process, the stakeholders should be ready to discuss and consider how the "Challenges" identified above in **Step 2)** may be addressed. This step generally requires collective, critical self-analysis of the background and reasons why such "Challenges" arose in the first place, and how they may be most productively addressed. A set of guiding questions, prepared on the basis of the compiled documentations of past lake basin management experiences, may be very useful for this step.

Determining the means and approaches for addressing the identified "Challenges" will usually require a great deal of thought and 'soul-searching' on the part of the Platform members. This may range from simple information-sharing (i.e., for the concerned stakeholders to decide to share information already available, but exclusively owned by each stakeholder separately), to collective actions (i.e., for the concerned stakeholders to undertake joint actions by mobilizing collective resources), to joint engagement in developing and implementing various intervention plans and projects anew, possibly by involving external technical and financial cooperation programs willing to be part of the jointly developed ILBM Platform Process.

There are two important considerations for assessing incremental improvements in lake basin governance; namely, (1) Time intervals for review and assessment; and (2) Assessment methodologies and indicators.

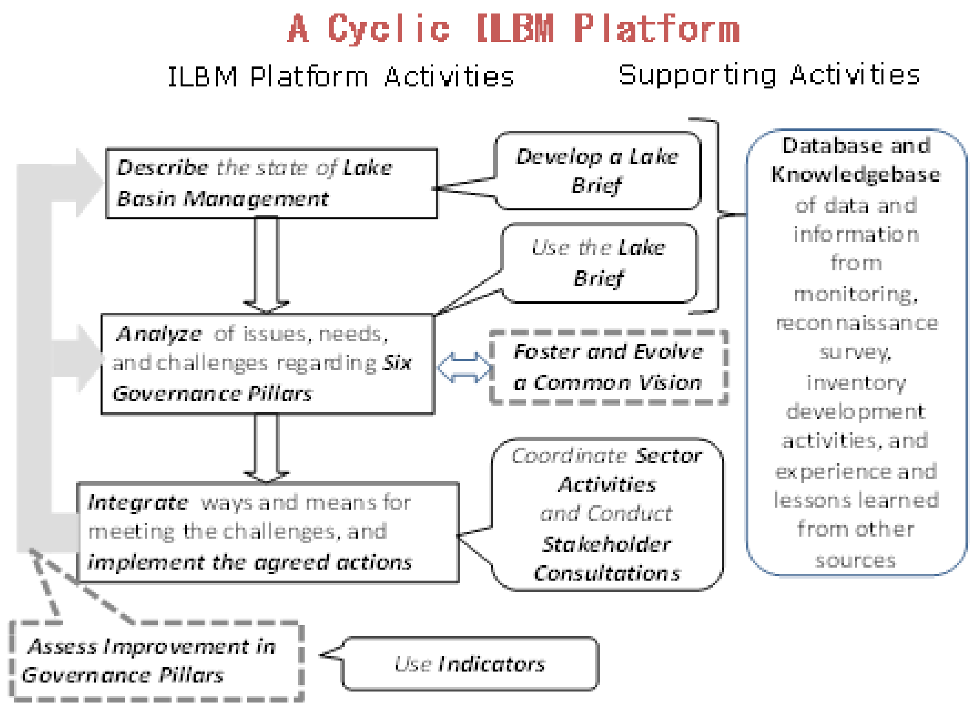


Figure 5 - Flow Diagram of Cyclic ILBM Platform Process

The time intervals for review and assessment can vary from a few months to several years in order to observe measurable improvement, depending on the nature of the challenge to be addressed. For example, if monitoring of lake surface water is regularly conducted at certain sampling points, and data are readily available, a time interval period longer than the monitoring interval would then be meaningful. On the other hand, the state of the lake bottom ecosystem, for example, would probably not be part of a regular sampling program, and its analysis may require special sampling and laboratory analysis techniques involving a team of specially-assembled researchers. The assessment methodologies and indicators to be adopted for the Platform Process also can vary widely, depending on the nature of governance improvement challenges. Among the methodologies in the literature, the one proposed here is used for monitoring and assessment of international transboundary environmental projects by the Global Environment Facility (DUDA, 2002). This methodology uses two types of “output-oriented” indicators, and one type of “outcome-oriented” indicator. The two “output-oriented” indicators include the “enabling process indicators,” and the “stress reduction indicators,” which enable and set needed actions into motion, while the “outcome-oriented” indicators measure actual responses in the lake basin to the “output-oriented” actions, as follows:

a) Examples of “**enabling process indicators**” may include: Realization of stakeholder involvement in the creation of a management plan; enactment of regulations on the mesh size of nets in order to reduce the quantity of inadvertently-harvested juvenile fish; and legal and institutional reforms for harmonization of various environmental management plans;

b) Examples of “**stress reduction indicators**” may include: Increased reed bed area resulting from de-siltation operations; reduced industrial pollution loading because of more stringent enforcement; reduced excess water withdrawals; reduced agrochemical application per cropland area; reduced silt and sediment carried into the lake;

c) Examples of “**environmental status indicators**” may include: Decreased nutrient concentrations; improvement in the state of ecosystem health, as reflected in an increased biodiversity index and, utilizing questionnaire surveys, determining the extent to which communities and stakeholders benefitted from the measured changes in environmental conditions.

It is to be noted that the values and information associated with “stress reduction indicators” and the “enabling process indicators,” which can be regarded as the necessary-condition indicators, are easier to obtain, being rather straightforward measures of progress toward improved lake basin governance. In contrast, some of the “environmental status indicator” values are not easy to obtain, and are more difficult to interpret, compared to the other two types of indicators. This is because of the ‘lag period’ that typically occurs after corrective or remediative actions have been undertaken for a lake because of its long water residence time, meaning that some period of time will pass before actual improvements become noticed and/or measurable. Thus, the indicator values have to be interpreted on a much greater long-term basis, and sometimes with the help of auxiliary tools of analysis and interpretation such as sophisticated and specialized instrumentation and mathematical modeling tools. Nevertheless, the indicator is indispensable in the Platform Process.

6.1 APPLICATION CASES AND THEIR TYPOLOGY

The number of ILBM application cases is slowly, but steadily, growing in different regions of the world, each being at different stages of Platform development. The time required for a Platform Process to evolve from one stage to the next, i.e., from 1) preparation of a lake brief, to 2) development of a Basic Platform Process, and finally to 3) development of a Cyclic Platform Process, depends in part on the adequacy of the available human and financial resources. A summary of these three categories of ILBM outputs in different regions/countries is presented in **Table 1**. Many of the application cases have so far been part of research and applied study projects, while some have been undertaken in connection with technical cooperation programs. In the case of Malaysia, Nepal and the Philippines, for example, national government initiatives have been quite instrumental, while in the case of India and Mexico, local governments and major scientific organizations of national status have facilitated the implementation of the projects, while also maintaining a close relationship with their national program frameworks.

Preparation of a lake brief, development of a Basic Process, and development of a Cyclic Process would each take a few years to be completed. A general observation of these cases reveals that the provisionally-completed lake briefs serve as useful guides within the first 1-2 years, and address the immediate needs for improving basin governance. Platform members would likely be less amenable to undertaking the Basic and Cyclic Processes, which require more systematic assessment of the incremental improvements. There are a large number of cases in which the lake briefs served to address both immediate and longer-term needs without having a clear cyclic process of assessment, incremental goal setting, and introduction of necessary measures for implementation. In other words, the process remained a Basic Process, and did not evolve to a Cyclic Process. Finally, a limited number of cases have illustrated the inclination to become a Cyclic Process, with the introduction of measures of governance improvement, using indicators reflecting the extent of stress reduction, enabling process and environmental status. A brief description of each of the major application cases included in **Table 1** is given in **Annex 6**, in Nakamura and Rast (2011), "A Summary of Major ILBM Application Cases."

The following briefly describes some of the features of the lake basin cases listed in the above-noted table:

- **African Region**
  - Chivero (Zimbabwe): The lake has been under serious threat largely because of basin governance failure due to the deterioration of socio-political and economic situation in the past decades;
  - Nakuru (Kenya): An ILBM Process is adopted to address multiple management plans under multiple sector/ stakeholder engagements;
  - Nyanza Gulf (Kenya): Basin governance improvement through broad stakeholder involvement is seriously lacking, although an assortment of ILBM-related interactions are taking place through the GEF-World Bank-supported LVEMPII program.

- **India**
  - An assessment of the JICA (Japan International Cooperation Agency)-assisted plan for the Conservation and Management of Lake Bhopal has been assessed using the ILBM framework;
  - Ujiani Reservoir is well known for Jala Dhindi (water-course pilgrimage), which played an important part of the preparation of its ILBM Lake Brief that formed a basis for subsequent activities in the city of Pune, as well as the downstream regions toward the reservoir;
  - The Ahar River, one of the rivers supporting the lake complex of Udipur City, otherwise called the City of Lakes, is the first site of a “green bridge” technology for environmental restoration of the river, being an example of innovation under the “Technology Pillar” of ILBM Platform Process;
  - Lake Pushkar is a well-known pilgrimage lake facing a serious water level decline for various reasons, including neglect, causing an uproar by most of the basin population, which is heavily dependent on the lake for spiritual, social and economic values; ILBM is now regarded as the most promising approach for the lake restoration with broad participation;
  - Other lake/river basins with ILBM related activities being conducted include Lake Hussinsagar, and a river in the Thane district of Maharashtra State, where the ILBM concept has been helping to address child-malnutrition alleviation challenges;

- **Japan**

  - Various ILBM-related field visits and studies have been conducted for analysis of basin governance, both for designated and non-designated lakes, under the Special Measures for the Preservation of Lake Water Quality (commonly referred to as the "Lake Law") of Japan;

- **Malaysia**

  - Lake briefs have been prepared for about 30 lakes to date under its Strategic Plan for Lake and Reservoir Management, being coordinated by the National Hydraulic Research Institute of Malaysia, with a wide variety of management plans attributable to the lake briefs;

- **Mexico**

  - Significant progress in ILBM Platform development has been made in both the Lake Chapala and Lerma River basin micro-watershed regions over a period of four years, particularly with regard to the stakeholder initiative, through horizontal (through regional networks), as well as vertical (national, state, and local linkages), collaboration for accelerating the ILBM Platform Process;

- **Nepal**

  - A draft National Lake Conservation Plan(NLCP)has been developed, based heavily on the ILBM framework as implemented by the National Lake Conservation and Development Committee, Ministry of Tourism and Civil Aviation, with about 20 lake basins currently having been identified as priority ILBM targets for intensive field studies for governance improvement;

- **The Philippines**

  - Laguna Lake experiences have been spearheading the use of ILBM framework as a common basis for dealing with various challenges facing the lake and its basin;
  - Lake Lanao, an ancient lake with many indigenous species of flora and fauna, has been facing serious environmental and ecological degradation, due in large part to water level fluctuations caused by hydropower generation, forcing the lake people (the Maranao people) to lose their livelihoods; the ongoing efforts will hopefully facilitate significant changes for the better in the not–too-distant future.

- **Russia**

- A Lake Brief has been prepared for each of the three lakes in the northwestern part of Russia, by the National Institute of Limnology, Saint Petersburg, and preliminary efforts have been undertaken to prepare a Lake Brief for the Caspian Sea and Aral Sea;

- **USA**

- The results of Independent studies undertaken to test the applicability and usefulness of the ILBM framework were presented in November 2012 at the International Symposium of the North American Lake Management Society (NALMS).

Table 1 - Typological Categorization of ILBM Application Cases for the Period 2008-2012

(continue)

	Summary of ILBM Application Cases: 2008-2012				
	Lake/River Basin Name	**ILBM Process Reached[1]**	**Temporal Scope[2]**	**Government Invol-vement**	**External Support[4]**
1. African Region	Chivero Nakuru Nyanza Gulf	MP(WS-LB) MP(WS-LB-BP/CP) WS-LB-BP	Retro-Pro Retro-Pro Pro	Nat/State/***Loc*** Nat/ State/***Loc*** Nat/State/ ***Loc***	ILEC/MEnv-J ILEC/MEnv-J ILEC/MEnv-J
2. India	Bhopal Chilika Ujiani Res. Ahar River Pushkar	MP MP (WS-LB) WS-LB-BP WS-LB-BP LB	Retro Retro Retro-Pro Pro Retro	***Nat/State/***Loc ***Nat/State/Loc***Nat/ ***State/Loc***Nat/ State/***LocNat/*** State/***Loc***	JICA IAAB in Collaboration with SU-ILEC/MEdu-J
3. Japan	Biwa Saroma Shinji-Nakaumi	CP (FS) CP (FS) CP (FS)	Retro Retro Retro	***Nat/State/Loc Nat/State/Loc Nat/ State/Loc***	Under NLWQP Under LLWQP Under NLWQP
4. Malaysia	Bukit Merah Putrajaya Chini Others	MP(WS-LB) MP(WS-LB) WS-LB-BP WS-LB	Retro-Pro Retro-Pro Retro-Pro	***Nat/State/***Loc***Nat/ State/***Loc***Nat/State/*** Loc	Malaysian Gov. Organizations in collaboration with SU/ILEC/MEdu-J

(continuation)

	Summary of ILBM Application Cases: 2008-2012				
	Lake/River Basin Name	**ILBM Process Reached[1]**	**Temporal Scope[2]**	**Government Involvement**	**External Support[4]**
5. Mexico	Chapala Lerma basin micro-watersheds	WS-LB-BP WS-CP	Retro-Pro Pro	***Nat/State/Loc*** Nat/***State/Loc***	Corazón de La Tierra, and SU/ILEC/MEdu-J
6. Nepal	Begnas Phewa Rupa Others	LB MP(LB) LB-BP) LB	Retro Retro Retro-Pro Retro	***Nat/***State***/Loc Nat/*** State***/Loc Nat/***State***/ Loc***	Nepalese Gov. Organizations in collaboration with SU/ILEC/MEdu-J
7. Philippines	Laguna Lanao Rinconada Seven Lakes Taal	MP(LB) LB WS SEM SEM	Retro Retro	***Nat/State/Loc***Nat***/ State/Loc Nat/*** State***/Loc***Nat/State***/ Loc*** Nat/State***/Loc***	LLDA in collaboration with SU/ILEC/MEdu-J
8. Russia	Ilmen Ladoga Chudsko – Pskovskoe (Peipsi)	LB LB LB	Review Review Review	***Nat***/State/Loc***Nat/*** State/Loc***Nat***/ State/Loc	Russian Academy of Science in collaboration with SU/ILEC/MEdu-J
9. USA	Upper Potomac River Southern Wisconsin lakes	Independent Study Independent Study	Pro Retro	Nat/State***/Loc*** Nat/State***/Loc***	TSU SWRPC

1. **BP**: Basic Process in progress; **CP**: Cyclic Process is in progress; **FS**: Since the lakes are under the statutory framework similar to the ILBM concept, only field studies have been conducted under the ILBM research projects; **LB**:A Lake Brief has been prepared; **MP**: The existing management program is forming a basis for ILBM; **SEM**: An introductory ILBM seminar has been conducted; **WS**: Short-term ILBM workshops have been conducted;
2. **Pro**: Emphasis has been placed on prospective assessment of upcoming challenges using the ILBM framework; **Retro**: Emphasis has been placed on retrospective assessment using the ILBM framework;**Review**: Emphasis has been placed on retrospective natural science assessment using Annex A. of Lake Brief.

3. **Loc**: In strong relation to the local program framework; **Nat**: to the National program framework; **State**: to the state program framework; The major program frameworks are identified in italic bold characters.

4. **IAAB**: Indian Association of Aquatic Biologists; **ILEC**: International Lake Environment Committee, Japan; **LLDA**: Laguna Lake Development Authority; **LLWQP**: Local Lake Water Quality Conservation Plan, Hokkaido, Japan; **MEdu**: Ministry of Education, Sports, Culture and Science, Japan; **MEnv:** Ministry of Environment, Japan; **NLWQP**: National Lake Water Quality Conservation Plan, Japan; **SU**: Shiga University, Japan; **SWRPC**: Southeastern Wisconsin Regional Planning Commission, USA; **TSU**: Texas State University, USA

6.2 TYPICAL FORMS OF PLANS AND THEIR IMPLICATIONS IN THE ILBM PLATFORM PROCESS

In discussing the role of ILBM Platform in the planning process, four general categories of plans for lakebasin management are described below; namely, Vision Plans, Short-term Action Plans, Intervention Plans, and Comprehensive Plans. The presumption in the following discussion is that Vision and Action Plans can be statutory or non-statutory. In contrast, most Intervention and Comprehensive Plans are statutory in nature. Use of the previously-noted "output-oriented" indicators is relevant in evaluating the status of the various plans, which are characterized as follows:

1. Characterization of Vision Plans:

- The goal of a Vision Plan is usually to bring water stakeholders together to develop a common or at least compatible agenda for sustainable lake management, as well as to foster a sense of ownership about the future of the lake basin in question;
- Vision plans usually consist of a menu of strategies and opportunities directed toward the relatively long-term future;
- The degree of formality associated with Vision Plans can range from being very informal (voluntarily at village level) to being very formal (national or international level, with some institutional and financial commitments);
- The level of institutional commitment, and the required financial and manpower resources, are likely to be rather moderate, compared to the level associated with implementation of other types of plans.

2. *Characterization of Action Plans:*

- Action Plans are generally short-term, although there are cases whereby a sequence of short-term action plans can constitute a long-term action plan; they are not necessarily sectoral in character;
- An action plan is a series of steps or activities to achieve a specific goal, whose major elements include: (1) identifying a specific goal to be achieved; (2) identifying specific tasks or steps directed at what needs to be done; (3) identifying responsibilities and assignments, thereby noting who will undertake what specific task; (4) identifying the time horizon, in order to determine when the identified tasks are to be done and the goal achieved; (5) producing a time line and planning milestones, including a schedule of work and measures of the progress being made; and (6) identifying available resource possibilities, including identifying what specific funds are available for what specific activities;
- There are action plans consisting of local actions, initiatives and commitments with little or no financial resources.

3. *Characterization of Intervention Plans:*

- An intervention is a specific activity (or set of related activities) intended to achieve a set of objectives in a particular setting, using a common strategy for output delivery; an intervention has distinct process and outcome objectives, and a protocol outlining the implementation steps;
- Intervention plans for resource development and conservation/remediation purposes are generally developed and implemented by public sector agencies, and tend to have strong sectoral orientation with financial and manpower commitments because they often involve physical facilities;
- Typical intervention plans can range from resource development interventions, such as installation of intake facilities for large-scale water abstraction for riparian paddy field irrigation, to development of a fish cage system along the reservoir shoreline for licensed commercial operations, etc., to environmental conservation and ecological restoration interventions such as dredging of sediments from the lake bottom to improve deteriorating water quality, or constructing a sediment trap along the inflowing channels to the lake for improving fish habitat, etc.;

4. *Characterization of Comprehensive Plans:*

- Unlike a Vision Statement, implementing a lake basin management plan requires prescribing details of the long-term structural and nonstructural actions to be carried out; the long-term goals must be met by a range of relevant organizations;
- Since implementation of the plan may be longer than the timeframe for usual budgetary considerations, the agencies responsible for carrying out the plan may or may not have the needed level of financial and manpower resources;

- For the plan to be viable, it must usually be scaled down to meet budgetary constraints, and subsequently revised over time;
- A comprehensive plan is often developed on the basis of holistic considerations for achieving sustainability objectives to effect changes in the environmental status indicators, as well as assuming long-term institutional and financial commitments.

The ILBM Platform Process may be applied to all four forms of plans, although in different ways among the cases. There are cases where the preparation of a Lake Brief alone was sufficiently useful without the development of a Platform Process, or where the platform development may essentially remain at the Basic Process level, or even where the platform development may evolve to a full-fledged Cyclic Process. **Figure 6** provides a general typology of the application cases that describe the pre-ILBM initial condition of management; namely, those having(a)*Little or No Management plan; having (b) Independent Sector-specific Management Plans* (i.e., sector plans for fisheries, water supplies, pollution control, etc., are undertaken completely independently); *or having (c) Cross-Sector Management Plans* (the sector plans are undertaken with some coordination, for example, through water quality monitoring and under a given statutory framework). In regard to post-ILBM adaptation of one or more of the four plan types (i.e., Vision Plan, Action Plan, Intervention Plan, Comprehensive Plan), the following general observations are relevant:

Vision Plans and Action Plans Generally Entail a Basic-Platform Process

- ILBM Platforms can be "Basic" in nature because a plan must usually reflect explicit, as well as implicit, community values, and once developed, it can remain intact through the planning period, thereby not requiring the plan itself to be evolving;
- Reminding the public at large about the spirit of the vision through periodic activities, however, is a very important role to be played by the Platform.

Intervention Plans Entails a Basic Platform Process and then a Cyclic Platform Process

- Intervention plans developed and implemented by sectoral agencies usually require specialized technical inputs form experts in the field.
- Most intervention projects are directed towards achieving a rather sharply-focused output, accompanied by rather rigorous financial and institutional (including manpower) resource commitments and timeframe for completion, often with rather-limited local actions. In such cases, the Cyclic Platform may not function well, compared to the Action Plan cases.

- The more congested the resource use becomes, however, the more they can coordinate their resource use, indicating the Platform working in a "cyclic" manner may prove quite effective in adjusting to emerging needs, as well as mid-course corrections and adjustments.

Comprehensive Plans Generally Entails a Cyclic ILBM Platform Process

- A comprehensive plan for lake basin management generally includes many citizen-group Action Plans and many sector-agency Intervention Plans, and integration of these two types of Plans is likely to be achieved through a Cyclic ILBM Platform Process;
- Implementation of a Comprehensive Plan requires overcoming sector conflicts and gradually decreasing stakeholder commitments, rendering a Cyclic ILBM Platform Process to be favorably adoptable.

Overall, the planning must be accompanied by a system for measuring the extent of governance improvements with the ILBM Platform Process supporting it in one way or another.

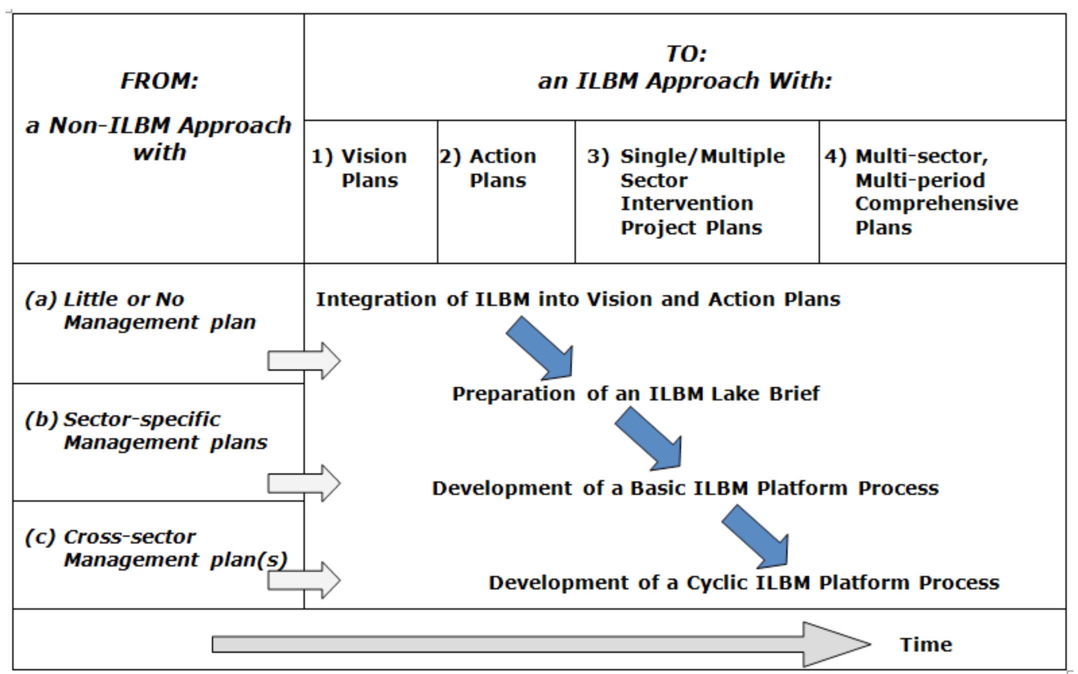


Figure 6 - Transformation from a Non-ILBM Approach to an ILBM Approach in Planning

6.3 MANAGEMENT REASONS / PURPOSES AS ASSOCIATED WITH GOVERNANCE PILLARS

As previously discussed in Section **2.1**, the management reasons/purposes for lake basin management can vary widely, ranging from **a)** developing resource values; **b)** enhancing resource values; **c)** decongesting resource use; **d)** resolving resource use conflicts; **e)** reducing environmental stress; **f)** rehabilitating and restoring riparian habitats; **g)** protecting resource value damages from extreme events; and **h)** taking precautionary adaptation and mitigation measures; and finally to **i)** improving overall ecosystem health. It is important to recognize that lake basins are usually managed for multiple reasons/purposes, and that these different reasons/purposes may or may not be adequately inter-harmonized. It is also important to note that a particular lake basin can undergo a gradual shift in focus from one reason/purpose to another, with their inter-phasing more likely to occur in the management direction from **a)** to **i)**, than in the direction from **i)** to **a)**. For a lake basin to be effectively managed for sustainable use of its life-supporting ecosystem services, it is clear that lake basin stakeholders must strive continuously for a greater level of inter-harmonization and inter-phasing of these reasons/purposes.

To achieve a greater level of inter-harmonization and inter-phasing, these different management reasons/purposes, **a) - i)** as noted above, must be associated with the corresponding level of each of these Six Pillars of Governance. As further clarification, the Six Pillars of Governance are expressed in more specific terms in **Figure 7**; namely, institutional orientation regarding ecosystem services; policy orientation in government; a participatory approach in management, an information and knowledge focus, technology emphasis, and financial resource inputs. The gradients associated with each of these Six Pillars of governance may now be conceptually associated with the management reason/purpose. The institutional orientation, for example, can range from a more “singular structure” to a more “plural” structure, the policy orientation in government can range from a more “short-term output” to a more “long-term outcome”; and the financial resource orientation can range from one more toward short-term “economic-gain focus” to one more toward long-term “ecosystem-gain focus”, etc., in relation to each of the management reasons/purposes, **a) - i)**. This is an important conceptual presentation of ILBM, implying that lake basin stakeholders must recognize their own association with the individual Pillar issues is always relative, and occurs in response to the management reason/purpose of which they may not be immediately engaged, but of which they should be fully aware. It also implies that, in order to reach some agreeable mix of these governance qualities, basin stakeholders must achieve a greater level of inter-harmonization and inter-phasing of management reasons/purposes. This is a driving force of the ILBM Platform Process, and facilitates stakeholders being able to bring themselves together to meet the collective governance challenge over time, slowly and gradually. The above observation implies that ILBM has the flexibility to address the subtle implications of governance challenges, such as resource use conflicts and assessment of planning alternatives in management. In regard to the former (i.e., resolving use conflicts), the stakeholder groups may find it easier to resolve their conflicts with the ILBM Platform than without it. As an example, a case involving the Lerma River – Lake Chapala – Santiago River complex in Mexico, presented in **Annex 5** in Nakamura and Rast (2011),"A Practical Approach in ILBM Pillar Assessment: An Example," describes an iterative process for bridging the gaps between stakeholder ideas about meeting governance challenges. In regard to the latter (i.e., assessment of planning alternatives), Saunders (2012) presents an interesting application of the ILBM framework, using the modified approach highlighted in the above example in addressing management issues in sub-watersheds in the interstate Potomac River Basin in the USA.

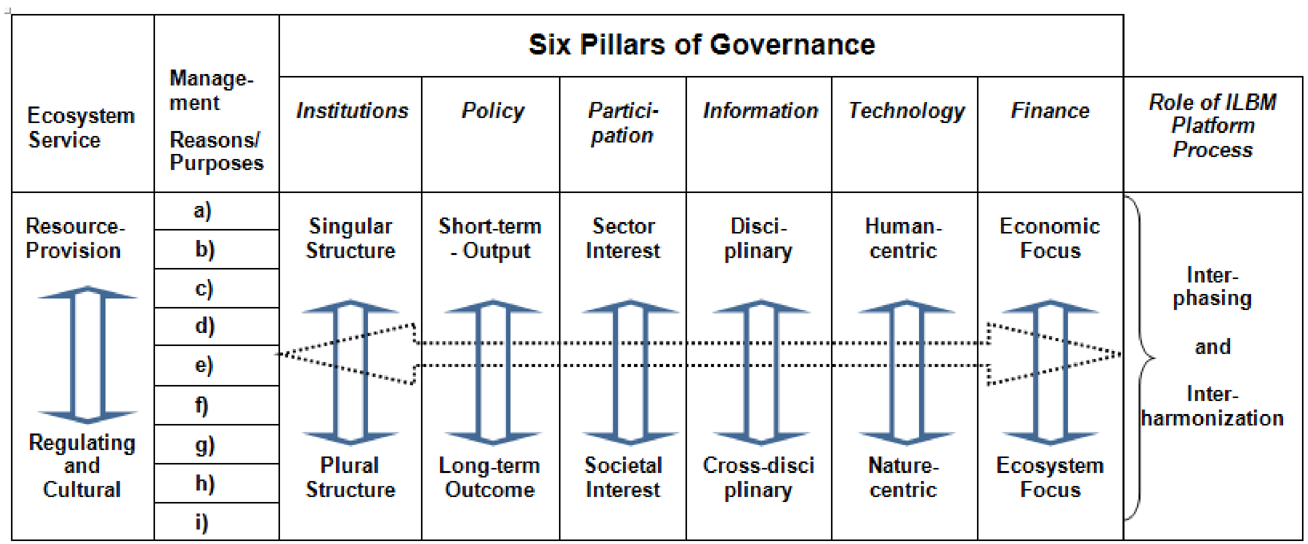


Figure 7 - Management Reasons/Purposes as Related to the Six Pillars of Governance

a) developing resource values
b) enhancing resource values
c) decongesting resource use
d) resolving resource use conflicts
e) reducing environmental stress
f) rehabilitating and restoring riparian habitats
g) protecting resource value damages from extreme events
h) taking precautionary adaptation and mitigation measures
i) improving the overall ecosystem health

} Multiple Management Reasons/Purposes

6.4 STAGES OF ILBM PLATFORM DEVELOPMENT

It is emphasized that the development of an ILBM Platform Process is not a stand-alone, one-time project, but rather a long-term governance challenge to be met by the entire lake basin society and stakeholders. Once initiated, the process must evolve and be sustained over coming decades and, over the course of time, the process will have to become owned by the basin community at large, hopefully by being integrated into a local/national statutory framework. **Figure 8** provides a schematic example of such a long-term process, in which the timeframe is divided into four phases; Phase I is a Preparatory Phase, Phase **II** is a Getting Started Period, Phase **III** is a Trial-and-Error Period, and Phase **IV** is a Sustainability Challenge Phase. In addition to being a governance improvement process by itself, the Cyclic Process during Phase II and Phase III should also be able to guide the process of planning and implementing various public and private sector management intervention projects. Introduction of a sewerage system, for example, would have to be well integrated into the ILBM Platform Process to facilitate the sustainability of its construction, management and operation. For already-existing management intervention programs, the Platform Process should be able to provide an informative retrospective, as well as prospective, assessment to help adjust the course of preparation toward the future with a more coherent and concerted approach to governance improvement. With such a broad range of reasons/purposes, the management of lakes and their basins is approached within ILBM within the corresponding range of sectoral activities, with or without formal plans. As the reasons/purposes become more and more inclusive and comprehensive (i.e., shifting in the management direction from **a)** to **i)** in **Figure 7**), the individual sector activities/plans must be brought together under the umbrella of a more comprehensive management plan. The type and the nature of such comprehensive management plans also vary widely, depending on the existing national statutory and policy frameworks in the case of many developed countries, and on the contractual framework in the case of bilateral and multilateral technical collaboration involving developing countries. The ILBM Platform Process may be usefully engaged in either case, since these plans generally recognize the importance of the broad engagement of the basin community in the process of implementation, if not the actual development, of such plans. A typical example of the former is the Lake Water Quality Conservation Plan, as stipulated in the statutory framework of the Special Measures for the Preservation of Lake Water Quality of Japan (commonly referred to as the "Lake Law"), as introduced in **Annex 7** of Nakamura and Rast (2011). A typical example of the latter is the Lake Victoria Environmental Management Plan, with Phase I and II being implemented by the World Bank for the East African Union member countries, as stipulated in the International Waters Framework of the Global Environment Facility (GEF).

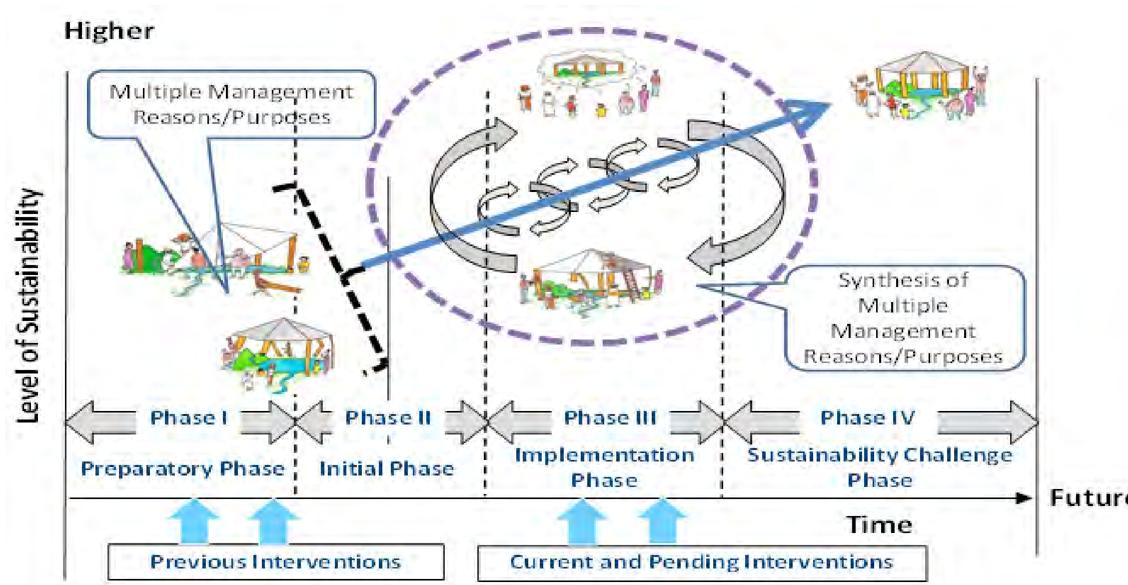


Figure 8 - ILBM Platform Process in Stages, with Gradual Synthesis of Management Reasons/Purposes

6.5 CHALLENGES IN SUSTAINING AN ILBM PLATFORM PROCESS

As noted in the introduction to this document, ILBM is a comprehensive approach for managing lakes and reservoirs for sustainable ecosystem services through gradual, continuous and holistic improvement of basin governance, with the ILBM Platform being a virtual stage for collective stakeholder actions for improving lake basin governance through the application of ILBM. While the number of ILBM application cases is growing, whether or not a particular lake basin community being introduced to the concept would be inclined to engage in the Platform Process depends on many factors. Some of the most important of these factors is as follows:

1. ***Existence of Lead Organizations***

The range of types and nature of organizations that can lead the ILBM Platform Process can include government agencies, local/national research institutions, including universities, citizen groups, local/national/international NGOs, and perhaps even private-sector organizations. Which of the above types of organizations would play the lead role in ILBM-related activities depends in part on the political, administrative and cultural climates of the involved country(ies). In highly centralistic nations, for example, the ILBM Platform process may not function unless government organizations collectively play a lead role, with little or no inputs from NGOs and citizens. On the other hand, in countries in which the government prefers a facilitative role, the citizen groups and NGOs may have a much more prominent role in the Process. As long as the Platform can be developed to play an impartial facilitating role, however, the basin community can decide on the type and nature of the lead organization to suit the national and local situations. Since there would be nothing for any particular organization to gain, in attempting to exclusively own the process, the initiated process by any kind of organization is likely to be collectively owned as long as it is supported by the international ILBM network. In this regard, it is important to note that lake basin management projects in developing countries are sometimes supported by bilateral and multilateral funding and technical cooperation agencies. Because of their showcase nature, they tend to attract a disproportionate share of human and financial resources of the basin community, thereby perhaps also significantly affecting the way the entire lake basin is managed. It is important to emphasize here that such a project should be regarded only as a catalytic intervention project, and that lake basin management should be owned by the basin community as a whole, making such a project become an integral part of the basin governance framework through the ILBM Platform Process.

2. Establishment of an ILBM Secretariat

The lead organization as identified above is usually best suited to also serve as the ILBM 'secretariat.' It is also possible, however, for the secretariat to be formed with representatives from the major platform members, thereby collectively burdening the due share of the required human and financial resources. The secretariat can decide upon the focal point individual or organization of the regional and international network of ILBM activities. It can also organize the ILBM-related local activities, including ILBM workshops/seminars, and development of a common knowledgebase platform, for sharing the already-available data and information among the platform members. It may also develop a protocol for joint analysis of the state of lake basin governance.

3. Meeting the Financial Requirements

Implementation of the ILBM Platform Process will have to address financial and manpower requirements for activities such as document preparation, convening of meetings, undertaking joint studies, and compiling and analyzing lake basin governance data and information. Even though the required resources are almost insignificant, compared to the long-term collective benefit accruing to the lake basin community as a whole, there are cases in which inadequate financial resources can become a hindrance to efficient implementation of the Platform Process. There may be cases, for example, where some stakeholders are located in areas too remote to be able to participate actively in the Platform activities, despite the fact that they should be playing an important role. In general, however, the Platform Process is a long-term process, with an important goal being to sustain collective interest and commitment, even at a minimal level of activities at the onset of the Process. The long-term, gradual improvement of lake basin governance should produce some noticeable changes in the minds of stakeholders in such a way that the necessary funds may somehow be raised from among Platform members. It is also important for those developing country lake basins involved in external technical and financial collaboration projects to have such projects set aside a due portion of their financial commitment to address the sustenance of the ILBM Platform.

4. Access to Data and Information Resources

The requirement for data and information resources would usually be most intensive at the time when a lake brief is being prepared for the first time. It can be detailed and expansive, with expertise contributions coming from academic institutions and government offices willing to be among the founding members of the Platform Process. Although the more complete the better, a lake brief also can be gradually improved over time through a participatory process of data/information generation and compilation. Thus, an in complete initial version of the Platform is not necessarily a serious concern. It is important to have reliable scientific and policy data and information, thereby making reliance on academic and governmental sources of information essentially unavoidable. On the other hand, a lake brief is not meant to be a scientific paper of the type typically published in academic publications, nor is it meant to be a classified governmental policy paper. Rather, it should be a document that can be prepared initially with the information already available in the public domain, and readily accessible to all interested stakeholders. What is important is the joint process of generating, compiling and analyzing the data to be continuously updated for assessing the incremental improvement of specific aspects of basin governance, i.e., the Six Pillars of Governance, which the Platform members should become more and more familiar with, and accustomed to, over the longer term. A serious problem may be faced by lake basin stakeholders, however, when the major source of information can only be acquired from government agencies at significant expense and time requirements, and/or in connection with the implementation of externally-funded projects in which an enormous quantity of human and financial resources are invested within a short period of time, with perhaps little or no involvement of the resident capacity of the lake basin stakeholder individuals and organizations. This is a matter that must be recognized both by the concerned bilateral and multilateral organizations and programs, and by the counterpart institutions in charge of the respective governmental programs.

While the aim of ILBM is to attain long-term sustainability of lake basin resources and their use, the experience to date suggests that, in many parts of the world, the magnitude, as well as the rate, of lake basin resource degradation is enormous and continuing. There are some fundamental challenges in managing lakes and their basins, regardless of ILBM applications. Although the emerged typology pertains to the way ILBM may help achieve the sustainability of lake basin resources and their use, it is not designed to attain sustainability itself. Attainment of sustainable use of any ecosystem has been, and will continue to be, a long-term global challenge that must be integrated as a mainstream issue facing the international community.

7 KNOWLEDGE BASE AND DATA BASE SYSTEMS

An enormous quantity of information and data has been generated so far, and will continue to be generated, on a wide range of thematic subjects pertaining to lake basin management, on both a national and international basis. Much of it pertains to natural science topics, including physical, chemical and biological aspects (limnology, hydrology, climatology, ecology, biochemistry, etc.), all of which contribute to a better understanding of the state of lakes, reservoirs and other lentic water bodies. There also is a growing number of studies on the managerial aspects of aquatic, terrestrial and riparian ecosystems, including water quality, sediment quality, and shoreline environments, together with the inflowing and outflowing water systems, extending out to the upper watershed tributaries. A needed component not yet been produced, however, is a means of compiling and utilizing holistically- and practically-synthesized information on such thematic and disciplinary subjects. Focusing both on the compilation of global experiences and lessons learned in managing lakes and their basins, for example, a detailed account of the Six ILBM Governance Pillars is provided in the document, "Managing Lakes and their Basins for Sustainable Use: A Report for Lake Basin Managers and Stakeholders," (ILEC, 2005). An electronic training module of this document also is available on the website: (http://wldb.ilec.or.jp/ILBMTrainingMaterials/ index.html). This document has played an instrumental role in the conceptualization process of ILBM, and now that the number of such efforts is growing, developing and sharing the knowledge being continually generated and accumulated is even more important. An interactive knowledge base *cum* knowledge mining system, called LAKES (Learning Acceleration and Knowledge Enhancement System) has been developed to address this goal. LAKES currently has the capacity to process hundreds of documents for the purpose of 'mining' the imbedded knowledge with the use of free keywords or an included thesaurus, ranging from the level of whole documents, down to pages, paragraphs, and even individual sentences. LAKES is also linked to a database system called the World Lake Database, a repository of the output of Survey of the State of World Lakes (1986-1988) for reviewing and downloading information and data for individual lakes, as well as for cross-cutting analysis among the lakes of water quality parameters. This system is also capable of serving as a depository of lake basin management data that may already have been generated and made public in the form of hard-copy reports and technical papers, but not in the form of an electronic database because of an inability to develop and maintain such a system. As the number of ILBM-related efforts increases, the need for LAKES will definitely increase as data and information compiled in the form of a Lake Brief are also expected to grow. Screenshot Images of the "LAKES" Knowledge Base System and the World Lake Database System are shown in **Figure 9 and Figure 10.**

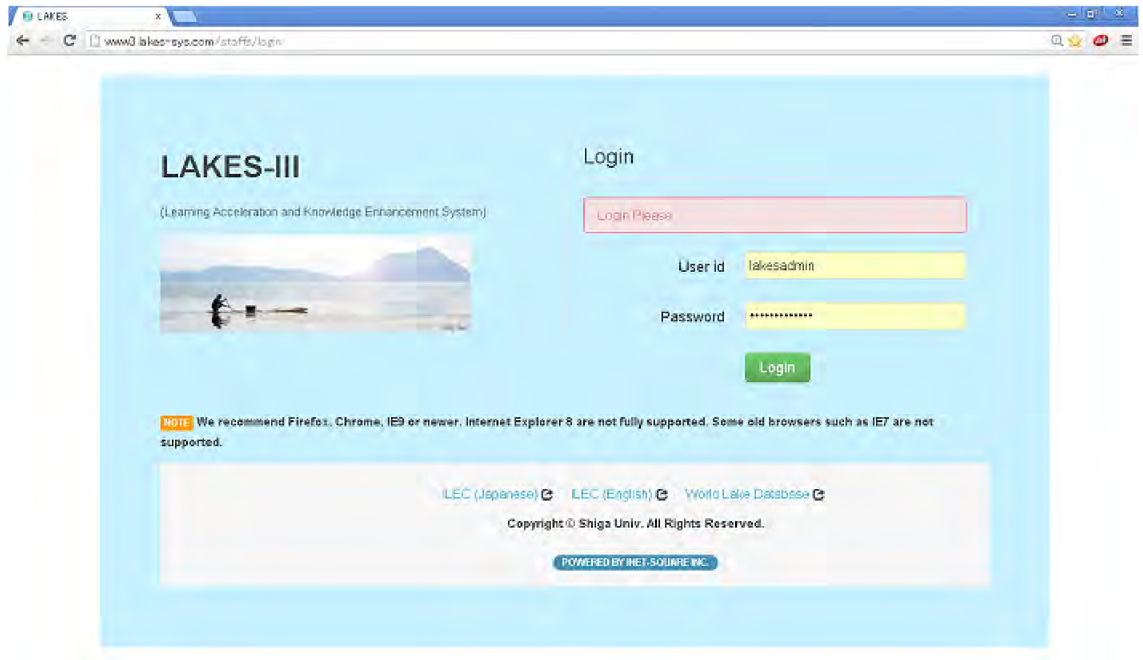


Figure 9 - A Screenshot Image of "LAKES-III"Knowledge Base System

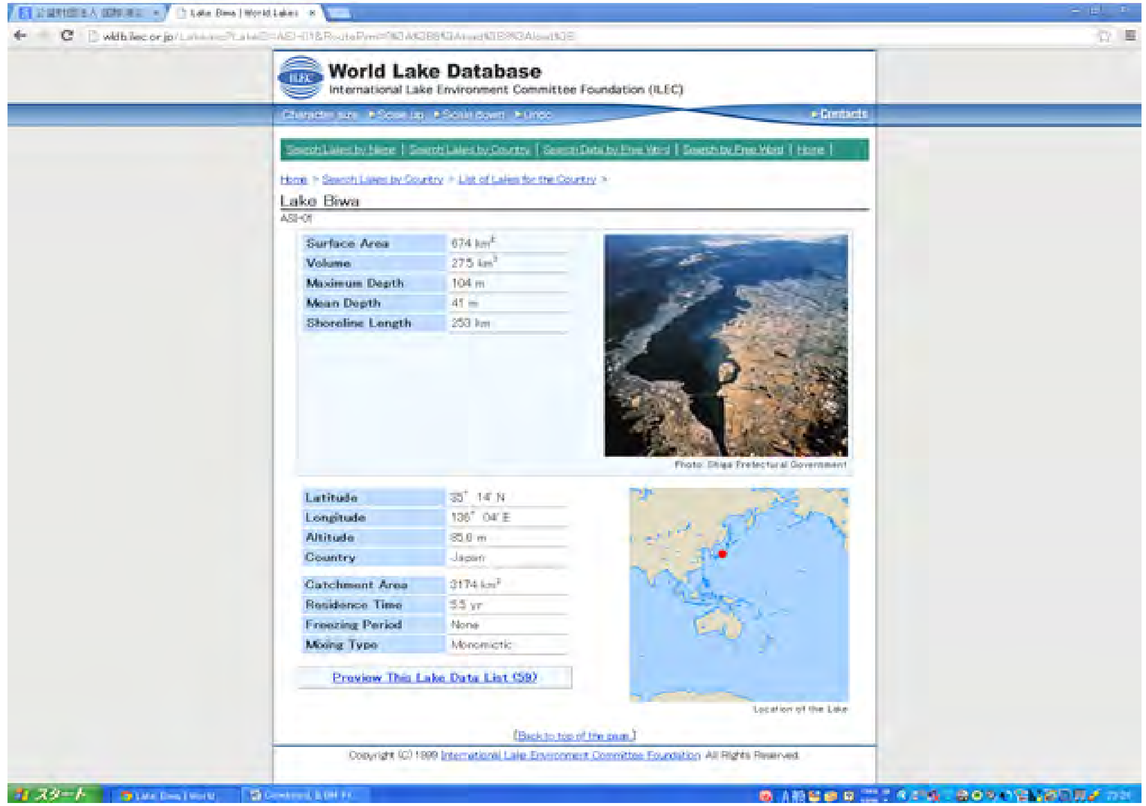


Figure 10 - A Screenshot Image of World Lake Database

8 SUMMARY AND WAY FORWARD

On a global scale, the terrestrial and sub-terrestrial land constituting the basins of rivers and their sub-surface flows, lakes, estuaries, and lagoons and marshlands and other enclosed and semi-enclosed water bodies, have undergone tremendous transformations over the past centuries, with the rate of transformation even increasing over the past several decades. The impacts of this transformation, in the form of environmental pollution and ecosystem degradation, have transcended far and wide to receptor water systems as well, including aquifers, marine ecosystems, and the oceans. Despite all the efforts undertaken thus far to mitigate and restore these water systems, this global trend is far from being reversed. As a consequence of this reality, the lentic (naturally non-flowing, with historically fostered ecosystem and anthropological implications, in contrast to simply being hydrostatic) parts of these linked water systems, have been seriously impacted, hindering the sustainable use of their resource values. In fact, the pursuit toward environmental and ecosystem sustainability of lentic water systems is very different from that of lotic (naturally flowing, with similar implications as "lentic," and not simply hydrodynamic) systems. Thus, managing linked water systems with imbedded lentic properties requires an approach that recognizes and takes into account their unique physico-chemical and biological features, including their integrating nature, long water retention time, and complex response dynamics.

As a further consideration, management of linked water systems with imbedded lentic properties also must consider policy orientations amenable to their resource-use governance. This is because lake basin resources typically exhibit the feature of being "common property" in their existence and use. This means resource users must practice self-restraint in their pursuit of the resource values of lakes if they wish them to be sustainable. The suitable institutional form to achieve this long-term goal, however, may emerge only after a long, gradual and adaptive process of collective adjustments. This is in contrast to the reality of the resource development sectors often being hesitant to allocate their funds and manpower for purposes other than meeting their own immediate resource requirements. It is difficult, therefore, if not impossible, to prescribe a management framework that is universally workable for water systems with imbedded lentic system properties. Herein lies the underlying reason for the need to conceptualize an approach to help lake basin stakeholders manage lentic water systems for sustainable use through gradual, continuous and holistic improvement of basin governance. Indeed, if we have learned anything from managing lentic water systems to date, it is that their management is a continuing process requiring adaptation to changing conditions, rather than a one-time, stand-alone project.

The reasons/purposes for managing linked water systems range from developing resource values to improving overall ecosystem health. Although the conventional approach of developing and implementing a plan would obviously be indispensable for responding to the above reasons/purposes, it is nevertheless only half the story. Implementing a prescribed plan will not necessarily result in improved governance that will ensure the sustainable use of lake basin resources. Therefore, in focusing on improving the Six Pillars of Governance (i.e., institutions, policies, participation, information, technologies and finance), Integrated Lake Basin Management (ILBM) has been conceptualized to capture the essential requirements for managing water systems with lentic-lotic (not simply hydrostatic-hydrodynamic) properties for sustainable use.

The needed governance improvement process can take the form of the ILBM Platform Process, which can evolve from assessing the current governance challenges, as well as the means for incremental management improvements (i.e., from the preparation of a Lake Brief, to a cyclic process of governance improvement over time). In fact, the typological analysis of ILBM case applications between 2008-2012 has provided a number of illuminating insights, for example, on the transformation from a non-ILBM approach to an ILBM approach in planning, and on the management reasons/purposes as related to the Six Governance Pillars of ILBM. For the latter, the important message is that basin stakeholders must achieve a greater level of inter-harmonization and inter-phasing of management reasons/purposes in order to reach some agreeable mix of governance qualities. There are now sufficient experiences from lake basins around the world that demonstrate the ILBM Platform Process provides a useful basis for achieving this important goal.

As the number of ILBM case applications continues to increase, the cumulative knowledge about the ILBM Platform Process also increases, allowing for new insights to be developed, as well as greater cross-fertilization of experiences to take place, as reflected in the expanding database, knowledge base and training module. This increased knowledge and insight will definitely help address the increasing number of ILBM application needs. Indeed, if the environmental pollution and ecosystem degradation of aquifers, marine ecosystems, and the oceans is to be deterred, the lentic components of the linked terrestrial and sub-terrestrial water systems must be sustainably managed. This quite simply means the issue of lentic water management must be mainstreamed in the global water arena, especially policy directives, which are currently focused too exclusively on Integrated Water Resources Management (IWRM). No United Nations initiative has yet been put forth to mainstream “lakes” within the global water agenda, despite the fact its many UN documents highlight the ‘importance’ of IWRM. This is not to say that IWRM is not important, but rather that global experiences to date indicate it cannot adequately address the assessment and management challenges of lentic water systems, or the complexities and management implications of linked lentic-lotic water systems. Thus, it is now time to recognize that ILBM must be promoted to deal with linked water systems of a lentic-lotic nature, focusing on their governance improvement at a local, national, sub-continental, continental and international level.

REFERENCES

ILEC. 2005. *Managing Lakes and Their Basins for Sustainable Use: A Report for Lake Basin Managers and Stakeholders*. International Lake Environment Committee Foundation (ILEC), Kusatsu, Japan. http://www.ilec.or.jp/en/wp/wp-content/uploads/2013/03/LBMI_Main_Report_22February20061.pdf

Nakamura, M. and W. Rast 2014. *Development of ILBM Platform Process: Evolving Guidelines through Participatory Improvement*, 2nd Edition. Research Center for Sustainability and Environment, Shiga University and International Lake Environment Committee Foundation (ILEC), Kusatsu, Japan. http://www.ilec.or.jp/en/wp/wp-content/uploads/2013/02/Development-of-ILBM-Platform-Process_2nd_Edition11.pdf

Shiklomanov, I. 1993. World fresh water resources in *Water in Crisis: A Guide to the World's Fresh Water Resources,* edited by P. H. Gleick, Oxford University Press, N.Y.

United Nations General Assembly. 2015. Transforming our World: The 2030 Agenda for Global Action: *Final draft of the outcome document for the UN Summit to adopt the Post-2015 Development Agenda.* Attachment as Annex A/69/L.85 to the United Nations General Assembly A/69/L.85, Agenda Items 13 (a) and 115. http://www.un.org/ga/search/view_doc.asp?symbol=A/69/L.85&Lang=E

World Resources Institute. 2005. *Ecosystems and Human Well-being: General Synthesis - A Report of the Millennium Ecosystem Assessment,* Island Press, Washington, DC. http://www.millenniumassessment.org/documents/document.356.aspx.pdf

SUMMARY

ENHANCING WATER MANAGEMENT CAPACITY IN A CHANGING WORLD A HYDRAULIC ENGINEERING VISION

Raúl Antonio Lopardo[1]

[1] Academia Nacional de Ciencias Exactas, Físicas y Naturales. República Argentina.

ABSTRACT

The importance of water governance in Latin America and the Caribbean is clearly reflected in the series of experiences, proposals and processes of reform of water legislation and management in most of the countries in the region, as well as in the current programs and proposals for reforming water-related public services, particularly urban drinking water supply and sanitation utilities. There are several expertise interacting with the water management, but the role of engineering is particularly important because its impact over the natural and social systems. In the author's opinion, more important than the "environmental impact assessment" of a hydraulic structure (usually positive because of economical factors) is the effective design of all hydraulic structures taking into account the environmental aspects during the project itself, by hydraulic engineers with environmental conception and holistic subject point of view. Well, then hydraulic engineer's education needs to be according to the changing world requirements. The author concludes that engineering education should focus not only on scientific excellence and technological capacity to develop their projects, but also find the appropriate methodology for such projects of interest to the Society and accessible to the media through the public hearings.

1 INTRODUCTION

International agencies consider water issues among the most crucial for this century. Water is essential for life and the quality of life, and the way it is used and managed has a great impact on the environment. Winston Churchill, the British statesman, once said that people realize how important water is only when they lack it. The concept is valid; and it can be expanded as follows: “authorities take water into consideration when towns are already flooded”.

In the author opinion, a clear description about the mean of “water governance” was published by CEPAL (SOLANES; JURAVLEV, 2006). Then, most of the next sentences are from this reference with limited changes.

> The water crisis is mainly a crisis of governance. Working towards effective water governance requires an enabling environment and appropriate institutional structures that allow stakeholders to work together for effective water management. Financial practices must be realigned to support the sustainable use of water resources. (GLOBAL WATER PARTNERSHIP, 2000).

To ensure good governance, the involvement of the public and the interests of all stakeholders must be included in the management of water resources. To stop the unsustainable exploitation of water resources, by developing water management strategies at the regional, national and local levels, which promote both equitable access and adequate supplies. Each country should have in place applicable arrangements for the governance of water affairs at all levels and, where appropriate, accelerate water sector reforms. Good governance, capacity building and financing are of the utmost importance to succeed in our efforts. In this context, we shall promote integrated water resources management (SOLANES; JURAVLEV, 2006).

Finally, Governments have the primary role in promoting improved access to safe drinking water, basic sanitation, sustainable and secure tenure, and adequate shelter, through improved governance at all levels and appropriate enabling environments and regulatory frameworks, adopting a pro-poor approach and with the active involvement of all stakeholders. All of the countries of the region are facing constant challenges, and as a result need to come up with legislative and organizational answers that can prevent and resolve growing conflicts over water use, as well as mitigate extreme natural phenomena (SOLANES; JURAVLEV; 2006).

The concept of governance as applied to water refers to the capability of a social system to mobilize energies, in a coherent manner, for the sustainable development of water resources.

> The notion includes the ability to design public policies (and mobilize social resources in support of them) which are socially accepted, which have as their goal the sustainable development and use of water resources, and to make their implementation effective by the different actors/stakeholders involved in the process (ROGERS, 2002).

In order to be effective, governance must be transparent, open, accountable, participatory, communicative, incentive-based, sustainable, equitable, coherent, efficient, integrative and ethical.

Governance implies the capacity to both generate and implement appropriate policies. These capacities are the result of having established consensus, having devised coherent management systems (regimes based on institutions, laws, cultural factors, knowledge and practices), as we11 as adequate administration of the system (based on social participation and acceptance, and capacity building). As can be seen, a core element of governance is the capacity of constructing (that is, introducing and developing) institutional arrangements in harmony with the nature of the abilities, limitations and expectations of the system or area under consideration.

2 WATER GOVERNANCE IN LATIN AMERICA

The importance of the term "governance" in the region is currently associated, to a large extent, with both the limitations and the possibilities of societies in implementing the profound institutional changes that have been characteristic of the past decades. These changes have often implied the creation of a new institutional structure, which has meant the design and recognition of new ground rules, the creation of organizations and the development of new forms of relationships, both formal and informal, of public and private actors. Any process of reforming a social order is the result of the radical transformation and dismantling of the previous social order. In fact, what may lie at the heart of the problems or the crisis in governance in many countries is the incompatibility of previous institutional arrangements with the new ones.

The crisis will be more acute and extensive according to the scale of the changes undertaken, the pre-existing skills and capacities and their usefulness in dealing with the challenges posed by the transformation, and, in particular, according to the coherence of the new institutional arrangements taking into account the structure and nature of the society and the possibilities and restrictions in place for effectively dealing with the proposed new ground rules (CORRALES, 2003).

Even when there are general guidelines, there are no set models, and issues are resolved as they arise; consequently flexibility and adjustments to time and place are of great importance. Governance is influenced by globalization and by each country's national situation, the lack of adjustment of legal systems and institutions, and the existence of special legal arrangements, as well as by pressures from special interest groups.

The growing awareness within the Latin America region of concerns such as the unsustainable use of water, its scarcity, pollution, monopoly control and the lack of access to water-related public services of significant sectors of the population, all illustrate the relevance of the issue. The importance of water governance in Latin America and the Caribbean is clearly reflected in the series of experiences, proposals for and processes of reform of water legislation and management in most of the countries in the region, as well as in the current programs and proposals for reforming water-related public services, particularly urban drinking water supply and sanitation utilities. In some cases these proposals have been developed locally, with significant local input, while in other cases they have been proposed by external agencies.

There are several professions interacting with the water management, but the role of engineering is particularly important because its impact is very important, as the more frequent human "action" over the natural and ecological system.

3 HYDRAULIC ENGINEERING AND WATER MANAGEMENT

For the last forty years efforts have been made to increase public awareness of the need to protect the planet against environmental degradation. Such efforts have taken roots in countries that are pioneers in this field where past human actions and all development projects were systematically revised.

Though there is a close interconnection between water and the environment, on the one hand, and water and development, on the other, their utterly opposed characteristics may render water for development unsuitable for environmental conservation. Protection of human life and improvement of the standard of living require for engineering works which may, in turn, disrupt natural ecosystem integrity. Humanity is then at a crossroads where it must decide whether to build more structures to meet increasing population's needs for housing, food and water or acknowledge the fact that it can no longer tolerate the environmental degradation that these structures cause.

Development of the social environment is shaped by investment projects aimed at improving the life of the human race and, consequently, the quality of the social environment. This was the purpose of many projects all over the world but no steps were taken to prevent the ecosystem, and sometimes the social environment itself, from degrading.

Investment projects for social benefits and environmental conservation are two major premises of sustainable development. Engineering has an inescapable and non-transferable responsibility for the technical execution of investment projects and plays a leading role in environmental impact studies, especially in the hydraulic field, since it deals with fluids in general, and water in particular for which projects are continually devised.

According to the holistic approach that is used to characterize the environment, water should be analysed as a global system made up of many inter-related components or components that are inter-related with the environment. To this objective, engineers should necessarily work with specialists in other disciplines (HJORTH et al., 1991).

Hydraulic engineering is one of the oldest professions, initially based on empiricism. Its scope is clearly defined and very wide. Since ancient times, the necessity of water to satisfy basic corporal requirements and the effort of mankind in order to dominate this resource (today scarce and vulnerable) have obliged to develop a very wide set of technological aspects. Nowadays, there are excellent physical and mathematical tools to attack a big amount of basic and applied problems, but at same time there's a lack of research to close the gap between the hydraulic phenomena and its whole interpretation. For this reason, hydraulics is not a closed branch of engineering.

An idea of the social impact of water engineering can be assessed taking into account the benefits that it has brought to the society, for example developing natural desert zones or providing energy. From an opposite point of view, this importance is enhanced by unfortunate accidents related to hydraulic structures, which cause losses of human lives, alterations of the environment and contingent expenses. But this aspects are not only associated with large dams, ports or waterways, even small hydraulic projects can affect seriously population and environment.

The greatest environmental impact of a hydraulic work is its own destruction More than 50% of the bridges in the United States of America failed due to hydraulic faults. The sum total of bridge failures caused by earthquakes, typhoons, structural calculation errors, defective foundations, accidents and terrorist attacks does not equal the number of structures that have failed because they were poorly conceived as "hydraulic structures" (MURILLO, 1987).

Between 1935 and 1985, 173 dams all over the world failed at a rate of 3.5 dam failures per year. During that period, 80 dams (46% of the total) failed due to overflow, i.e., wrong design of flood spillways (MALINOW, 1991). Dam failures bring about tremendous social consequences, such as loss of human lives, serious economic disasters and irreversible and deep environmental degradation.

Regardless of the safety factor in hydraulic works, there are many hydraulic structures that are not at risk, but have design errors that prevent them from operating according to the way designers originally planned. The fact that the environment was not considered as a determining component in project formulation, many water works exerted a negative impact. Sometimes, engineers don't take into account the environmental aspects, as decisive factors in the general conception of the hydraulic structures and in many cases dams were negative for the Society, which financed them. However, in other examples, the negative opinions of ecologists and stakeholders were clearly not true and numerous dams have excellent behaviour.

Though it is large dams that are being closely scrutinized by many organizations, small-scale hydraulic structures may also exert a harmful effect on the life and property of the people living in the area where they were erected. There are many examples of minor hydraulic dam failures that curtailed ample job opportunities in regions with water deficit, brought about local economic disruption, restricted regional industrial activities and stirred people to emigrate. In Argentina, after the Zanjón Frías Dam disaster in 1937, no destruction of large dams, with more than 15 m high, has been recorded. Nevertheless, in 1999 and 2000 two small irrigation projects that were used for local irrigation and water supply broke down (COMITÉ ARGENTINO DE PRESAS, 2000). In fact, small-scale projects and other water works are undertaken with practically no environmental assessment or control. They are designed by “local experts”, built by “unsuitable companies”, seldom inspected and no maintenance operations are performed.

Several other hydraulic structures didn’t fail, but showed errors that forbid a profitable exploitation. The omission of environmental aspects in the engineering design of these works is one of the most frequent mistakes.

For this purpose, the proclamation and discussion (perhaps successful in the past) is not enough and the technical quantification of environmental impacts is imperative. Hydraulic Engineering has excellent tools for these requirements, in particular the development and use of physical and mathematical models. In the author's opinion, more important than the "environmental impact assessment" of a hydraulic structure (usually positive because economical factors) is the effective design of all hydraulic structures taking into account the environmental aspects in the project itself, by hydraulic engineers with environmental conception and holistic view of the subject.

4 THE CHANGING WORLD (ELECTRONICS, INFORMATICS, WATER AND ENVIRONMENT)

Nobody doubts that, society is undergoing profound and rapid changes. They affect its philosophical and organizational basis. Then, the educational formation for water-environment professionals must take into account these conditions for a successful future.

During the last sixty years, a wonderful transformation of electronics has been developed. It is clear that the integrated circuits introduce a revolution into human lives. In relation with engineering, electronics incorporated new possibilities to acquire and understand the natural environment. Satellites, different types of sensors, high resolution video cameras, let the engineer “see” the nature in a different way and help to the correct interpretation of diverse natural phenomena.

Especially in relation to hydraulic engineering, the “new” electronic gave the tools to surpass the “mean values hydraulics”, carrying the interpretation and quantification of the general random process of turbulent flows, in particular macro turbulent flows. Since the 80’, by means of pressure transducers and data loggers it was possible to measure and to analyze random signals in macro turbulent flows to demonstrate the existence of cavitation due to pressure pulses (LOPARDO et al., 1987). Other examples of rather new electronic instruments are laser and acoustic anemometers, digital geodesic, topographical and hydrometrical equipment, hydro-meteorological radar and several high sensibility sensors for water quality

It is important to point out that a new field of development in electronics arises, dedicated to the measurement of biological parameters, necessary for the environmental assessment of lakes, reservoirs and other water bodies. Biologists are now considering the cooperation with electronic and hydraulic engineers in order to put in operation a new instrumental base.

Although computers seem to be the most exciting example of electronic revolution, the social and professional impact of the use implies the need of a special treatment, as an informatics revolution. Computers have strongly influenced all branches of engineering, acting in combination with the new set of electronic instruments.

At the end of the XIX Century and the beginning of the XX Century the physical modeling technique was considered as a research matter. It must give answers in the cases where the fundamental equations of fluid dynamics were limited.

Mathematical modeling began to settle as an engineers' tool around 1950, with the use of computers. In the 80's, the growing of personal computers, each day cheaper and more powerful, made this tool capable to displace the physical modeling in several fields. Nowadays, there exists a total cooperation between both methodologies, numerical and experimental. As a local example in the INA's Hydraulic Laboratory (Argentina), several two and three dimensional numerical models and detailed physical models were used for the definition of the third lock system in the Panama Canal.

Also, computers were able to solve problems faced with limited tools in the past. In the last two decades different mathematical models of turbulence, pollutant dispersion (BOD, heavy metals, oil), wave patterns, erosion and sedimentation, porous media flow, and 3-D hydrodynamics are usual tools.

Although computers are very useful tools, this "informatics revolution" is still wider. It covers all about information, not only about computers. It involves the data production, storing and processing. As electronics improves the obtaining of data from the natural environment, the revolution of information is changing the manner in which data are stored, processed, transmitted and shared. This includes all applications of computers with other devices. The combination of computers with satellites lead to the appearance of GIS (Geographical Information System) which, introduced into mathematical models, helps with the basic data and optimize the final interpretation of results.

The possible trends show an increase in the demand of hydraulic and environmental studies using mathematical modeling, trying to lower costs and times, and a stronger cooperation with experimental facilities of physical modeling in three-dimensional problems. It is possible to thing that GIS will finally reduce some difficulties of models calibration.

There is no doubt that in the observed precipitation, the changing pattern is the signature of global climate change. Precipitation is being globally reallocated by climate change. Perhaps it is the least developed that will experience the most adverse consequences of climate change.

5 HYDRAULIC ENGINEERS EDUCATION IN A CHANGING WORLD

Dramatic economic and social changes worldwide call for conceptual modifications in the education of hydraulic engineers based on the information technology and environmental revolutions, as these elements have to be considered in the development of infrastructure works aimed at social development.

Life-long education in association with the concept of "educational society" is a key criterion of comprehensive education. For a new pedagogy of Hydraulic Engineering (in view of the complex issues it has to deal with), the "learning to learn" approach is essential. An adequate synergy between universities and research institutions facilitates access to the new knowledge required for a life-long learning process.

Since the times of Archimedes and Leonardo Da Vinci, hydraulics has evolved gradually through perplexities and mistakes, success and failure, serious disputes, analytical proposals, experience and plagiarism, transient theories and permanent laws. At present, it can be said that its excellent physical and mathematical foundations enable it to address a large portion of basic subjects; however, a whole universe of indispensable research and creative work is still needed to fill the gap between the true nature of the phenomena it deals with and their complete and final interpretation. Thus, hydraulics is always facing new challenges. Each of our meetings is clear proof of the validity of original research work.

Nevertheless, careful analysis of events in the past forty years reveals the need to introduce conceptual modifications in the education of hydraulic engineers in view of the dramatic socio-economic changes that have taken place worldwide, such as the information technology and environmental revolutions (LOPARDO; BOMBARDELLI, 1999).

Life-long education is the key to comprehensive education. The concept transcends the distinction between basic and continuing education and coincides with the notion of "educational society", one in which everything offers an opportunity for the individual to learn and develop skills.

Thus, continuing education aims at providing everybody with multi-purpose education. To this end, it is necessary to complement all the educational possibilities each country already offers.

Hydraulic engineering is closely linked to community development. To be of help to society, it must keep pace with changes and incorporate the ideas propounded by the electronic, IT and environmental revolutions. But, how can hydraulic engineers can be trained in keeping with the IT revolution? Computerizing the education, perhaps? IT offers a new infrastructure that will have an impact on the learning process, though there is a risk of using it to do just what was done before, sometimes worse.

Today we can produce new colors, new sounds and new shapes. Because of the advance of IT, people tend to believe that the Internet is the new philosopher's stone, and forget that education –which provides the context for human development— is culture, not an isolated technology (REGGINI, 2000).

Conventional education will be the sum of all available resources, and teleconference will allow users to project their physical presence to all kinds of expositions and laboratories. At the same time, reading a good book still remains as the foremost example of distance learning: the reading takes place away from the author in space and time.

It is crucial to assess how new information technologies impact on learning modes, both theory and practice. Assuming that the contents of the digital age are excellent merely because they are expressed in the new language is a new form of fundamentalism. It should be borne in mind that information dissemination does not replace education, the true meaning of which goes beyond collecting data.

The first experiment was relevant to water, and took place 450 years before Christ. In the days that people knew not the existence of air (they think that the wind was the breath of the gods) Empedocles of Agrigento made the first experiment documented in the history, and proved its existence, using the clepsydra or water thief. In other words, Empedocles discovered something invisible. He thought that "the air had to be a matter so finely divided that it was impossible to see"´(SAGAN, 1980). At the end of the Middle Age, Leonardo Da Vinci performed laboratory research on liquids flows and described the hydraulic jump and mentioned the turbulence.

Then, in engineering education is essential to develop the spirit of experimentation, the need to search for real data, the analysis of information obtained through probably the most modern instruments coming from the electronics and information revolutions. The importance of experimentation in engineering education is linked to basic training through the "scientific method" and applied training in the development of some "engineering criteria" to contrast their projects to reality.

With respect to the environmental revolution, for some years now people all over the world have been aware of the need to protect the planet from imminent environmental degradation. In this connection, a matter for debate in academia is the way of preparing professionals to deal with the different issues posed by environmental studies.

The salient feature of such studies is that they call for a fluid interrelationship between specialists in many disciplines, difficult *"a priori"*. This has given rise to the formation of "trans disciplinary teams", in which, in pursuit of a common objective, professionals in various fields of specialization contribute their knowledge while trying to understand and reconcile different points of view. To this end, a contribution we can make is the education of hydraulic engineers for sustainable development. Sustainability is a laborious process of agreed changes. It is a path towards an asymptotic objective endowed with new behavioral codes.

Only a professional equipped with sound basic training can successfully meet current challenges. Only education can instill the cultural bases needed to decipher the meaning of mutations occurring so fast. To this end, the mass of available information should be carefully selected for a better interpretation of the changes. The general educational premise of the new millennium will focus on devising a new development model that is more respectful of the individual's nature and rhythms. Professional education may be said to rest on four pillars (DELORS, 1996): *learning how ton know, learning to do, learning to coexist, and learning to be.*

To *"learn how to know"* is essential to combine a sufficiently broad general knowledge with the opportunity to deepen their knowledge in a small number of subjects, which is also "learning to learn"**.** We must *"learn to do"* in order to acquire not only an occupational skill but a competition that will enable the individual to deal with many technical situations. *"Learn to coexist"* implies the development of understanding towards the other and the perception of the forms of interdependence, enabling the student to work as a team, undertaking joint projects and learning to manage conflicts. Finally, it should be emphasized *"learning to be",* in order to flourish better personality, develop their critical thinking and being able to act with ever greater autonomy, judgment and personal responsibility. Education should not neglect any of the possibilities of an individual: memory, reason, an esthetic sense, physical skills, communication skills...

This learning process of water sciences for sustainable development should be considered as the true approach to change. An adequate synergy between universities and research institutions facilitates access to the new knowledge required for a life-long learning process.

The constant evolution of basic sciences and technical applications calls for the introduction of new disciplines and technologies, an increasing variety of orientations and information in university curricula. The time usually required for a first university degree does not suffice for the reasonable training of a professional who expects to be a specialist in a given field and have a broad general education. This is why systematic graduate and postgraduate training should be supplemented with different options in order to offer graduates and undergraduates the possibility of continuing and updating their education.

6 HYDRAULIC ENGINEERING AND SOCIAL COMMUNICATION

In the occasion of the author's participation as an official panelist of Argentina in "Water Tribune", within the framework of the International Expo Zaragoza 2008, during the week for the field of "Water and Society", was raised an interesting debate about the treatment of aspects of the water in the mass media. Within the complex and broad topic has noted the particular relevance that the host gave him the television media, which will be assigned a key action on the information society as a whole.

A topic of greatest interest and controversy was given by a Spanish journalist, who presented partial results of a survey on participation in the "TV news" of water issues. Overall, preliminary results of this work yet to conclude, note that 74% of the population of Spain is reported only through television, especially the “TV news”, to which credit is given well above the "opinion programs", which is estimated we are objective enough. For the mass audience, the "news" given by the speaker is impersonal and trustworthy, while other programs are tinged ideological overtones. This result demonstrates the enormous responsibility of those who run these notices, because they own a kind of "absolute truth".

On the other hand, has emerged from this study 4,000 news surveyed in four different television programs in a period of two months only 3.8% of the volume of information was related to water issues. Within this low total, the journalist mentioned that 32% refers to rain, 20% to flooding, 28.6% to ocean issues, particularly pollution of coastal regions, 11.3% to droughts and only 8% to the management of water resources.

As was stated, news generally has catastrophic image of water, and a marked concern for the environmental health of the oceans. They have low interest issues instead of a technological, economic, social, and policies related to water management. The journalist considers water as part of the "aesthetics of the sublime," the sinister beauty of the phenomena is that the information continues to dominate television. About this aspect, although the evaluation of surveys in Spain nuances and differences that arise can be applied locally, it is intended in the near future that a multidisciplinary team with members of the water area and the area of journalism attack similar surveys Latin America and Argentina in particular.

Besides the importance of disseminating water resources projects through mass media, is of fundamental importance that the engineer has adequate training to integrate functional teams to include environmental aspects. The hydraulic engineer should be trained in order to maintain a constructive dialogue with members of the society to pay attention to their complaints and opinions and, if to be sure of having the most suitable alternative work, a willingness, interest and ability to convey that these social media project and defend it with conviction, but always warning about the negative impacts as well as clearly stating the positive.

On the other hand, shows the growing need that the engineer should spread their knowledge in language understandable to the rest of society, through its presence on public hearings and meetings of political or popular discussion, where the influence of mass media is also crucial.

Taking the case of public hearings, the professional must be prepared not only to address criticisms and objections regarding the potential impacts of his project, but to show with balance and understanding that the views of the social environment are taken into account, evaluating the relevance of them without previous disqualifications. It should exercise broad discretion teacher and explain adequately the reason for the decisions made.

The more complex case can occur when the hydraulic engineer is faced with a community that has suffered the destructive effects of water-borne disaster and called a meeting with leaders, journalists and stakeholders. They should focus on communicating the real causes, usually more than one, trying to raise the possible solutions rather than finding blame, which the media and society itself are generally focused.

8 CONCLUSIONS

For a productive relationship between research, education and career development, all available means in the region should be used. The objective of "life-long education" is to provide not only hydraulic engineers but water users as well with knowledge of water sciences. To this end, continuing education for sustainable development should be encouraged and while the irreplaceable role of conventional education should be acknowledged, new information technologies cannot be ignored.

Train teachers to students interested in experimental science not only be of interest for the future of the few engaged in his profession to research, but for all other activities that will assess the technological and psychological difficulties to which are those subject.

One of the serious problems facing engineering today is for the appropriate dissemination of achievements in relation to the requirements of the Society. The Engineer is systematically observed with caution by the mass media, who consider him dependent on a powerful client (as the Government itself) that threatens the rest of the population. His opinion is constantly put into question by professionals from other disciplines, the journalists themselves and people without any knowledge on subjects.

Must be recognized the failure in the engineers' ability to disseminate to the media in a timely manner the scope, benefits, problems and possible impacts of their projects. If we don't admit our mistakes we cannot credibly reach the Society.

When projecting a hydraulic structure, displacement of populations should be treated with special care, with a sense of organization and political sensitivity. For these populations relaying must inescapably signify an improvement in their standard of living, as those directly affected by the project should be the first beneficiaries. The particular actions affecting vulnerable ethnic groups need special attention.

It is important to develop ecological and social research in dams and reservoirs that have seen years of service. If you proceed to collect, process, evaluate and publish, in a carefully targeted research box, the great body of knowledge resulting from our long experience in the operation of many dams and reservoirs, could be eliminated errors and shortcomings, could prevent controversy about the impact of dam projects and could be clarified and resolved more easily related problems. Then, engineering education should focus not only on scientific excellence and technological capacity to develop their projects but have to find the appropriate methodology for such projects of interest to the Society and accessible to the media through the public hearings.

Moreover, the real development and improvement of quality of life is an inescapable contribution to environmental conservation, because as said Indira Gandhi, “the worst environmental impact is poverty”.

REFERENCES

Comité Argentino de Presas (2000), "Presa en Anillaco: segunda presa rota en menos de un año", Boletín Electrónico del CAP, cap@argensoft.com.ar, Cipolletti, Argentina.

Corrales, M.E. (2003): “Gobernabilidad de los servicios de agua potable y saneamiento en América Latina”, Global Water Partnership, Stockholm, Sweden.

Delors, J. (1996): "Learning: the Treasure Within", UNESCO, Paris.

Hjorth, P., Kobus, H., Nachtnebel, H.P., Nottage, A. & Robarts, R. (1991): "Relating hydraulics and ecological processes", Journal of Hydraulic Research, Vol. 29, extra issue, pág. 8-19.

Lopardo, R.A., De Lío, J.C.& Vernet, G.F. (1987): “The role of pressure fluctuations in the design of hydraulic structures”, in Design of Hydraulic Structures, edited by R. Kia y M.L. Albertson, Colorado State University, Fort Collins, pág. 161-175.

Lopardo, R.A. & Bombardelli, F. (1999): "On the Interdisciplinary Formation for the Water-Environment Engineering", International Symposium "The Learning Society and the Water-Environment", UNESCO, Paris, pp. 158-162.

Malinow, G. V. (1991): "La seguridad de presas existentes durante crecidas extraordinarias", D C, Ministerio de Defensa, Dirección Nacional de Defensa Civil, Año I, Nº 1.

Murillo, J.A.: (1987) "The scourge of scour", Civil Engineering, ASCE, New York, pág. 66-68.

Reggini, H.C.: “El fundamentalismo digital”, La Nación, Buenos Aires, 17 de mayo de 2000.

Rogers, P. (2002): “Water governance in Latin America and the Caribbean”, Inter-American Development Bank, Washington D.D., USA.

Sagan, Carl (1980): “Cosmos”, Random House, New Yorke.

Solanes, M. & Jouravlev, A. (2006): “Water governance for development and sustainability”, CEPAL, Santiago, Chile.

WATER RESOURCES AVAILABILITY AND SECTORIAL ANALYSIS FOR SUSTAINABLE DEVELOPMENT IN AFRICA[1]

Salif Diop[2]

[1] *INTERNATIONAL SYMPOSIUM on "ENHANCING WATER MANAGEMENT CAPACITY in a CHANGING WORLD" - Sao Paulo, Brazil, June 25 to 28, 2012.*

[2] *Professor of University, Member, National Academy of Sciences of Senegal; Member of African Academy of Sciences and The Academy of Sciences for the Developing World. - Head, Ecosystems Section Scientific Assessment Branch - Division of Early Warning and Assessment (DEWA) - United Nations Environment Programme - 1, UN Avenue – Gigiri - P.O.Box 30552 - Nairobi, 00100 Kenya. E-mail: salif.diop@unep.org. Personal Website: http://www.esalifdiop.org.*

ABSTRACT

This paper refers to availability of water resources in africa and the evaluation of various sectors fundamental for sustainable development in the african continent. The purpose of this synthesis is to analyze the mounting water challenges the African continent is facing with its growing populations and identify the opportunities for the Africa continent to overcome some of the challenges. Among the existing opportunities, the possibilities to tap into the important water resources of the continent for the purpose of irrigation, industry, hydropower, tourism, sectors for which less than ten percent of the water resources in Africa are presently utilized.

1 INTRODUCTION

Africa's water is held in large rivers, widespread aquifers, large dams, lakes and wetlands as well as in atmospheric water vapor and soil moisture. The rivers provide transportation arteries, habitat for fish and other freshwater organisms and water for drinking and irrigation. Most economies in Africa are closely tied to natural resources. Water is directly or indirectly used in almost every economic sector including agriculture, manufacturing, trade, mining, tourism, transport, and telecommunications, among others.

Agriculture—largely rain-fed—is the single most important driver of economic growth for most African countries. The agricultural sector accounts for about 20 per cent of Africa's GDP, 60 per cent of its labor force and 20 per cent of the total merchandise exports, and is the main source of income for 90 per cent of the rural population (UNECA, 2007). Compared to other sectors, GDP growth originating in agriculture is about four times more effective in raising incomes of poor people, with even higher potential multipliers from investing in agricultural water (WORLD BANK, 2009). Water is both an ecosystem "good", providing drinking water, irrigation and hydropower, and an ecosystem "service", supplying people, whether they are aware of it or not, with functions such as cycling nutrients and supporting habitat for fish and other aquatic organisms, as well as "cultural services" such as scenic vistas and recreational opportunities.

The purpose of this synthesis is to analyze the mounting water challenges the African continent is facing with its growing populations and identify the opportunities for the Africa continent to overcome some of the challenges. Among the existing opportunities, the possibilities to tap into the important water resources of the continent for the purpose of irrigation, industry, hydropower, tourism, sectors for which less than ten percent of the water resources in Africa are presently utilized.

2 ANALYSIS OF THE MAIN CHALLENGES, CONSTRAINTS AND OPPORTUNITIES

2.1 CHALLENGE 1: THE MILLENNIUM DEVELOPMENT GOAL'S SAFE WATER TARGET IS TO REDUCE BY HALF THE PROPORTION OF THE POPULATION WITHOUT SUSTAINABLE ACCESS TO SAFE DRINKING WATER BY 2015

2.1.1 The situation

Sub-Saharan Africa accounts for more than third of that number, with about 330 million people without access to safe drinking water. Africa's progress towards the MDG drinking water target is slow and uneven, and the continent as a whole will not reach the goal. Although the proportion of people in sub-Saharan Africa using improved sources of drinking water increased by 14 per cent from 1990 to 2008, only 60 per cent of its population had such access by the end of that period (WHO/UNICEF, 2010). Based on current trends, sub-Saharan Africa will not reach the MDG water target until 2040 (UNDP, 2006a). A recent survey revealed a bleak future in which only two countries (Kenya and South Africa) are estimated to have more than 75 per cent of what is needed to achieve the sanitation target, and five countries are estimated to have more than 75 per cent of what is needed to achieve the MDG target for drinking water (WHO, UN-WATER, 2010).

- *There are large disparities in the provision of safe water*: sub-Saharan Africa has by far the lowest coverage rates of piped water among world regions (50 per cent) (WHO/UNICEF, 2010). The increase in numbers of people with access to other improved sources of drinking water was 3.5 times higher than the rise in people with piped water on premises. Only five per cent of the rural population receives piped water in their homes compared to 35 per cent of urban dwellers (WHO/ UNICEF, 2010).

Limited access to water means that Africa has a high incidence of water-related disease: The incidence of water-related and waterborne diseases such as cholera, malaria, Guinea worm and river blindness is high in Africa, mainly due to limited access to water and sanitation.

- The lack of safe water is debilitating to the economy: In economic terms, the lack of proper water and sanitation services in developing countries translates into the loss of revenues and the inability to generate and sustain livelihoods, due in large part to the debilitating effects of water-related disease . In addition, the time and energy lost in hauling water from long distances, predominantly undertaken by women and girls, deprives them of time to engage in livelihood generating activities and attending school.

2.1.2 The Constraints

There are many reasons for the lack of progress in providing the people of Africa with safe drinking water, including the following:

- Exploding peri-urban areas and more affluent consumers: In some regions, growing populations have caused the ranks of the destitute to swell. In Cairo and other large cities on the continent, sprawling city limits and rapidly growing populations (from both natural growth and in-migration from rural areas) have created extensive squatter settlements or slums, challenging the abilities of water management institutions to provide adequate water and sanitation infrastructure. On the other hand, as some city dwellers become more affluent and industrial development expands with economic growth, the demand for better and more water services also grows.
- *Lack of access, regulation and public utilities:* Throughout Africa, there are areas where water and sanitation services are more easily accessible than others.

2.1.3 The Opportunities

In spite of the situation and formidable challenges, there are opportunities to improve safe water availability in Africa and lessons can be learned from some African countries that have seen the most progress. The strongest performers in terms of piped water-service expansion are Benin, Burkina Faso, Chad, Ethiopia, Mali and Senegal, all showing growth rates of four to eight per cent per year (BANERJEE et al., 2009). While rural populations continue to lag behind urban populations globally, countries as diverse as Morocco and Uganda have sustained rapid increases in rural coverage (UNDP, 2006a).

- *Improve financing:* According to the 2006 UNDP Human Development Report, governments need to spend about one per cent of GDP on water and sanitation. Additionally, increased international aid would play a very crucial role in catalyzing access to improved water sources. More funding from tariff s, taxes and transfers, in the right mix, can help meet national goals for sustainable water access (HASHIMOTO ACTION PLAN, 2010);

- *Encourage concessions in privatization schemes:* Private investment by domestic and foreign companies that assume responsibility for financing and operating water systems can improve efficiency, reduce water losses, increase supply, extend meters and revenue collection and enlarge coverage. In Morocco, which created four concessions between 1997 and 2002, coverage increased as did consumer satisfaction scores (UNDP, 2006a);
- *Subsidize connections for the poor*: Subsidizing connections for poor households and implementing innovative payment strategies may remove an important barrier to expanding the water-supply network. In Côte d'Ivoire, for example, a Water Development Fund surtax is included in bills, with about 40 per cent of the proceeds used for connection subsidies;

Target informal settlements: Some utilities have shown an unwillingness to extend services to households lacking legal title, fearing that it could jeopardize their revenue collection. Using creativity to deal with this dilemma may solve water access problems for people in these Settlements.

- *Institute or improve regulation:* Regulatory authorities are important to ensure that providers are managed in a way that secures both equity and efficiency independent of politics. Where administrative capacity and regulatory institutions are lacking, citizens can take a pro-active role, pressing for more information and publicizing underperformance by water utilities (UNDP, 2006a);
- *Target rural communities:* Opportunities in rural communities include adoption of free-standing small-scale systems capable of treating water; recovering wastewater for re-use and capturing resulting gases as a source of energy for power, lighting and cooking—support to community level projects on water resources management, water supply and sanitation in over 30 countries has demonstrated this;
- *Encourage entrepreneurship for simple water purification techniques:* Solutions using local ingenuity and simple tools and mechanisms have been shown to improve access to safe drinking water.

2.2 CHALLENGE 2

The Millennium Development Goal's sanitation target is to reduce by half the proportion of the population without sustainable access to basic sanitation by 2015. Increasing people's access to water will help Africa reach this target, while ensuring that water sources are not contaminated by sanitation facilities will help it to reach the MDG safe drinking water target.

2.2.1 The Situation

- There are about 2.6 billion people in the world who do not have access to improved sanitation facilities of which about 585 million people are in Africa . Less than half of the people living in 35 African countries do not have such access. Use of improved sanitation facilities in sub-Saharan Africa is very low, at an overall 31 per cent, with great disparities between urban and rural areas. The MDG target requires that 63 per cent of the region's population has access to improved sanitation by 2015. That amounts to 370 million more people than the estimated 242 million who were using such facilities in 2006 (WHO/UNICEF, 2010). Most African countries will not meet the target;
- *Access to sanitation is rising in Africa, but there are large disparities in its provision:* The coverage rates for sanitation are far lower than those for water, even in higher-income groups. Notable increase in the use of improved sanitation facilities has been made in North Africa, but throughout the continent, regional disparities are still very apparent. Sub-Saharan Africa is the only region where more than half the population still does not have any access to better sanitation, with a striking contrast between urban areas, which are better served, and rural ones (WHO/UNICEF, 2010);
- *Although sanitation coverage is rising, population growth is outpacing provision efforts:* Although Africa had one of the world's lowest sanitation coverage rates in 1990; the number of people using improved sanitation facilities in sub-Saharan Africa has improved over the years. However, efforts to reach the MDG sanitation target have been unable to catch up with the population growth;
- *Lack of sanitation is a cause of waterborne disease:* Cholera epidemics are a major risk in areas with high concentrations of people and poor sanitation. Heavy rains can flood latrines, contaminating water and exposing populations to cholera bacteria. Groundwater can also become contaminated by improper sanitation;
- *Economies and human livelihoods suffer from the lack of sanitation:* Lack of sanitation hurts local economies when resulting poor health leads to lost working days, school absenteeism and increased time to take care of the sick.

2.2.2 The Constraints

The obstacles to providing proper sanitation facilities are the same as those faced in the provision of safe drinking water: exploding peri-urban and slum areas, economic growth and higher demand, geographical isolation, dearth of public utilities and regulation, and the high costs of water provision.

- *Lack of financial and technical resources:* Sanitation investments have lagged behind water supply by almost a decade. Poor economic performance and associated financial and technological limitations continue to be at the root of the slow progress in supplying adequate sanitation services, which suffers from chronic under-funding.

2.2.3 The Opportunities

The improvement of sanitation services is inextricably linked to the improvement of water provision. Thus, the same opportunities outlined in the previous section apply here and there are lessons to be learned from countries that have made the most strides in increasing sanitation coverage.

- *Recognize the potential to generate revenues from sanitation technologies:* The business opportunities afforded by investing in sanitation is now being recognized and Africa could benefit by market-based approaches;
- *Encourage and support simple solutions from entrepreneurs*: Entrepreneurs are increasingly bringing out low technology and affordable toilets. In Tanzania, for example, a concrete slab to install above pit latrines is now available for about $5.00;
- *Introduce urban water tariff s:* A study in Egypt showed that if urban water tariff s were raised to cover operations and maintenance costs, enough financial resources could be freed up to finance urgently required investment in sanitation infrastructure (UNDP, 2006);
- *Increase sanitation's share in total aid:* Aid for sanitation and drinking water is increasing in absolute terms, but its share of total aid decreased from eight per cent in 1997 to five per cent in 2008 (WHO; UN-WATER, 2010). If water and sanitation targets were achieved, sub-Saharan Africa would save about US$2 per capita—equivalent to about 12 per cent of public health spending. Reduced spending would release resources for other priorities, including addressing HIV/AIDS (UNDP, 2006);
- *Adopt system financing:* This opportunity is especially relevant if national plans include clear funding estimates for attaining their targets;
- *Build partnerships between the government and civil society for educational campaigns:* There is an opportunity to increase capacity building through stronger partnerships between the government and civil institutions.

2.3 CHALLENGE 3

Given the many watersheds shared by numerous African nations and the potential for discord over water management in them, there is a need and an opportunity to avoid conflict by cooperating in transboundary water basins.

2.3.1 The Situation

- *Africa has a large number of shared watersheds:* There are 263 international river basins covering almost one half of the total land surface of the globe and affecting 40 per cent of the world's population. Of these, Africa has 63 shared basins covering about 63 per cent of the continental area . Africa has more rivers shared by three or more countries than any other continent. Every country in Africa has at least one international river, with the Congo basin shared by as many as 11 countries;
- *There is a potential for conflict over water resources*: There are a number of ways in which disagreements over water use can arise among parties that share the resource: where one country transfers or threatens to transfer water outside the basin (for example, there is a planned project to transfer water from the Ubangi River to Lake Chad); when activities in upstream sections of a basin threaten downstream users and vice-versa (in the Okavango Transboundary watershed, for example, there is the potential for disputes between users in Angola and Namibia in the upper part of the river and those in Botswana downstream); where development outside a river basin threatens the river's water availability or quality, or vice-versa (for example, urban and industrial developments outside the Congo basin watershed make demands on the basin's waters); where there is competition for the same water among different economic sectors both within and between countries, including irrigation, hydroelectricity, industry, navigation, tourism, mining, etc.; and finally, when richer countries or large corporate development projects threaten water use by poorer users in another part of the basin (ROY; 2010).

There are at least 94 international water agreements in Africa: Worldwide, about 3 600 international waters treaties have been signed between 805 AD and 1984. Out of 145 international agreements signed between two or more states sharing water-basins in the last century, about 94 occurred in Africa, dating back from late 1800s (WOLF, 1998). Figure 3.3.2 shows the number of countries sharing river basins in Africa's top shared basins and the number of transboundary treaties in those watersheds. It also illustrates the number of treaties in each of Africa's major basins.

2.3.2 The Constraints

- *Population growth is diminishing shared water supplies:* Perpetual population growth and existing hydro-political complexities in Africa's international river basins will inevitably place high stress on shared water resources and on the agreements that govern them. Africa's ever-growing population will certainly increase the demand for water. As demand increases and water supply decreases, the possibility for conflicts between transboundary nations could rise;
- *Climate change threatens to stress shared waters:* Predicted climate changes may have negative impacts on supply and demand, and may further exacerbate situations in which water is shared among countries;
- *Water is declining in shared aquifers:* Africa's aquifers contain large amounts of fossil water, which is thousands of years old. Their recharge rate is now much less than the withdrawal rate (UNEP, 2006). A drop in groundwater levels or a decline in its quality may threaten the political stability of the region, especially where numerous countries share the resource (TURTON, 2008b);
- T*here are seasonal differences in water supplies:* Conflicts can also occur between upstream and downstream users due to large seasonal variations in water flows and periodic droughts and floods that are characteristic in Africa (TURTON et al., 2006);
- *Inadequate joint management laws and conflicting national interests stress joint management capacities*: Given that Africa's national boundaries are not aligned with water bodies, water resource management needs to include regional considerations rather than just national objectives (ASHTON, 2007). Vague or inadequate international laws regarding joint management of shared waters, however, make it hard for riparian states to manage both a single basin with other states and multiple basins in the same state. The water needs and economic situation in each country also varies (TURTON, 2008b). Conflicting interests and inequity in capacities between riparian states further constrain negotiations on international watershed management (VAN DER ZAAG, 2007). The Southern African Development Community (SADC) and the Senegal River Development Organization (OMVS) are the only two organizations that operate basin-wide shared water management (KLIOT et al., 2001).

2.3.3 The Opportunities

International water cooperation presents an opportunity to deal with these challenges and constraints through negotiated basin sharing for both withdrawal and in-stream water uses. The sustainability of water available within a river basin that crosses two or more countries may be assured and even increased via transboundary agreements. Such agreements help ensure equity in the provision of water for all and help maintain peace and security.

There are several examples of transboundary water agreements and other sharing mechanisms that have been successful in helping riparian African nations negotiate equitable water sharing and that illustrate the potential for such agreements to be a catalyst for wider political cooperation.

- *Learn from successful transboundary cooperation eff orts and agreements among African states:* Successful transboundary water distribution is inherently dependent on political cooperation between the involved riparian states. In the absence of strong rules and laws, treaties are the best form of formal river basin management.

2.4 CHALLENGE 4

With a growing population, Africa needs more food and must secure the water needed to ensure its supply at the same time as water resources are becoming scarcer.

2.4.1 The Situation

- *Agricultural growth is the mainstay of most African economies:* Farming is the source of livelihood for about 70 per cent of Africa's population that are rural-based. In sub-Saharan Africa, mostly small-scale farming represents about 30 per cent of GDP and at least 40 per cent of export value. In a number of Africa's smaller nations, agriculture plays a much greater role, accounting for 80 per cent or more of export earnings. Studies have shown that other economic sectors on the continent tend to perform well when there is positive growth in the agricultural sector;
- *Agriculture is the greatest user of water in Africa:* Globally, agriculture accounts for 70 per cent of water consumption (UNEP, 2008) but in Africa, as much as 86 per cent of total annual freshwater withdrawal goes to agriculture. Thus, the demand for food is the most important driver of water use in Africa;

- *There is inadequate water use for sustainable food production:* Inadequate water for food production continues to compromise the wellbeing and economic productivity of Africa's people, thus curtailing their ability to generate revenue required for improving the availability and access to water for food.
- *Africa suffers from food insecurity and 30 per cent of the population lives with chronic hunger:* Lack of water contributes to the situation of food insecurity, a situation in which people lack adequate physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active healthy life. Economic water scarcity is a contributing factor to food insecurity, especially in sub-Saharan Africa.

2.4.2 The Constraints

- *Per capita food intake is rising:* As Africa's population rapidly becomes more urbanized; increasingly large amounts of water are needed to meet food requirements; Not only are there more people to feed in cities, but urbanization is also generally accompanied by a rise in personal income and an increase in per capita food intake. In addition, people tend to shift away from staples towards richer diets containing products that require more water to produce such as meat, fruits, vegetables, sugars and oils;
- *Food production is not increasing:* About one third of the continent's people live in drought prone areas, and the rising population and increasing affluence and demand for different foods has not been matched by a corresponding increase in food production;
- *Green water efficiency is very low:* A large portion of water for crop production in Africa comes from rainfall that is eventually transpired by crops as soil moisture (green water), around six per cent is from surface and groundwater sources (blue water). Green-water use efficiency is still very low, with studies showing that only 15 per cent of the terrestrial rainwater is used by plants for the production of food, fodder and fiber in sub-Saharan Africa, partly due to excessive losses caused by poor land management practices;
- *Irrigation capacity is underdeveloped:* There is underinvestment in water infrastructure for irrigation across the continent, with only seven per cent of cultivated land equipped for irrigation in 2005 (FAO, 2005). In sub-Saharan Africa, the proportion was only 3.8 per cent of arable land. By comparison, 28.7 per cent of the Near East and North Africa's cultivated land was irrigated, and in South Asia, the proportion was as high as 39 per cent.

2.4.3 The Opportunities

- *Learn from the 1960-1990 Green Revolution:* There are lessons to be learned for Africa from the Green Revolution, which saw the yield of major cereals (rice, wheat and maize) more than double during the period 1960-1990 in Asia and Latin America, arresting the threat of famine and lowering the prices of staple crops (FAO, 2005). By focusing on small farmer-based agriculture, countries that were food deficit 40 years ago are now food exporters. National governments controlled their own agricultural policies and the main focus of agricultural research was to promote local and appropriate technologies. Although there are natural, social and economic differences, the Asian food crisis at that time was described in the same breadth and in terms used for Africa today: high population growth rates, widespread poverty, hunger and malnutrition.
- *Promote a greener, Green Revolution in Africa:* By initiating a green (ecological friendly), Green Revolution, Africa has an opportunity to grow more food from the same amount of water or grow the same amount of food using less water. The use of irrigation, synthetic fertilizers, chemical pesticides, early maturing and high yielding dwarf seed varieties (the dwarf varieties of rice and wheat were less susceptible to falling over, enabling the application of large amounts of water and fertilizer to boost yields) were critical components of the Green Revolution technology package in Asia. Record yields were realized but higher rates of poisonings from the chemical pesticides were also recorded in many areas, in addition to intense eutrophication of aquifers and waterways. In Asia, the ecological costs of the Green Revolution have risen and a growing number of farmers are turning back to non-chemical or less-chemical agriculture. Alternative sustainable farming practices include agroforestry and intercropping cereals with legumes to improve nitrogen deficient soils and reduce reliance on synthetic fertilizers and pesticides. Increasing productivity on existing cropland is fundamental if Africa is to avoid destroying vital ecosystems such as its biodiversity-rich wetlands and rainforests. Africa can avoid the environmentally damaging aspects of such a revolution by focusing on a green, Green Revolution.
- *Increase irrigation to increase food security:* The estimated rate of agricultural output increase needed to achieve food security in Africa is 3.3 per cent per year. The potential for meeting this estimate exists, since two-thirds of African countries have developed less than 20 per cent of their agricultural production and less than 5 per cent of the cultivated area is under irrigation in all but four countries (UNECA, 2006). Without investment in irrigation, it will be difficult to increase food production, reduce the financial burden of agricultural imports and increase food security. Irrigation increases yields of most crops by 100 to 400 per cent. In sub-Saharan Africa, only four per cent of cropland

is irrigated, so farmers need to make significant investments in irrigation to increase their productivity. Irrigation makes it possible to:

- Control soil moisture and therefore exploit an extended cropping season to boost agricultural yields and outputs;
- Supplement unreliable rainfall, and grow a wider range of crops, including high value crops for the export market;
- Maintain food production levels and contribute to price stability through control over production levels;
- Achieve food security at local levels through increased income and improved health and nutrition; and
- Bridge national gaps between production and demand of food crops;
- *Avoid the pitfalls of over-irrigation:* Irrigation development was an important component of the Asian Green Revolution, used to double yields by supplementing unreliable rainfall.
- *Invest in simple and inexpensive irrigation technologies:* These offer the best advantages for increasing irrigation for food production, but they must be managed carefully to avoid environmental damage, which is already extensive, and the spread of water-borne diseases. Parts of sub-Saharan Africa have large untapped reserves of groundwater and there is great potential for harvesting water runoff and for farming lowlands and valley bottoms that catch it naturally. With investment, this potential could be unleashed. Other water conservation techniques include switching from surface to "smarter" irrigation techniques like micro-irrigation and mulching and using cover crops to minimize the loss of available green water. Increases in the level of irrigation can come from both surface and ground water, drawing lessons from within and outside the region on viable small to medium scale irrigation techniques that require limited infrastructural development and can reach many farmers.

Methods such as pumping from rivers on an individual and small group basis, and locally manufactured drip systems are still to be fully exploited (IAASTD, 2009). Surface irrigation is easy to operate and maintain, and can be developed at the farm level with minimal capital investment, with an indicative field application efficiency of around 60 per cent. Most energy requirements for surface irrigation systems come from gravity, and the systems are less affected by climatic and water quality characteristics (FAO, 1989a, 1989b).

Sprinkler irrigation has a high irrigation field application efficiency of around 75 per cent, and is easy to design and simple to install and operate. It can be adapted for all types of soils, many kinds of field crops and small irregular plots, and is less expensive than many other modern irrigation systems (FAO 1989b, 2007a). Drip irrigation is the most advanced irrigation method with the highest field application efficiency of around 90 per cent. Water is applied to each plant separately in small, frequent, precise quantities through dripper emitters. Switching from sprinkler irrigation to drip systems has resulted in a reduction in water use by 30-60 per cent .

- *Tie irrigation development to issues of social equity and environmental sustainability:* The large scale irrigation schemes of the past have lost favor because of their social, environmental and financial costs. Now, project planners are seeking the participation of farmers in designing and managing irrigation plans. In implementing small-scale irrigation projects, there are opportunities to extend benefits to enhance social and environmental sustainability .
- *Secure sustainable investment for the green, Green Revolution:* Technologies such as the development of underutilized irrigation potential, and the development of high yielding and more drought tolerant varieties can work for Africa if there is good investment (WORLD BANK, 2008). African farmers can reduce reliance on food imports and protect against the import of low-price grains. Governments in Africa are taking ownership of their own agricultural policies through initiatives such as the Comprehensive Africa Agriculture Development Programme (CAADP), which provides the framework for supporting the design and implementation of national agriculture and food security strategies (MDG AFRICA STEERING GROUP, 2008). This initiative presents an opportunity for development partners and the private sector to support national governments, and to reduce donor fragmentation so that financing can be channeled to effectively support the implementation of national-scale agriculture strategies within the framework.
- *Invest in targeted breeding of drought-tolerant varieties:* For example, the AfDB funded and African Rice Initiative coordinated project contributed to a six per cent increase in the continent's rice output during 2007 (World Bank 2008). Such targeted breeding can produce crop varieties that are higher yielding, more droughts tolerant, utilize fertilizers more efficiently, and are more resistant to pests. It is important to note that genetically modified organisms (including crops) are still considered an emerging issue in Africa since they present the following concerns and uncertainties in light of increasing cooperation and trade:

- The issues of bio-safety;
- The impact of GMOs on the environment;
- Trade with non-GMO partners;
- Ethics issues;
- Intellectual property rights; and,
- Access to seeds by small-scale farmer.

2.5 CHALLENGE 5

Develop Africa's water resources for hydroelectricity to boost energy security.

2.5.1 The Situation

Hydroelectricity supplies 32 per cent of Africa's energy; electricity consumption in Africa is the lowest in the world; Many African nations have a per capita electricity consumption of less than 80 kWh/yr (Figure 3.5.3, next page), compared to 26 280 kWh/yr in Norway, 17 655 kWh/yr in Canada, and 13 800 kWh/yr in the United States. Access to electricity is uneven; only one in four people in Africa has access to electricity. More than 90 per cent of the rural population relies on biomass energy sources that include wood, crop waste, charcoal and manure for cooking and heating, and candles and kerosene for lighting electricity. Supply is often unreliable; Even where access to electricity is available, it does not necessarily mean that electricity is available on demand. People frequently have to cope with unreliable supply and this disrupts economic activity at all levels and hampers progress; wars have destroyed existing electricity service in some areas; and Africa's hydro potential is underdeveloped.

2.5.2 The Constraints

The capacity to generate hydropower is unequal across the continent; Constraints to hydropower development in Africa include the unavailability of suitable sites, large capital requirements, long lead times to develop, concerns over social and environmental impacts, political instability, and the impacts of climate variability on water resources (WORLD BANK, 2010). Low demand and dispersed populations also hinder rapid exploitation as well as the increase in demand from population and economic growth that challenge the ability of countries to provide increased power. Climate change will exacerbate rainfall could hinder hydro potential in some areas; Climate change is expected to affect Africa's water resources. Hydro dams will need to avoid the environmental and social impacts historically characteristic of large dam developments. The capacity to generate hydropower is unequal across the continent: Across Africa, available sites for hydro development are unevenly distributed. For example, the average potential in North Africa is 41 000 GWh compared to 653 361 GWh in Central Africa (Figure 3.5.6). In spite of its enormous hydroelectric potential, the Central

Africa sub-region is the least electrified with only 2.6 per cent power production, while the Southern Africa sub-region is the most electrified (MDG AFRICA STEERING GROUP, 2008).

2.5.3 The Opportunities

Recognize that Africa has enormous hydroelectricity potential; Africa is the "underdammed" continent. Only three per cent of its renewable water is used, against 52 per cent in Asia. So there is plenty of scope for an African dam-building boom. Africa's vast hydropower potential is yet to be tapped, hence the need to develop hydropower because it will boost the economy and human well-being, invest in hydroelectricity rather than fossil fuels, which makes sense in an era of climate change; learn from the many African countries that have developed hydropower successfully; learn from and copy successful regional power pools; and develop small-scale hydropower projects to avoid the environmental and human costs associated with large dams. Meanwhile, regional power pools are able to reduce costs and improve conditions on the supply side. Operational costs are lower, due to investment in least-cost power generation plants on a regional basis. Benefits on the supply side, all contributing to increased reliability, include reduced coincident peak loads on the regional power pool, compared with the sum of the individual peak loads for each national power grid; shared power generation reserves for the interconnected power grids; and increased robustness to deal with local droughts or other unexpected events. The Grand Inga dam in the Democratic Republic of Congo (DRC) is one of the key projects that will support regional pools. The project is estimated to cost $80 billion and to have a total installed capacity of 44 000 MWh. Difficulties associated with the project include an absence of political consensus and legal harmonization. Nigeria is expected to be the largest consumer. The carbon-emission reduction potential is expected to help attract necessary investment. Most of the power will be used for industry or for export. Inga 1 and Inga 2 were commissioned in 1972 and 1982, as part of an industrial development scheme in the DRC. The two dams currently operate at only 40 per cent capacity because they have never received maintenance. The World Bank is partially financing a project to rehabilitate these dams.

When Inga 2 was built, a 1 800-km transmission line was also built to transport the power to state owned copper mines in the Katanga province, bypassing nearly every city and village underneath. A component of the Grand Inga project could be expanded for household electricity access, particularly in the DRC, where access is estimated to be 13 per cent in urban areas and only three per cent in rural areas.

2.6 CHALLENGE 6

Meet Africa's growing demand for water in a time of ever-scarcer water resources.

2.6.1 The Situation

More than 40 per cent of Africa's population lives in the arid, semi-arid and dry sub-humid areas; the amount of water available per person in Africa is far below the global average and is declining; The continental annual average water availability per person is 4 008 m3/capita/year, well below the global average of 6 498 m3/ capita/year (FAO, 2009). Annual per capita water availability has declined from 37 175 m3 in 1750 to 4 008 m3 in 2008. It has been predicted that the proportion of the African population at risk of water stress and scarcity will increase from 47 per cent in 2000 to 65 per cent in 2025, affecting 18 countries; groundwater is falling; and rainfall is also declining in some regions.

2.6.2 The Constraints

Demand for water is increasing with population growth and economic development: with population projected to reach nearly two billion people by the year 2050 (UNFPA, 2009), water supplies will be stretched to provide adequately for all uses. Africa's average population growth rate between 2005 and 2010 was 2.3 per cent, the highest in the world (UNFPA 2009). Development of water resources is inadequate; prices to access water are generally distorted; and water provision is highly inefficient.

2.6.3 The Opportunities

Further develop and manage water resources sustainably: Given the presence of ample available water resources and their underdevelopment, one of the opportunities for addressing Africa's water scarcity is to further develop and manage its water sustainably (UNECA, 2006). Economic development is needed to ensure a sustainable fl ow of funds for water infrastructure. There is also considerable scope for improved agricultural production and food security through irrigation and rain-fed agriculture, which does not necessarily lead to increased demand for water; improve water use productivity; improve urban planning for better water provision; rationalize water prices; and protect Africa's water towers.

2.7 CHALLENGE 7

Prevent water pollution, and address land degradation related to rainfall variability and the impacts of such degradation on water resources.

2.7.1 The Situation

The Sahel has been subject to enormous rainfall fluctuations. Over the last three decades, the Sahel has suffered from land degradation; groundwater resources are being polluted by saltwater intrusion, and Africa's scarce water supplies are being polluted by point sources.

2.7.2 The Constraints

Lack of valuing of ecosystem services; political instability and conflict within and between countries; poor agricultural practices and farming on marginal lands that affect water use or water resources; and lack of structured water monitoring and good governance.

2.7.3 The Opportunities

Maintain vital ecosystem functions; e.g. in 1998, South Africa established the National Water Act to set aside or allocate water of a certain quantity and quality to maintain the basic ecological functions of aquatic ecosystems. This amount of water is called an Environmental or Ecological Reserve. In other words, they protect the legitimate right of rivers and other ecosystems to their own water when water allocation decisions are made.

Although stakeholders sometimes interpret such protection or allocation as being in direct competition with human needs, the Environmental Reserve represents an opportunity to maintain the health of rivers and other ecosystems that provide water-related ecosystem goods and services (maintaining water flows, for example) for the benefit of society. Sustaining various ecological functions through the Reserve in turn guarantees and prolongs the sustainability of ecosystems. ; foster the greening of the Sahel by encouraging adaptation to drought; and support scientific assessments of both land degradation and water quality. There is a need for both systematic global and national assessments of land degradation and desertification focusing on slow variables to understand long-term trends in land degradation and the potential for recovery. Such studies could allow the planning of effective responses to long-term drought (UNEP, 2007). There is considerable knowledge and expertise among scientists in Africa to help plan and implement sustainable water strategies to address land degradation and pollution. Establishing centres of excellence staffed with African scientists networking with other water research and management experts would build Africa's capacity to monitor water quality, collect data and identify good water management approaches.

According to researchers at a meeting organized by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Niger (23-25 September 2006), the degradation of drylands in Africa can be reversed. Rehabilitation does not necessarily lead to full land recovery, but it may restore the land to 50-75 per cent of its former productivity, depending on soil and economic conditions. Through rehabilitation by tree planting, sustainable farming practices and groundwater replenishment, the land can become more productive again. Farmer-led rehabilitation initiatives in the Sahel in the past 30 years have started paying dividends.

2.8 CHALLENGE 8

Manage Africa's water under the impacts of global climate change.

2.8.1 The Situation

Global warming and its human cause are undeniable; warming patterns in Africa are consistent with global ones; Africa is already subject to important spatial and temporal rainfall variability and the situation is even more complicated in the case of precipitation, with notable spatial and temporal variability. Inter-annual rainfall variability is large over most of Africa and multi-decadal variability is also substantial in some regions. In West Africa (4°-20°N; 20°W-40°E), a decline in annual rainfall has been observed since the end of the 1960s, with a decrease of 20-40 per cent noted between the periods 1931-1960 and 1968-1990. Increased inter-annual variability, however, has been observed in the post-1970 period, with higher rainfall anomalies and more intense and widespread droughts reported; drought in Africa is common and some regions are becoming drier; Africa's repeated drought cycles kill thousands of people each event; and floods also occur regularly with severe impacts on peoples' livelihoods.

2.8.2 The Constraints

Africa is one of the most vulnerable continents to climate change and climate variability; the convergence of multiple stressors limits Africa's capability to address climate change impacts; increased rainfall variability contributes to Africa's economic limitations in adapting to climate change impacts; population growth in peri-urban areas will exacerbate flooding events; climate change will likely increase aridity, with important impacts on food

production; climate change will increase water stress in Africa; climate variability and change could result in low-lying lands being inundated; climate change impacts in productive aquatic ecosystems will be costly economically and in terms of food supplies; and it is likely that climate change will affect disease vectors.

2.8.3 The Opportunities

Reinforce traditional adaptation mechanisms; Although Africa as a whole, especially its governments, have a low capacity for adaptation, many African communities in arid and semi-arid areas have developed traditional adaptation strategies to face great inter-annual climate variability and extreme events. An unusually persistent drought may increase people's vulnerability in the short term, but it can encourage adaptation in the medium to long term. This is particularly true for the drought-prone area in the Sahel region, which is susceptible to frequent climatic hazards; provide early warning; It is as important for local communities to have early warning systems as it is to be supplied with relief, because at the onset of adverse environmental changes the critical decisions are made at the household level.

Better forecasting and early warning systems are a prerequisite for adaptation, particularly to predict and prevent the effects of floods, droughts and tropical cyclones as well as for indicating the planting dates to coincide with the beginning of the rainy season and predicting whether there will be disease outbreaks in areas that are prone to epidemics (UNFCCC, 2006). Improved early warning systems and their application will reduce vulnerability to future risks associated with climate variability and change (IPCC, 2007a).

Introduce adaptation measures informed by a more reliable system of seasonal predictions; Such measures include managing agriculture and water resources better, diversifying livelihoods and improving production efficiencies in arid lands and marginal areas by intensifying livestock densities, using natural fertilizers and practicing soil and water conservation, for example (UNFCCC, 2006; IPCC, 2007a). Improvement in present-day rain-fed agriculture can enhance resilience for future periods of drought stress through technological steps like water-harvesting systems, dam building, water conservation and agricultural practices, drip irrigation, and developing drought resistant and early-maturing crop varieties and alternative crop and hybrid varieties. Biotechnology research could also yield tremendous benefits if it leads to drought- and pest-resistant rice, drought-tolerant maize and insect-resistant millet, sorghum and cassava, among other crops; support public-private partnerships that develop innovative adaptation measures; and improve physical infrastructure; Improvements to physical infrastructure may improve adaptive capacity. Building improved communication and road networks for better exchange of knowledge and information, for example, gives people an opportunity to migrate more easily in case of extreme events due to climate change. On the other hand, general deterioration in infrastructure threatens the supply of water during droughts and floods.

2.9 CHALLENGE 9

Enhance Africa's capacity to address its water challenges. To address Africa's mounting challenge of economic water scarcity, it will need to strengthen and sustain financial, human and institutional capacities to effectively develop and utilize water resources.

2.9.1 The Situation

Africa faces a situation of economic water scarcity; and current institutional, financial and human capacities for managing water are lacking. There is a lack of sustainable financing mechanisms for water-related investments, including transboundary water resources development, water supply, sanitation, hydropower and irrigation, among others and under fi nuancing of the water and sanitation sector in many countries has led to deterioration and potential collapse of infrastructure.

2.9.2 The Constraints

Inadequate and unsustainable funding arrangements for water resources management; insufficient knowledge base; lack of an effective research and technology base; and weak institutional arrangements and legal frameworks for the ownership, allocation and management of water resources. In particular, there is a need to fill the following gaps:

- Low institutional and human capacity levels;
- Limited comprehensive studies on vulnerability analysis;
- Equally limited studies on possible adaptation measures and their cost-benefit analysis;
- Lack of quantification of the different components of Africa's water balance. While estimates are available in the literature for continental average annual rainfall and evapotranspiration, research data are lacking for other components such as surface runoff, infiltration, groundwater storage and groundwater discharge, among others;
- Groundwater quantity and quality monitoring is very irregular in most countries due to a lack of;
- expertise to collect and analyze the data for the continent's development;
- Wide gaps in ground and surface water information and knowledge in the water sector across Africa;
- Lack of earth observation systems and lack of in-country and regional capacity for analyzing;
- and interpreting observational data;
- Data on economically exploitable small-scale hydropower potential is limited or not available;
- for most African countries, and there are wide variations on how much hydropower potential;
- has been exploited overall;
- Lack of decision-support systems and tools that are relevant to Africa's local water resources;
- management needs;
- Lack of real-time data collection and transmission technology to facilitate sharing, such as through the Internet for meteorological and hydrological data;
- Lack of a coordinated, effective and financially sustainable continental system or database for;
- data collection, assessment and dissemination for national and transboundary water basins;
- and for supporting strategic development decisions on the continent;
- Lack of commitment in the mobilization and leveraging of financial resources by African countries also affects the above data issues directly or indirectly. A typical example is the;
- implementation of the 2003 Comprehensive Africa Agriculture Development Programme;
- (CAADP), the Africa-owned and Africa-led initiative to boost agricultural production on the continent through irrigation and water management, among other measures. In 2003, member countries made a commitment to spend ten per cent of their total national expenditures on agriculture, but by the year 2008, only a handful of countries had implemented what they promised.

2.9.3 The Opportunities

Reform water institutions; There is potential to enhance human resources and the capacity of water resource institutions, including the decentralization of water resource management activities to the most appropriate levels for stakeholders, as well as strengthening existing initiatives.; improve public-private partnerships; Governments have the opportunity to improve public-private partnership arrangements for the development of water infrastructure.

The financial model of Public-Private Partnerships (PPPs) involves a sharing of risk and responsibility between the state and private firms, while the state retains control of the assets. Although such partnerships were expected to improve services without the disadvantages of privatization (unemployment, higher prices and corruption), they have fallen short of expectations; costs are often greater for the consumer, the private sector may not always be more efficient and big government contracts are often abused. If governments improve the system for dealing with the private sector by being disciplined and using highly transparent procedures, there is the potential for gains in efficiency and effectiveness in water management. There is evidence that PPPs in Africa have been most successful when planning, communication and commitment are strong, and when governments have implemented effective monitoring, regulation and enforcement. Governments must also perform thorough feasibility studies to examine affordability, value for investment and risk transfer.; and improve the knowledge base through human capacity building; Opportunities to identify training needs for water resources assessment and management, and to train a cadre of water professionals need to be fostered and acted upon to improve the level of information about Africa's water resources, uses and needs.

Training should aim to ensure that staff is retained and that their knowledge and skills are frequently upgraded (UNECA, 2009.). Governments need to ensure that information and education programmes are an integral part of the development process, and to provide water specialists with the training and means to implement IWRM (INPIM, 1992). The proper policy frameworks for planning, developing and managing water resources that implement recent advancements in the science and technology of water management also need to be in place to take advantage of available knowledge and skills. This knowledge includes local and indigenous knowledge and wisdom about water resources.

3 CONCLUSION

Water in Africa is at the core of sustainable development being closely linked to the nine challenges as highlighted above. This synthesis paper indicates that all those water challenges are interlinked and they need to be addressed in a holistic manner through the process of Integrated Water Resources Management (IWRM), with the perspective of improving human well-being in Africa. This is a critical step if States want to find adequate responses to the mounting water challenges the African continent is facing with its growing populations while addressing the significant challenges that remain in order to achieve sustainable development on the continent. Although the constrains are many as highlighted in the text, there are however several opportunities for the African continent to overcome some of the most important challenges by tapping into the huge under-utilized water resources of the continent for the purpose of irrigation, industry, hydropower, tourism and other sectors for the economic development of Africa.

REFERENCES

Banerjee S., Diallo A., Foster V., Wodon Q. (2009). Trends in Household Coverage in Modern Infrastructure Services in Africa. World Bank Policy Research. World Bank. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1372957##. (Last accessed on May 2, 2010).

FAO. (1989b). Irrigation Water Management: Irrigation scheduling. Food and Agriculture Organization of the \United Nations.FAO Training manual number 4. Rome.

FAO. (1989a). Guidelines for designing and evaluating surface irrigation systems. Food and Agriculture Organization of the United Nations.FAO Irrigation and Drainage Paper 45. Rome.

FAO. (1989b). Irrigation Water Management: Irrigation scheduling. Food and Agriculture Organization of the United Nations.FAO Training manual number 4. Rome.

FAO. (2005). Special Event on Green Revolution in Africa. Background document. Committee on World Food Security 31st Session – 23-26 May 2005. Food and Agriculture Organization of the United Nations. http://www.fao.org/unfao/bodies/cfs/cfs31/cfs2005_events_en.htm. (Last accessed on April 25, 2010).

FAO. (2009). AQUASTAT database. Food and Agriculture Organization of the United Nations http://www.fao.org/nr/aquastat. (Last accessed on January 13, 2010). FAO. (2010). "Water and Food Security". Food and Agriculture Organization of the United Nations. http://www.fao.org/worldfoodsummit/english/fsheets/water.pdf (Last accessed on September 15, 2010).

IAASTD. (2009). "Summary for Decision Makers of the Sub-Saharan Africa (SSA) Report". International Assessment of Agricultural Knowledge, Science and Technology for Development. Island Press.

IPCC. (2007a). Summary for Policymakers: Contribution of Working Group II to the Fourth Assessment. Intergovernmental Panel on Climate Change.

IPCC. (2007b). Africa. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press,Cambridge UK, 433-467.

Kliot, N., Shmueli, D., Shamir, U. (2001). Institutions for management of transboundary water resources: their nature, characteristics and shortcomings. Water Policy 3: 229-255.

MDG Africa Steering Group. (2008). Achieving the Millennium Development Goals in Africa. Recommendations of the MDG Africa Steering Group. June 2008. http://www.mdgafrica.org/pdf/MDG%20Africa%20Steering%20Group%20 Recommendations%20-%20English%20-%20HighRes.pdf. (Last accessed May 9, 2010).

Roy, D., Barr, J., and Venema, H. (2010). Ecosystem Approaches in Transboundary Integrated Water Resources Management (IWRM): A Review of Transboundary River Basins. (Unpublished report). IISD, Winnipeg, Canada and UNEP, Nairobi.

Turton, A., Earle, A., Malzbender, D., Ashton, P. (2006). Hydroplitical Vulnerability and Resilience along Africa's International Waters. In Hydropolitical Vulnerability and Resilience along International Waters: Africa pp 19-67. United Nations Environmental Programme. http://www.awiru.up.ac.za/pdf/C_CH%202%20 UNEP%20Africa.pdf. (Last accessed on April 30, 2010).

Turton, A. (2003). The Hydropolitical dynamics of cooperation in Southern Africa: A strategic perspective on institutional development in international river basins. In Hydropolitical dynamics of cooperation in Southern Africa, pp. 83-103. http://www.anthonyturton.com/admin/my_documents/my_fi les/2BA_Chapter_4.pdf (Last accessed on April 30).

Turton A. (2008a). The Southern African Hydropolitical Complex. Management of Transboundary Rivers and Lakes pp. 21-79. Turton A. (2008b). A South African perspective on a possible benefi t-sharing approach for transboundary waters in the SADC Region. Water Alternatives (1) 180:200.

UNDP. (2006a). Human Development Report 2006. United Nations Development Programme. http://hdr.undp.org/en/ reports/global/hdr2006/ (Last accessed on May 2, 2010).

UNDP (2006b). "Human Development Report 2006 Presskit". United Nations Development Programme. http://hdr. undp.org/en/media/HDR_2006_Presskit_ EN.pdf, (Last accessed on May 2, 2010).

UNECA. (2006). "African Water Development Report. Economic Commission for Africa." United Nations http://www. uneca.org/awich/AWDR_2006.htm (Last accessed on 30 May 2010).

UNECA. (2006). African Water Development Report. United Nations Economic Commission for Africa. http://www.uneca.org/awich/AWDR_2006.htm (Last accessed on September 15, 2010).

UNECA. (2009). Economic Report on Africa 2009: Developing African Agriculture Through Regional Value Chains. United Nations Economic Commission for Africa, Addis Ababa, Ethiopia. http://www.uneca.org/era2009/ERA2009_ENG_Full.pdf. (Last accessed on May 25, 2010).

UNEP. (2002). Atlas of International Freshwater Agreements. United Nations Environment Programme.

UNEP. (2006). Hydropolitical Vulnerability and Resilience along International Waters: Africa. United Nations Environment Program.

UNEP (2006). Africa Environment Outlook 2. United Nations Environment Programme, Nairobi. UNEP. (2007). Chapter 3: Land. In Global Environment Outlook GEO4 Environment for development. United Nations Environment Programme, Nairobi.

UNEP. (2008). Africa: Atlas of our Changing Environment. United Nations Environment Programme. Division of Early Warning, Nairobi.

UNFCCC. (2006). Background paper on Impacts, Vulnerability and Adaptation to Climate Change in Africa for the African Workshop on Adaptation Implementation of Decision 1/CP.10 of the UNFCCC Convention, Accra, Ghana, 21 - 23 September. United Nations Framework Convention on Climate Change.

UNFPA. (2009). State of World Population 2009: Facing a changing world: women, population and climate. United Nations Population Fund. New York: UNFPA. Water footprint. (n.d.). “Water footprint and virtual water”. http://www.waterfootprint.org/?page=fi les/home. (Last accessed on April 20, 2010).

Van der Zaag P. and Carmo Vaz A. (2003). Sharing the Incomati waters: cooperation and competition in the balance. Water Policy 5:349-368.

World Bank. (2008). “New, high yield rice spells millions in savings for African countries”. http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/AFRICAEXT/0,,contentMDK:21844287~menuPK:258657~pagePK:2865106~piPK:2865128~ theSitePK:258644,00.html. (Last accessed on April 26, 2010).

World Bank. (2010). Africa's Infrastructure, A Time for Transformation: Overview. http://siteresources.worldbank.org/INTAFRICA/Resources/aicd_overview_english_no-embargo.pdf. (Last accessed on April 29, 2010).

WHO/UNICEF. (2010). Progress on Sanitation and Drinking Water- 2010 Update. WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation. http://whqlibdoc.who.int/publications/2010/9789241563956_eng_full_text.pdf (Last accessed on May 20, 2010).

SESSION 4

TRANSBOUNDARY WATERS AND CONFLICTS: MANAGING WATER FOR PEACE

TRANSBOUNDARY WATER ISSUES IN SOUTH AMERICA

Fernando Urquidi-Barrau[1]

[1] Bolivian Academy of Sciences

ABSTRACT

South America is a large continent with a great amount of water resources; most of them shared by several countries. The continent has 28% of the world's freshwater resources and receives 29% of the world's rainfall with an estimated annual average of 1,560 mm of rainfall. It is estimated that about 85% of the continental surface water is discharged to the Atlantic Ocean, through three large basins: a) the Orinoco Basin, b) the Amazon Basin and c) the Rio de la Plata Basin (La Plata Basin). These large basins transbound all the countries of the continent, except for Chile. The Andes Cordillera, located in the eastern part of the continent, plays a vital role in the water supply to the three basins and other smaller coastal river basins. South America has 69 of the 279 world's transboundary river basins.Also, a large amount of continental freshwater is in aquifers; many of them transboundary. According to the UNESCO/OAS International Shared Aquifer Resources Management (ISARM) – Americas Programme, there are 38 identified transboundary aquifers in South America. The Guarani Aquifer is the largest aquifer. It transbounds four countries: Brazil, Paraguay, Uruguay and Argentina. The second largest is the Solmoes Aquifer, that transbounds Bolivia, Brazil, Colombia, Ecuador and Peru. The third largest is the Yrenda–Toba–Tarijeño, that transbounds Bolivia, Paraguay and Argentina. In South America, the transboundary water issues are primarily due to governance. Institutions lack the capacity to overcome conflicting approaches regarding the use and allocation of water, within one basin or aquifer system. This is reflected in the lack of integration, the sectoral approaches and the institutional resistance, which all contribute to the existing fragmented management of freshwater sources. However, the water-related systems are interdependent and have to be managed in an integrated manner. In the near future, the greatest challenge for all the South American countries will be the selection of appropriate institutional organizational models for management and protection of transboundary waters, since all of them have transboundary water issues.

1 INTRODUCTION

South America is a large continent with great amount of water resources; most of them shared by several countries. The surface of South America is 17.9 million km², about 13.4% of the world's total surface. It has as much as 28% of the world's freshwater resources, but only 6% of the world's population. The continent receives 29% of the world's rainfall with an estimated average of 1,560 mm of annual rainfall, the highest compared to other regions. Nevertheless, 23% of the continent is covered by arid or semi-arid areas.

About 85% of the continental surface water is discharged to the Atlantic Ocean through three large transboundary basins, namely: a) the Orinoco Basin, b) the Amazon Basin and c) the Rio de la Plata Basin (La Plata Basin). They drain about 11,987,000 km² or 69.3% of the total surface area of South America and flow through all the countries of the continent, with the exception of the Republic of Chile. The remaining 15% of the continental surface water flows through much smaller basins, most draining from the western ranges of the Andes to the Pacific Ocean and from coastal ranges near and parallel to the Atlantic Ocean.

A great number of the South American rivers' courses are international frontiers between two or more countries. About 69 out of the currently known 279 world's transboundary river basins or watersheds are located in the South American continent.

Large quantities of freshwater in South America is found in aquifers; many of them transboundary. The world's largest aquifer is the Guarani Aquifer, and underlies large areas of Argentina, Brazil, Paraguay and Uruguay. There are 38 identified transboundary aquifers in South America.

To resolve current transboundary water issues in the continent is necessary to select an appropriate model of institutional organization to manage and protect transboundary surface and underground waters. Several international treaties, agreements and programmes have been signed to analyse and to harmonize the legal framework affecting the waters in South America. Emphasizing the importance of this decision, the major basins of the continent are described, and an already solved surface water case study and three unsolved aquifer case studies are analysed in this paper.

2 TRANSBOUNDARY SURFACE WATERS

Located in the eastern part of the continent, the Andes Cordillera —a 7,240 km long mountain system — is the highest tropical snow-covered mountains in the world and plays a vital role in the water supply to the largest continental basins and the smaller Pacific coastal river basins. These water supplies are threatened by glacial melt due to global warming.

South America has 69 out of the currently known of the 279 world's transboundary river basins or watersheds. It is important to emphasize that a large number of the South American rivers' courses are international frontiers, which makes them an important issue for the maintenance of good relations amongst neighbouring nations. In the near future, a great challenge for all the South American countries is the selection of appropriate models of institutional organizations to manage and protect transboundary waters.

Several international treaties and agencies, including the UNESCO, the Organization of the American States (OAS), the International Hydrological Programme (IHP), and the Inter American Network of Academies of Sciences (IANAS), support agreements and programs to analyse and to harmonize the legal framework affecting these waters. The National University of El Litoral, Argentina and its Geohydrological Research Group have prepared the following map and revised list of the transboundary basins (Table 1). A list of the international water treaties, agreements and programmes are included in the annex of this paper.

Table 1 - transboundary water basins in South America

BASIN	TOTAL AREA (km^2)	COUNTRIES	SURFACE IN THE BASIN (km^2)	SURFACE IN THE BASIN (%)
Amaruco	5,600	Venezuela Guiana	4,900 700	86.89 13.11
Amazon	6,916,000	Brazil Perú Bolivia Colombia Ecuador Venezuela Guiana Suriname French Guiana	5,014,100 762,143 600,308 336,809 130,020 51,178 17,120 1,382 30	72.50 11.02 8.68 4.87 1.88 0.74 0.25 0.02 0.00
Comau	980	Chile Argentina	900 80	91.36 8.64
Corantijn/Courantyne	41,800	Guiana Suriname Brazil	21,700 19,900 80	52.06 47.75 0.19
Cullen	600	Chile Argentina	500 100	83.00 17.00
Chira-Catamayo	15,700	Perú Ecuador	9,800 5,800	62.23 37.23
Jurado	700	Colombia Panamá	500 200	71.42 28.58
Lago Fagnano	3,200	Argentina Chile	2,700 500	85.17 14.83
Laguna Mirim	55,000	Uruguay Brazil	31,200 23,800	56.69 43.24
Oiapoque	23,300	French Guiana Brazil	13,700 9,500	58.92 41.00

BASIN	TOTAL AREA (km²)	COUNTRIES	SURFACE IN THE BASIN (km²)	SURFACE IN THE BASIN (%)
Orinoco	927,400	Venezuela Colombia Brazil	604,500 321,700 800	65.18 34.68 0.08
Palena	13,300	Chile Argentina	7,300 6,000	54.87 45.13
Pascua	13,700	Chile Argentina	7,300 6,400	53.51 46.46
Patia	21,300	Colombia Ecuador	20,800 500	97.61 2.38
Puelo	8,400	Argentina Chile	5,500 2,900	66.03 33.97
Rio de la Plata	3,100,000 (4,144,000)	Brazil Argentina Paraguay Bolivia Uruguay	1,395,000 930,000 403,000 217,000 155,000	45,00 30,00 13,00 7.00 5.00
Titicaca – Poopo	111,800	Bolivia Perú Chile	63,000 48,000 800	56.32 42.94 0.70
Yelcho	11,100	Argentina Chile	6,900 4,200	62.14 37.86
Zapaleri	2,600	Chile Argentina Bolivia	1,600 500 500	59.60 19.65 19.65
Zarumilla	4,300	Ecuador Perú	3,400 900	78.71 21.29

2.1 ORINOCO RIVER BASIN

The Orinoco is one of the longest rivers in South America (2,140 km). Its drainage basin, sometimes called the *Orinoquia*, covers 927,000 km²; 65.2% in Venezuela and the remainder in Colombia. Additionally, a small area of about 800 km² was mentioned to be draining from the Brazilian side.

The average water discharge of the Orinoco River to its delta is about 36,000m³/sec, making the Orinoco River the third largest river in the world to discharge into an ocean. The river discharge variation is large; daily water flow averages have been measured from 1,050m³/sec to 8,200m³/sec at the Musinacio hydrographical measuring station, located near the outflow point of the Orinoco River. The variation in river water level is also large. Large areas in the Orinoco Basin are flooded during wet periods.

Figure 1 - map of the Orinoco River Basin
Source: Wikipedia (2005)

Most of the large tributaries of the Orinoco, such as the Apure, Meta and Guaviare Rivers, have their origin in the Andes Cordillera and join the Orinoco from the western side. The southern and the south western tributaries mainly flow from Colombia. Other large tributaries, such as the Caura River and the Caroni River have their origins on the Guiana Highlands and join the Orinoco from the eastern side. A peculiarity of the Orinoco River is that it divides its water into two streams in the south of the basin near its origin. One of the streams continues as the Orinoco River and the second stream, known as the Casiquiare Channel, discharges into the Amazon Basin.

The Orinoco Basin has a tropical climate. Two annual seasons can be distinguished through marked rainfall differences rather than temperature changes. The average daily temperatures in the Llanos (Venezuelan and Colombian Plains) do not vary greatly from its annual mean of 27 to 30°C. The rainy season extends from about April to November. The dry season is from December through March. Annual precipitation ranges from about 1 meter in the north to about 4 meters in the southern part of the basin.

Although the Orinoco River Basin is a transboundary basin, it does not have any signed international treaties between Colombia and Venezuela. Thankfully, there are not any registered water issues between these two countries.

2.2 AMAZON RIVER BASIN

The Amazon Basin covers a large portion of South America. The Amazon River and its tributaries drain an area of about 6,915,000 km^2, roughly 40% of the continent. This transboundary basin is located throughout nine countries: Bolivia, Brazil, Colombia, Ecuador, Guiana, Peru, Venezuela, Suriname and French Guiana (see Figure 3).

The Amazon Basin is bounded by the Guiana Highlands to the north and the Brazilian Highlands to the south. The Amazon River, which starts in the snowed capped eastern slopes of the Andes Cordillera at the west of the basin, is the second longest river in the world. It runs from the Peruvian Highlands for about 6,400 km before draining into the Atlantic Ocean. The Amazon River and its tributaries form the largest volume of surface watershed in the world. The total 209,000 m^3/seg (12 billion litres per minute) of water is discharged to the Atlantic Ocean; about 20% of the total water carried to the oceans by all rivers of the world and exceeds the combined discharge of the world's nine next largest rivers.

Politically, the basin is divided into the Bolivian Amazon Basin in the south, the Brazilian Amazônia Legal, the Peruvian Amazon, the Amazon Region of Colombia and parts of Ecuador and the Venezuelan State of Amazonas.

From a hydrological standpoint, the Amazon River system is divided into 10 sub-basins. The largest in area are the Solimoes, Negro, Xingú, Madeira, Tapajós, and Juruá sub-basins. In discharge terms, an estimated 65% of the basin's total flow into the Atlantic Ocean comes from the Solimoes and Madeira river sub-basins, which originate in the Andes and comprise about 60% of the basin's land area.

The population living in the Amazon River Basin is estimated to be approximately 10 million; mostly concentrated in urban areas along the river and its main tributaries. A high percentage of the total population consists of indigenous communities settled mainly along the banks of the river and belonging to ethno–linguistic groups.

Most of the basin is covered by tropical rainforest, which represent more than 56% of all broad leaf forests in the world. The Amazon rain forest is the largest in the world; it covers about 8,235,430 km^2 of dense tropical forest. Its ecosystems are characterized by great biodiversity; more than 30,000 plant species, nearly 2,000 fish species, 60 reptile species, 35 mammal families, and approximately 1,800 bird species.

The Amazon River Basin is also an important source of natural resources. It contains the world's largest known reserves of bauxite (nearly 15% of the world`s total) and industries within the basin are the world`s largest suppliers of iron and steel. Wood and wood by-products, gold, rare minerals and tin are other products are found in the Amazon River Basin and that have increasing demand for exportation.

Figure 2 - map of the Amazon River Basin

The slopes of the Andes Cordillera, due to the high rainfall, are subject to severe erosion; more than 1,000 tons/km²/year of its sediments flow toward the Atlantic Ocean. Measurements in the upper Madeira River Sub-Basin indicate that, of the 3,200 tons/km²/year of sediment produced, up to 60% reaches no farther than the Andean ranges. At this point, the sharply reduced longitudinal gradients lower the stream's carrying capacity which results in internal sediment deposition within the basin. Overall, the Amazon River transports an average of 600 to 800 million tons of sediment annually; the majority of the sediment comes from the Solimoes (62%) and Madeira (35%) river sub-basins originated in the Andes.

This Basin is governed with four international treaties and agreements. The most important one is the Treaty for Amazonian Cooperation signed in July 1978 by eight of the nine countries that comprise the Amazon Basin. Currently, there is a pending transboundary issue regarding the Madeira River energy, navigation, and soybean frontier expansion project. Because Brazil's large energy needs due its 180 million inhabitants, it has started the construction of the Jiraú and Santo Antônio dams to produce 7.58 GW of electricity in the Abuná-Porto Velho stretch of the Madeira River, State of Rondônia. It faces a strong opposition from international environmental groups and is highly questioned by the Bolivian Government.

2.3 RIO DE LA PLATA BASIN

The La Plata River Basin is considered to be one of the most important river basins of the world. It discharges between 23,000 to 28,000 m^3/sec of water, approximately one-fifth of the South American continent surface water flow. It is the second largest drainage basin in South America, about 3,100,000 km^2 (some publications mention 4,144,000 km^2). The basin covers about one fifth of the continent's surface. It drains waters from central portions of the continent to the south-western Atlantic Ocean.

Figure 3 - map of the Rio de la Plata Basin

The La Plata Basin comprises almost all the southern part of Brazil, the eastern part of Bolivia, a large part of Uruguay, the whole of Paraguay, and an extensive part of northern Argentina. In total, it accounts for 17% of the surface area of the South American continent (see Figure No. 4). This basin is comprised of three large sub-basins systems: the Paraná River, the Paraguay River, and the Uruguay River. Each of these waterways has unique characteristics that reflect its water sources as well as the human influences that define their flow patterns and environmental status. Additionally, water infiltrates into the groundwater system. The basin provides recharge for the Guarani Aquifer, one of the largest continental groundwater reservoirs in the world.

Table 2 - characteristics of the major rivers of the Rio de la Plata Basin

RIVERS	BASIN AREA (km^2)	LENGTH (km)	MEAN FLOW (m^3/sec)
Parana	1,600,000	2,570	17,140
Uruguay	440,000	1,850	4,300
Iguazú	61,000	1,320	1,540
Paraguay	1,095,000	2,415	3,810
Bermejo	120,000	1,780	550
Pilcomayo	272,000	1,125	195
De la Plata	3,100,000	270	23,000 – 28,000

Within this basin there are thirty-one large dams and fifty-seven large cities, with populations in excess of 100,000 persons, including the capital cities of Argentina, Brazil, Paraguay, and Uruguay. The total human population of the basin is estimated to be approximately 67 million.

The rivers of the La Plata River Basin are subject to pressures that have modified, and can further modify the quantity and quality of their waters. Fundamentally, these pressures are: i) extraordinary variations in the hydrological regime partly linked to climate variations and changes; and, ii) factors associated with land use changes, population growth, urbanization, agricultural, industrial, mining and oil, and infrastructure development.

The consequences of these pressures are not restricted to specific countries and have a transboundary character. These pressures will increase in the future, as the basin countries continue to enlarge their agricultural and industrial development bases and the provision of services to improve the living standards of their growing populations.

The Rio de la Plata Basin is politically governed by 18 treaties, agreements and protocols signed in the XX Century. Most of them are bilateral agreements and only two are trilateral. There is no treaty signed by the five countries, which comprise the whole Basin, in order to develop, protect and use the water flow and ecosystems. Argentina is the country most interested in promoting treaties and agreements because the discharging estuary of the Rio de la Plata is in front of its capital Buenos Aires. Buenos Aires uses the water from the estuary to supply its urban and industrial water needs.

3 CASE STUDY - TRANSBOUNDARY LAKE TITICACA – POPOO BASIN

At 14 degrees south, the Andes Cordillera divides in two ridges: the Eastern and Western Cordilleras. Between them, a closed endorheic hydrological system of approximately 140,000 km^2 is located between 3,600 and 4,500 metres above sea level (m.a.s.l.). This system, known as the Lake Titicaca – Poopo Basin, has four major sub-basins: Lake Titicaca (T), Desaguadero River (D), Lake Poopo (P) and Coipasa Salt Lake (S) (see Figure 5). Lake Titicaca is the largest lake in South America and is the highest navigable lake in the world. The Desaguadero River is Lake Titicaca's only outlet and drains into Lake Poopo; its overflow gives rise to Coipasa Salt Lake. The system is a transbound endorheic basin, which includes the underground waters.

Source: Prepared for the World Water Assessment Programme (WWAP) by AFDEC, 2002.

Figure 4 - map of the Lake Titicaca – Poopo Basin

This endorheic system is located in the southern part of Peru and the north-west of Bolivia. Situated to the north, the water source that feeds the lake belongs mostly to Peru. Of the five major rivers flowing into the lake, four run through Peruvian territory –Ramis, Huancane, Coata and Illpa Rivers. Inside Bolivian territory, the southern part of the system, is drier and ends in the Coipasa Salt Lake, which is formed by the evaporation of overflow from Lake Poopo. The characteristics of the TDP System are given below in Table 3.

Table 3 - characteristics of the TDPS System

(continue)

Basin	Area (km²)
Lake Titicaca	56.300
Desaguadero River	29.800
Lake Poopó	24.800
Coipasa Salt Lake	33.000
TDPS System	143.900
Lake Titicaca	
Average area	8.400 km^2
Average altitude	3.800 m.a.s.l.
Average volume	930 km^3
Maximum length	176 km
Maximum width	70 km
Maximum depth	283 m
Desaguadero River	
Length	398 km
Average flow	70 m^3/s
Average gradient	45 cm/km

(continuation)

Lake Poopó	
Average area	3.191 km²
Average altitude	3.686 m.a.s.l.
Colpasa Salt Lake	
Average area	2.225 km²
Average altitude	3657 m.a.s.l.

Four geographical units can be distinguished in the TDPS System: i) The mountain ridge, with altitudes greater than 4,200 m.a.s.l.; ii) Slopes and intermediate areas, ranging in altitude between 4,000 and 4,200 m.a.s.l. with moderate to steep slopes and a dense hydrographic network.; iii) The high plateau (Altiplano Boliviano), from 3,657 to 4,000 m.a.s.l., in which Lake Titicaca is located; iv) The surrounding area, the most densely populated of the system, varies in height from 3,812 to 3,900 m.a.s.l.

Between Titicaca and Poopo Lakes, there is a ridge rising to 1,000 metres above the level of the plateau. It splits from west to east by the Desaguadero River. Along the far western edge is a narrow strip of desert that runs along the Pacific coast, and to the east are the Amazon plains that extend to the Atlantic Ocean.

The climate within the TDPS System is characteristic to a high mountain region with a tropical hydrological regime of great interannual irregularity. The Lake Titicaca exercises a moderating influence on temperatures and rainfall in the surrounding area. Precipitation varies between 200 and 1,400 millimetres (mm), with maximum value of 800 to 1,400 mm at the centre of the lake.

The system shows zones of diminishing humidity from north to south; goes from humid around Lake Titicaca, to semi-arid in Lake Poopo, to arid in the Coipasa Salt Flat. There are great seasonal variations. It usually has wet summers, dry winters, a rainy period from December through March and a dry period from May through August. Its air temperature varies within the system, depending on latitude, longitude, altitude and proximity to the lake, with minimums of -10 to -7°C and maximums of 19 to 23°C.

Humidity is low throughout the system; it averages 54% and varies depending on latitude and season. This area also receives strong solar radiation with an annual yield of 533 calories per cm² per day; this high radiation explains the intense evaporation that occurs in Lake Titicaca.

3.1 ADMINISTRATIVE AND OPERATIVE CHALLENGES

The surface of Lake Titicaca is evenly distributed between Bolivia and Peru. These countries exercise an “exclusive and indivisible joint ownership” over its waters. Their joint ownership model does not only apply to the water of Lake Titicaca, but also to the entire watershed to ensure an integrated management of the water system of the basin.

Figure 6 shows the three institutions that manage and operate the TDPS System with clearly defined roles: a) the Ministry of Sustainable Development and Planning (Bolivia), b) the Peruvian Development Institute (Peru), and c) the Binational Autonomous Authority of Lake Titicaca (ALT).

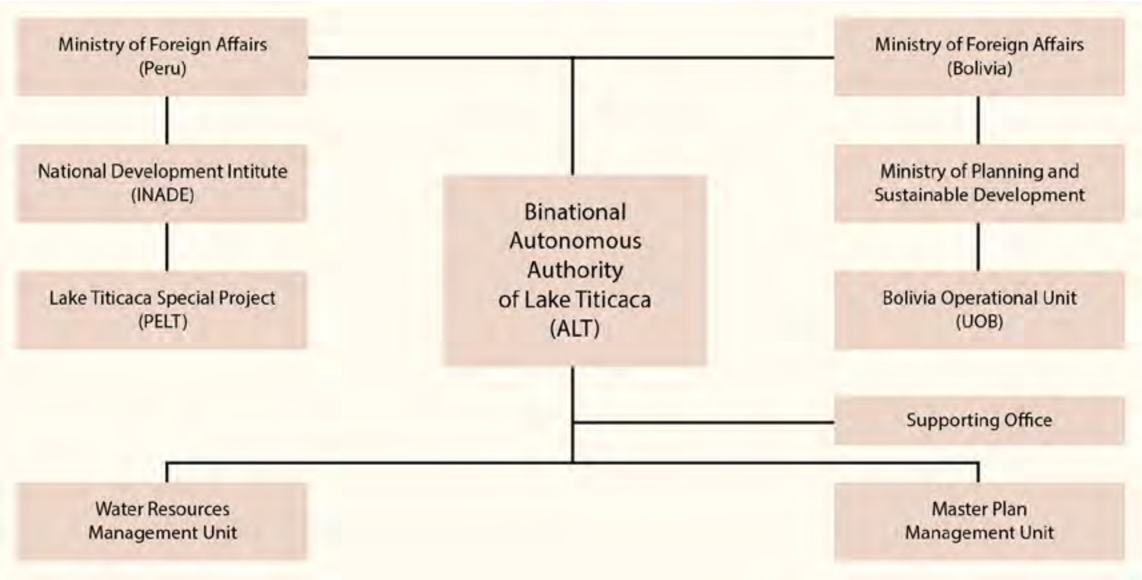


Figure 5 - ALT administrative and operative structure

Created on June 1996, the Binational Autonomous Authority of Lake Titicaca (ALT) is an entity of public international law with an Exchange of Diplomatic Notes between Bolivia and Perú. The ALT is an example that could be adapted to other boundary water basins.

The ALT, with its two national operative units, has the general function of promoting and conducting programmes and projects. It has to decide, implement and enforce the regulations on management, control and protection of the system's water resources within the framework of the adopted Master Plan. The Master Plan consists of two national projects established for Bolivia and Peru and both technically depend on ALT.

A unique feature of this system is the presence of indigenous, pre-Hispanic communities that follow their ancient cultural traditions and resist assimilation into Western-style societies. These people are extremely poor and only about 20% have access to water and sanitation. A large number of ALT programmes are directed to this population.

4 TRANSBOUNDARY AQUIFERS

According to the Glossary of Geology of the American Geological Institute (1977), an aquifer is a body of rock that contains sufficient saturated permeable material to conduct ground water to wells and springs. The size of the aquifers varies as well as the volume of water discharged. Ground water is a "hidden", very important and essential resource for many countries of the South American continent.

In recent decades groundwater has become a source of wealth and well-being for a growing society that shows an increasing need for water. However, in many cases, the current water usage is unsustainable; the amount of water discharged is greater than its recharging volume. This over usage is forcing the increase on drilling depths; reaching unsustainable limits in costs, water table depletion, or encountering, at deeper depths, inappropriate fresh water of poor quality.

A large quantity of freshwater in South America is found in aquifers; many of them transboundary. According to the UNESCO/OAS International Shared Aquifer Resources Management (ISARM) Americas Programme, there are 38 identified transboundary aquifers in South America (see Figure 5 and Table 4).

The largest aquifer in South America is the Guarani Aquifer, which transbound Brazil, Paraguay, Uruguay and Argentina. The second largest, with small amount of information on it, is the Solmoes Aquifer that transbound Bolivia, Brazil, Colombia, Ecuador and Peru. The third in size is the aquifer Yrenda –Toba –Tarijeño that transbound Bolivia, Paraguay and Argentina.

On a regional scale, the information on all the continent's transboundary aquifers is almost non-existent, very weak and often not up-dated. The global visualization of this problem is little known even in their own countries.

Many solutions to water deficit problems lie in better governance, with sharing water as one of the key challenges. In response, the International Hydrological Programme (IHP) Intergovernmental Council launched in 2000 the ISARM project to compile a world inventory of transboundary aquifers and to develop wise practices and guidance tools concerning shared groundwater resources management.

Figure 6 - map of transboundary aquifers in South America
Source: UNESCO/OAS ISARM Americas Programme

In 2002, the UN International Law Commission (ILC) embarked on the codification of the Law of Transboundary Aquifers to provide a legal regime for the proper management of aquifers considering their importance as freshwater resources.

Table 4 - list of the UNESCO/OAS Americas Programme Transboundary Aquifers

(continue)

Nr. IN MAP	TRANSBOUNDARY AQUIFER	COUNTRIES	Nr.
1	Guarani	Brazil, Paraguay, Uruguay, Argentina	4
2	Yrenda-Toba-Tarijeno	Bolivia, Paraguay, Argentina	3
3	Salto Chico – Salto Chico	Argentina, Uruguay	2
4	Litoreano-Chuy	Brazil, Uruguay	2
5	Puerto Yerua-Las Mercedes	Argentina, Uruguay	2
6	Probable	Argentina, Chile	2
7	El Condor	Argentina, Chile	2
8	Calua	Brazil, Uruguay, Argentina	3
9	Serra Gerai-Serra Gerai Arapei	Brazil, Paraguay, Uruguay, Argentina	4
10	Ignimbritas Cordillera Occidental	Bolivia, Chile, Perú	3
11	Solmoes	Bolivia, Brazil, Colombia, Ecuador, Perú	5
12	Jaci Parani y Pareci	Bolivia, Brazil	2
13	Pantanal	Bolivia, Brazil, Paraguay	3
14	Permianos	Brazil, Uruguay	2
15	Ica	Brazil, Colombia	2
16	Sedimentos Paleo-Proterozoico	Brazil, Guyana, Venezuela	3
17	Serra do Tucano	Brazil, Guyana	2
18	Boa Vista	Brazil, Guyana	2
19	Sem Denominacao	Brazil, Guyana	2
20	Costeiro	Brazil, Guyana	2
21	Fumas e Alto Gracas	Brazil, Paraguay	2
22	Zarumila – Machala	Ecuador, Peru	2

(continuation)

Nr. IN MAP	TRANSBOUNDARY AQUIFER	COUNTRIES	Nr.
23	Concorda – Capilna	Chile, Peru	2
24	Silala	Bolivia, Chile	2
25	Puna	Argentina, Chile	2
26	Tulcan	Colombia, Ecuador	2
27	Aquidauana – Aquidaban	Brazil, Paraguay	2
28	Agua Dulce Palmar de las Islas	Bolivia, Paraguay	2
29	Titicaca	Bolivia, Peru	2
30	Arauca	Colombia, Venezuela	2
31	Guajra	Colombia, Venezuela	2
32	San Antonio Urena Santander	Colombia, Venezuela	2
33	Sedimentos Grupo Roraima	Brazil, Venezuela	2
34	Sanderj; Coesewjne; A-Sand	Guyana, Surinam	2
35	Jurado – Coto	Colombia, Panama	2
63	Rio Negro – Itapucumi	Bolivia, Paraguay	2
64	Tumbes – Puyango	Ecuador, Peru	2
65	Chira – Catamayo	Ecuador, Peru	2
	Laguna Blanca – Maure	Peru, Bolivia, Chile	3
	Ollague – Chiguana	Bolivia, Chile	2

Source: UNESCO/OAS Americas Programme Transboundary Aquifers

5 CASE STUDIES OF TRANSBOUNDARY AQUIFERS

5.1 THE GUARANI AQUIFER SYSTEM (GAS)

The Guarani Aquifer System (GAS) constitutes one of the largest reservoirs of groundwater in the world. The water is found in the pores and fissures of sandstones, formed during the Mesozoic. They are covered by thick layers of basalts that confined them. Its current water storage is approximately 37.000 km^3 and a natural recharge of 166 km^3 per year. The water in the sandstones can be found at depths between 50 m to 1500 m, with temperatures that vary between 33°C and 65°C. This broad thermal range also offers possibilities for diverse geothermic applications.

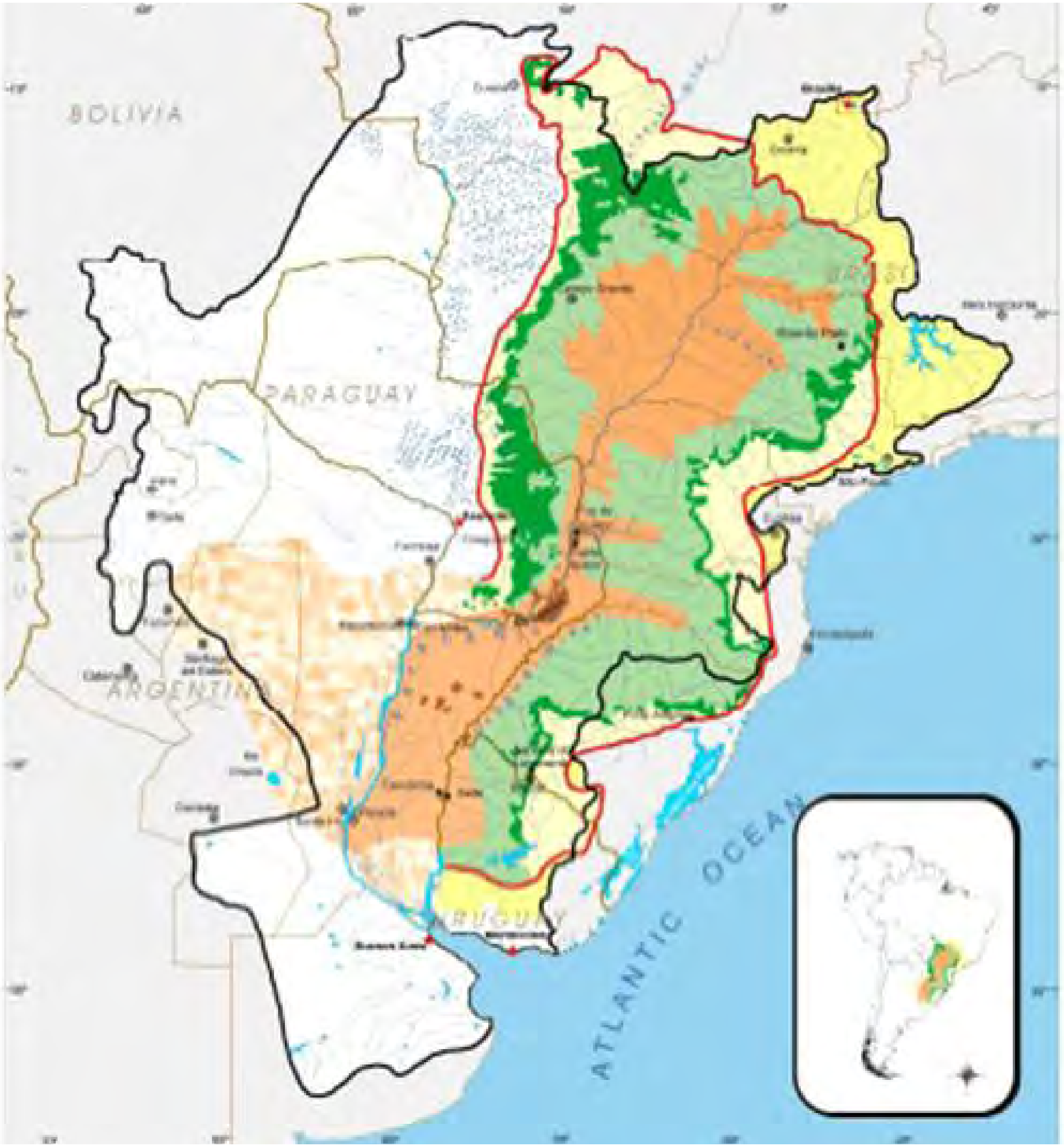


Figure 7 - Schematic map of the Guarani Aquifer system

The GAS is located in the eastern and mid-southern part of South America and underlies large areas of Argentina, Brazil, Paraguay and Uruguay. It is estimated that the total surface of the GAS is 1,190,000 km^2 with 850,000 km^2 in Brazil, 225,000 km^2 in Argentina, 70,000 km^2 in Paraguay and 45,000 km^2 in Uruguay.

Approximately 24 million people live in the area delimited by the boundaries of the aquifer and a total of 70 million people live in areas that are directly or indirectly influenced by it. The main use of the aquifer is for drinking water supply, but there are also industrial, agricultural irrigation and thermal tourism uses.

GAS is considered a very interesting study case by the Office for Sustainable Development and Environment of the Organization of American States (through the General Secretariat of the Guarani Aquifer Project). In 2003, the Environmental Protection and Sustainable Development of the Guarani Aquifer System Project was developed to support Argentina, Brazil, Paraguay and Uruguay in elaboration and implementation of a shared institutional, legal and technical framework to preserve and manage GAS for the current and future generations. The General Secretariat of the Project was to execute the project components between 2003 and 2007 in closed coordination with the four National Executing Agencies. The development of the Project was made possible thanks to the harmonious cooperation among Argentina, Brazil, Paraguay and Uruguay, the countries in which GAS is located, and with the cooperation of the Global Environment Facility (GEF), the World Bank (WB), the Organization of the American States (OAS), the Netherlands and German Governments and the International Atomic Energy Agency.

The long term objective of this Project is the sustainable management and use of GAS in the four countries, through an adequate and functional management framework, based on appropriate technical, scientific, institutional, legal, economical and environmental guidance. The main objectives of the Project were determined to be:

- To enhance and enlarge a technical knowledge of the Guarani Aquifer System;
- To implement a permanent Well Monitoring Network and an Information System for the whole GAS;
- To elaborate the Strategic Action Plan (SAP) and the Transboundary Diagnostic Analysis (TDA);

Te Project was organized in seven interrelated “components”, designed to aid in a better understanding of the morphology and behaviour of GAS regarding its use, conservation, and relationship with communities and institutions. This knowledge will create information about the development of systems and tools for coordinated management of the waters in GAS. The specific components of the GAS project were:

COMPONENT 1 - Expansion and consolidation of the current scientific and technical knowledge base of the Guarani Aquifer System;

COMPONENT 2 - Joint development and implementation of the Guarani Aquifer System Management Framework, based on an agreed Strategic Action Plan;

COMPONENT 3 - Promotion of public participation, social communication and environmental education;

COMPONENT 4 - Project Monitoring and evaluation, and dissemination of Results;

COMPONENT 5 - Development of groundwater management measures and mitigation measures within identified critical areas ("Hot Spots");

COMPONENT 6 - Assessment of geothermal energy potential use, "clean energy", from the GAS Projects;

COMPONENT 7 - Project Coordination and Management.

On August 2010, Argentina, Brazil, Paraguay and Uruguay signed a new agreement for the management of this complex system. The four countries are now involved in the ratification process and in the negotiations of institutional aspects, including an Annex to the Agreement on arbitration procedures.

5.2 THE SILALA AQUIFER SYSTEM

The Silala Aquifer System is shared by Bolivia (upstream) and Chile (downstream) and lies south of the Uyuni Salt Flat, approximately 280 km southwest of the town of Uyuni, Bolivia. The Silala waters begin at a high altitude --over 4,500 m.a.s.l.-- wetlands (called "*bofedales*") formed by groundwater springs that discharge in Sud Lípez Province, Potosí, Bolivia and in El Loa Province, Region II of Antofagasta, Chile. It is located right on the Bolivian/Chilean border (21°58' and 22°05' southern latitude and 67°55'and 68°05' western longitude).

More than 70 small-volume groundwater springs have been identified in Bolivian territory, and 23 springs in Chilean territory. All discharge flows from fractured ignimbrites (volcanic ash deposits) of Miocene age overlain by relatively impermeable andesitic lavas of Pliocene and Pleistocene age. Recent Carbon 14 age determination state that the groundwater was principally recharged by glacial melt water, 10,000 years ago. The Silala Aquifer System is considered a transboundary aquifer, but little is known about the underground flow component. The Silala does not have any drilled water well.

Most of the springs are drained by a series of small, man-made channels which direct the flow towards two central drainage channels. The North and South Channels join to form a Main Channel (Fig. 6). Each channel is clearly man-made because is lined with rocks and is very straight in certain stretches. The South Channel is nearly 3 km long and contributes about two thirds of the flow to the Main Channel. The North Channel is less than 1 km long and contributes the remaining third of the flow. The Main Channel directs the water for about 700 m before it crosses the international border into the Antofagasta II Region, Chile. In Chilean territory, the Main Channel flows over 7 km to confluence with the Cajon River, forming the San Pedro de Inacaliri River, a tributary of the Loa River. The Loa Basin is the largest in Chile and the only exoreic (allowing outflow) basin in the Antofagasta Region.

Mean discharge (of Bolivia) on the Main Channel near the border crossing is about 0.2 m^3/sec. The mean discharge in the Chilean side is 0.3 m^3/sec. The total discharge of the Silala Aquifer System is 0.5 m^3/sec. This flow rate is very significant considering that the Silala System Basin is situated in the Atacama Desert, the driest place on Earth. The mean annual precipitation and potential evaporation in the Basin average are 59 mm and 914 mm.

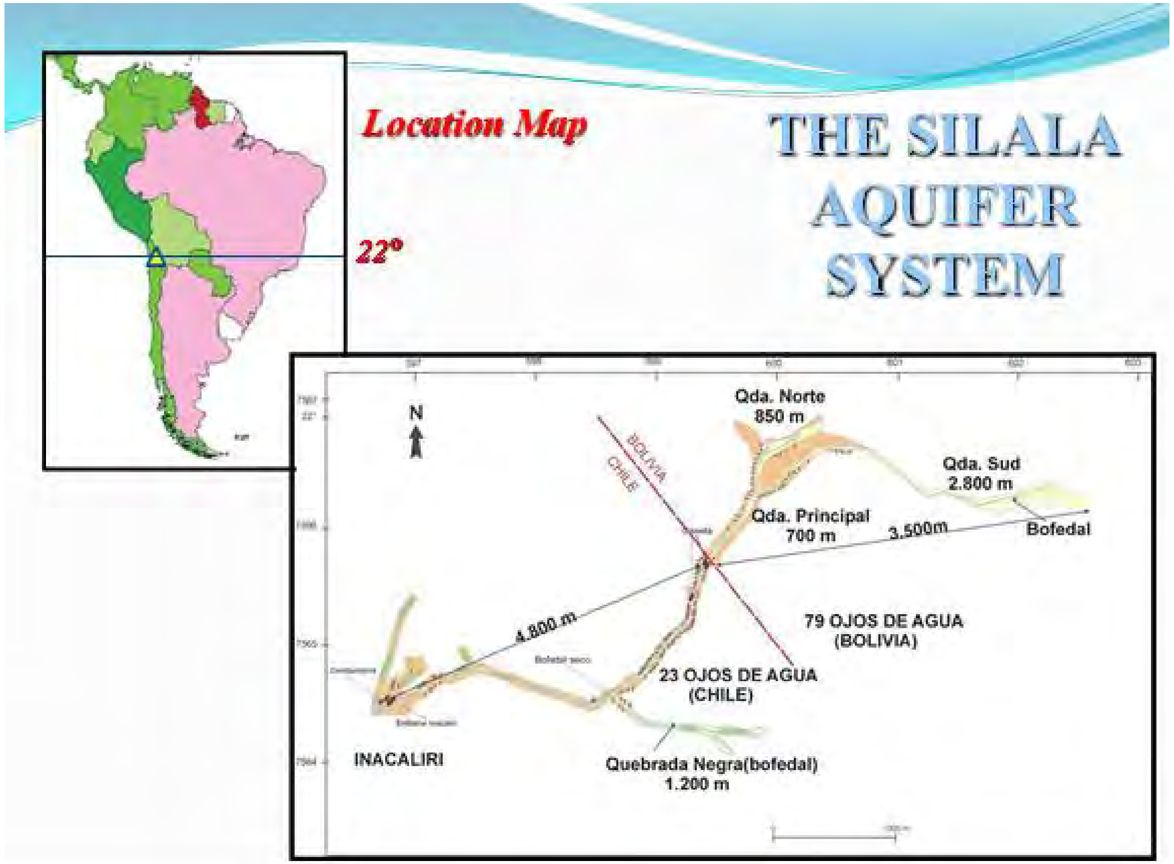


Figure 8 - location of the Silala aquifer system

Evidence of geological and soil studies, performed by the Bolivian Geological Survey (SERGEOTECMIN, 2002), suggests that the water of the Silala Springs never flowed overland naturally from Bolivia to Chile, prior to its channelization. A significant feature of the Main Channel, although clearly follows a natural drainage course, is of a natural fluvial-glacial erosion, which includes a relatively deep (tens of metres) canyon incised in the desert floor that has no signs or features of alluvial deposition.

The channels were constructed by the Antofagasta (Chili) & Bolivia Railway Co. Ltd. (FCAB, following the Spanish acronym), under a concession granted in 1908 by the Prefecture of Potosí, Bolivia, to power their steam run locomotives.

The channels were constructed to alter the natural course of the waters and to make more efficient the flow. In the mid-1950's, the railway company changed their steam engines for diesel engines, but continued its water concession. Since then, it has been delivering and selling the water to consumers of the cities of Calama and Antofagasta.

SERGEOTECMIN also studied the 25 degrees incline Quebrada Negra in Chilean territory, which is an undisturbed wetland (*bofedal*) with outcropping water from the Silala Aquifer. The Quebrada has no built channels and the water stays in the wetland and there is no natural flow surface of water registered at the bottom of the Quebrada. Evidently, this proves that the outcrop water from the aquifer flows only with the help of manmade channels.

Figure 9 - main channel of the Silala Water Outflow

The only Bolivian user of the Silala Aquifer waters is a small unit of soldiers stationed at the Silala advanced military post, constructed four years ago. The Silala Aquifer System is strategically important to Chile because it is a significant source of water for CODELCO's Chuquicamata and potable water of the nearby populations including the cities of Calama and Antofagasta. Chuquicamata is the largest open pit mine in the world and CODELCO is the world's largest copper producing company and generates about a third of the Chilean government's income.

The dispute over the Silala basin illustrates the importance of history and the effects of different national socio-economic philosophies have in the water resource management and on international negotiations concerning transboundary watercourses, regardless of their size. The Silala is about one million times smaller the Amazon (in terms of mean discharge) and far less known, yet is has been labelled the only "high risk" Basin in South America, because of the lack of official diplomatic relations between Bolivia and Chile and the fundamental disagreement as to whether or not the Silala is an international watercourse. Nevertheless, the two countries have made important strides towards an agreement concerning the use of the Basin.

The Silala case provides an example of the overlap between surface and groundwater regimes and the range of interpretations states can uphold regarding this complex interaction. The next step in this case will be to test the applicability of, and attempt to reconcile, the 1997 Watercourses Convention and the Draft *articles on the Law of Transboundary Aquifers* in the context of the Silala Basin.

5.3 THE YRENDA – TOBA – TARIJEÑO AQUIFER SYSTEM

The Yrenda – Toba – Tarijeño Aquifer is a regional hydrogeological system that is located in Paraguay, Argentina, and Bolivia. It is a semi confined to confined aquifer of unconsolidated formations of quaternary and tertiary sediments

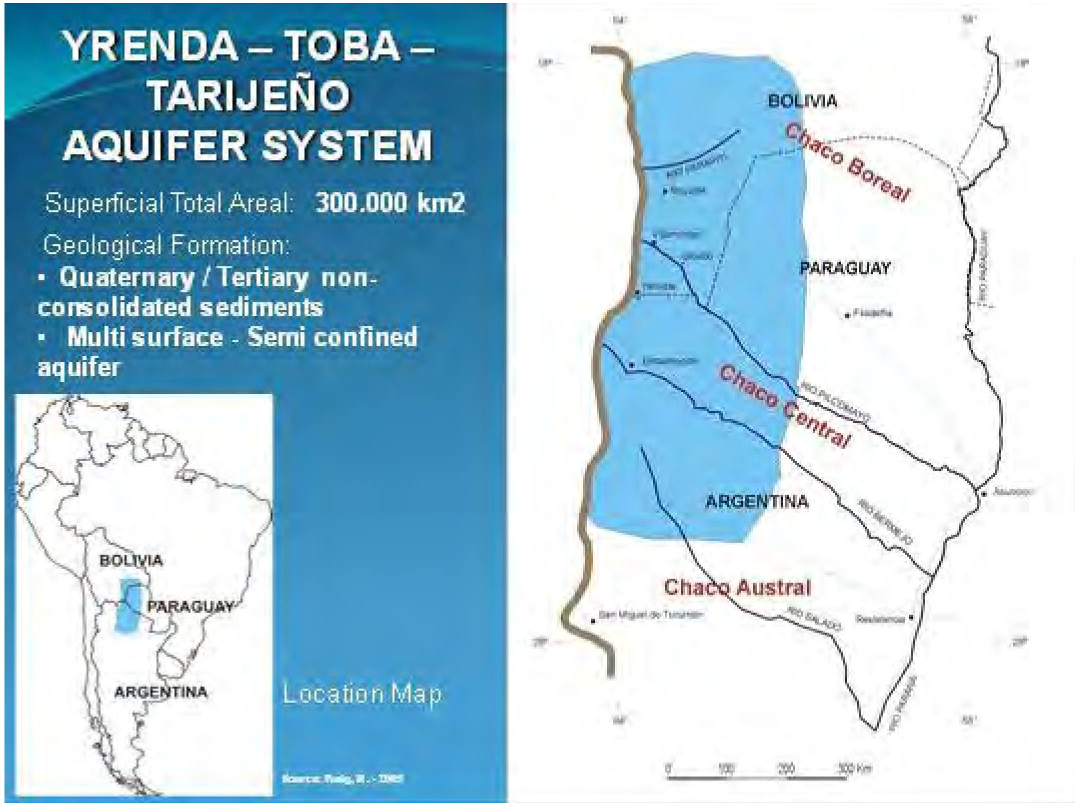


Figure 10 - location map of the Yrenda – Toba – Tarijeño Aquifer

In Bolivia it comprises the departments of Tarija, Chuquisaca and Santa Cruz, and it is associated with the alluvial cones of the large rivers of the Chaqueña plain, such as the Grande, the Parapetí, the Pilcomayo, the Rojo and the Salado rivers. The probable groundwater reserve in a large part of the Bolivian Chaco is not very well-known yet. To make suggestions of sustainable uses of the groundwater resource, it is necessary to study in depth aspects such as the recharge-discharge relationships.

It covers about two thirds of the western region of Paraguay, in the great region of El Chaco. In Argentina, it underlies the provinces of Tucumán, Salta, Santiago del Estero and Chaco.

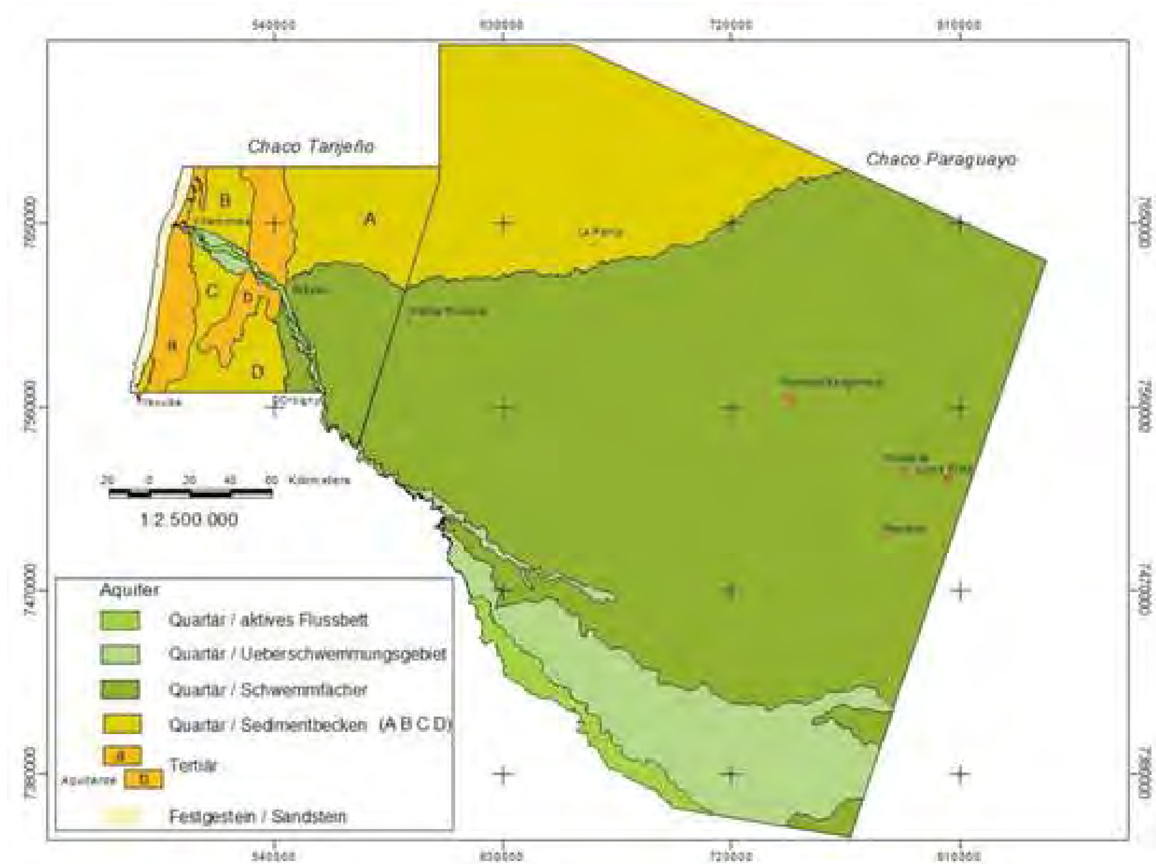


Figure 11 - geology of the Yrenda – Toba – Tarijeño Aquifer

Because of the geological heterogeneity of the permeable sediments that contain the water and its spatial variability, the water quality varies from saline-brackish to fresh. The amount of people dependent upon this resource (which should be better evaluated) is considered greater than 500.000.

The groundwater salinity increases along the flow direction, from west to east. The velocity is estimated in the range of 20 to 46 m/yr. The recharge takes place in the Bolivian region through direct infiltration of precipitation and river water in the Sub-Andean hills (Serranía del Aguaragüe). Paraguay is against the drilling of wells in the Aguaragüe region for local highly needed use.

Discharge occurs in twofold in the Chaco Paraguayan, depending on the area where it takes place:

a) In the central-east region, discharge gives place to wetlands of brackish-salty waters, due to the presence of an impervious barrier in the east that partly prevents its flow to the Paraguay River. The barrier causes an increase of the water level that lies very close to the surface in the eastern part of the Central Chaco. Due to the salinity, this situation is not reverted by limited groundwater extraction for domestic water supply of urban areas;

b) The over exploitation of the eastern aquifers allows the intrusion of salty groundwater from the Yrenda Aquifer System into the Eastern Region of Paraguay.

At the border to Bolivia, the Aquifer is characterized by permeability between 6-8 m/d and a transmissivity in the range of 400-200 m^2/d. In the Central Chaco, the permeability lies between 0.3 and 12 m/d and the transmissivity between 80 and 120 m^2/d, while the specific capacity varies in the range of 1.1 to 3.7 $m^3/h/m$. These variations are related to the distribution of the permeable sediments, as grain sizes decrease from west to east following the deposition track.

It is necessary to conclude the currently on-going studies of water usage in the recharge-discharge areas and water quality in these areas to have a complete understanding of the needs.

4.4 PANTANAL AQUIFER

The Pantanal Aquifer is a Basin of essential strategic importance within the context of water resources management in the countries that share it waters (Brazil, Bolivia, and Paraguay). It is a case study, like almost all the transboundary aquifers of South America, which lacks programmes of shared scientific information.

Figure 12 - satelite images of the Pantal Aquifer

Figure 10 shows the information available of the aquifer in the Brazilian side and the total lack of information in the Bolivian and Paraguayan sides. It shows the results obtained by a project elaborated by the Brazilian National Water Agency-ANA, OAS and UNEP to promote the formulation and implementation of a Strategic Action Program (SAP) for the Integrated Management of the Pantanal and Upper Paraguay River Basin.

As it is designed, the SAP Project activities are to enhance and provide protection to the environmental functioning of the predominant ecological system, to protect the wetland biodiversity, and to implement strategic activities that address the root causes of environmental degradation. This project should continue with the cooperation and involvement of the Bolivian and Paraguayan water authorities.

The project has six components:

a) Water quality and environmental protection;
b) Conservation of the Pantanal;
c) Soil degradation;
d) Stakeholder involvement and sustainable development;
e) Organizational structure development;
f) Watershed management program implementation.

5 CONCLUSIONS

The water crisis is primarily one of governance. Institutions lack the capacity to overcome conflicting approaches in the use and allocation of water from within one basin or aquifer system --both at national and transboundary level. The lack of integration, sectorial approaches and institutional resistance contribute to the fragmented management of freshwater sources. Water-related systems are interdependent and have to be managed in an integrated manner.

The lack of integration and governance in transboundary aquifers tend to show common problems in most the transboundary countries, amongst others:

- The lack of a precise definition of the aquifers in terms of location, size, limits and volume;
- The lack of a systematic monitoring of water tables and quality of water;
- The rigid handling of information by the institutions;
- The increase in water demand linked to population growth and economy expansion;
- The level of health and poorness related to the lack of adequate management of the water resources;
- The irrational use of water and lack of knowledge of the institutions in the governance of underground waters;
- The lack of a legal framework that include underground waters;

- The lack of environmental education by the population with respect to water;
- The lack of financial resources.

The strengthening of institutions responsible for water resources management in the different transboundary basins should be strongly encouraged. The generation and dissemination of information, and the integration of environmental concerns into economic development activities on a sustainable basis should also be strongly stressed.

REFERENCES

Bustamante Rocío, “El difícil camino de la formulación de una Nueva ley de aguas para Bolivia”, Conferencia presentada en el Seminario Taller del “. FORO DEL AGUA ”, Organizado por CGIAC y CONDESAN, Cochabamba, 23 y 24 de Febrero del 2000

Montes de Oca P., I. (2005). Geografía y Recursos Naturales de Bolivia. Editorial Offset Boliviana Ltda. La Paz, Bolivia.

Pasig, R. (2005). Aguas Subterráneas en el Sudeste de Bolivia. Política Exterior en Materia de Recursos Hídricos. UDAPEX (Ministerio de Relaciones Exteriores y Culto)-PNUD. EDOBOL. La Paz, Bolivia.

Programa UNESCO/OEA ISARM Américas. ACUÍFEROS TRANSFRONTERIZOS DE LAS AMÉRICAS. 1er TALLER DE COORDINACIÓN. Montevideo, Uruguay. 24-25 setiembre 2003

Rebouças, A. da C. 2006. Águas Subterrâneas. Águas Doces no Brasil. Escrituras. 3 ra. Edic. São Paulo, Brasil.
Unidad Operativa Boliviana de la Autoridad Binacional del Lago Titicaca UOB-ALT. 2001. Sistema T.D.P.S. La Paz, Bolivia

Urquidi Barrau, F. (2005a). Recursos hídricos en la frontera boliviano-chilena (Silala y Lauca). Política Exterior en Materia de Recursos Hídricos. UDAPEX (Ministerio de Relaciones Exteriores y Culto)-PNUD. EDOBOL. La Paz, Bolivia.

Urquidi Barrau, F. (2005b). Recursos hídricos en la frontera boliviano-peruana (Mauri). Política Exterior en Materia de Recursos Hídricos. UDAPEX (Ministerio de Relaciones Exteriores y Culto)-PNUD. EDOBOL. La Paz, Bolivia.

WORLD HEALTH ORGANIZATION. Guidelines for drinking water quality: recommendations, 2nd ed., Geneva: WHO, 1993. (v.1)

________. Guidelines for drinking water quality: health criteria and other supporting information, 2nd ed., Geneva: WHO, 1996. (v.2)

________. Guidelines for Drinking Water Quality. 3rd ed, Geneva: WHO, 2003.

ANNEX

LIST OF TRANSBOUNDARY WATER TREATIES IN SOUTH AMERICA

(continue)

TREATY NAME	COUNTRIES	DATE	TREATY BASIN
AMAZON BASIN			
Exchange of notes constituting an agreement for the construction of a hydroelectric plant in Cachuela Esperanza, supplementary to the agreement on economic and technical cooperation.	Brasil Bolivia	August 2, 1988	Beni Madeira Mamore
Agreement concerning the Cachuela Esperanza hydroelectric plant.	Brasil Bolivia	February 8, 1984	Beni
Treaty for Amazonian Cooperation.	Bolivia Brasil Colombia Ecuador Guaina Perú Suriname Venezuela	July 3, 1978	
Termination of the demarcation of the Peruvian-Ecuadorean frontier	Perú Ecuador	May 22, 1944	Amazon, Chira, Tumbes, Zarumilla
RIO DE LA PLATA BASIN			
Agreement for the use of natural resources and the development of the Cuareim river basin.	Brasil Uruguay	May 6, 1997	Cuareim
Agreement constituting the trilateral commission for the development of the Pilcomayo river basin.	Argentina Bolivia Paraguay	September 2, 1995	Pilcomayo
RIO DE LA PLATA BASIN			
Agreement for the multiple uses of the resources of the upper basin of the Bermejo river and the Grande de Tarija river.	Argentina Bolivia	June 9, 1995	Bermejo Grande de Tarija

(continue)

TREATY NAME	COUNTRIES	DATE	TREATY BASIN
RIO DE LA PLATA BASIN			
Agreement of cooperation for the use of natural resources and the development of the basin of the Cuareim river	Brasil Uruguay	March 11, 1991	Cuareim
Complementary agreement to the basic scientific and technical cooperation agreement in the area of water resources	Brasil Uruguay	March 11, 1991	Not specified
Decree No. 88.441 promulgating the agreement for water resources exploitation within the Uruguay river and its effluent the Pepiri-Guazu river	Brasil Argentina	June 29, 1983	Pepiri-Guazu, Uruguay
Treaty for the development of the water resources contained in the border reaches of the Uruguay river and its effluent, the Pepiri-Guazu river.	Brasil Argentina	May 17, 1980	Pepiri-Guazu, Uruguay
Agreement on Paraná River projects	Argentina Brasil Paraguay	October 19, 1979	Paraná
Statute of the Uruguay River in Salto, Eastern of Uruguay	Argentina Uruguay	February 26, 1975	Uruguay
Treaty on the boundary constituted by the Uruguay river	Argentina Uruguay	April 7, 1961	Uruguay
Agreement concerning a study of the utilization of the water power of the Apipe Falls	Argentina Paraguay	January 23, 1958	Paraná
Agreement concerning cooperation in a study on the utilization of the water power of the Acaray and Monday rivers	Brasil Paraguay	January 20, 1956	Acaray Monday
Agreement concerning the utilization of the rapids of the Uruguay river in the Salto Grande area	Argentina Uruguay	December 30, 1946	Uruguay
Supplementary boundary treaty on the river Pilcomayo and protocol annexed to the treaty	Argentina Paraguay	June 1, 1945	Pilcomayo
Supplementary boundary treaty	Argentina Paraguay	July 5, 1939	Pilcomayo
Convention to determine the legal status of the frontier between Brasil and Uruguay	Brasil Uruguay	December 20, 1933	Frontier or shared Waters

(continue)

TREATY NAME	COUNTRIES	DATE	TREATY BASIN
RIO DE LA PLATA BASIN			
Protocol between Uruguay and Argentina dealing with the questions of the jurisdiction of the River Plate	Argentina Uruguay	January 5, 1910	Rio de la Plata
CHUY			
Complementary agreement to the basic scientific and technical cooperation agreement in the area of water resources	Brasil Uruguay	March 11, 1991	Not specified
Convention regarding the determination of the legal status of the frontier between Brasil and Uruguay	Brasil Uruguay	December 20, 1933	Frontier or shared waters
MARONI			
Convention to fix the frontier of Suriname and French Guiana	France Netherlands	September 30, 1915	Maroni, Marcwinine
LAGOON MIRIN			
Convention regarding the determination of the legal status of the frontier between Brasil and Uruguay	Brasil Uruguay	December 20, 1933	Frontier or shared Waters
TREATY NAME	COUNTRIES	DATE	TREATY BASIN
LAGOON MIRIN			
Protocol between Uruguay and Argentina dealing with the questions of the jurisdiction of the River Plate	Argentina Uruguay	January 5, 1910	Rio de la Plata
Complementary agreement to the basic scientific and technical cooperation agreement in the area of water resources	Brasil Uruguay	March 11, 1991	Not specified
Convention regarding the determination Convention regarding the determination of the legal status of the frontier between Brasil and Uruguay	Brasil Uruguay	December 20, 1933	Frontier of shared waters
LAKE TITICACA – POOPO			
Exchange of Diplomatic Notes related to the creation of the Autonomous Binational Authority of the Basin of the Lake Titicaca, Desaguadero River, Lake Poopó and Coipasa Salt Flat System	Bolivia Perú	June 21, 1993	Desaguadero, Poopó, Salar de Coipasa, Titicaca
Agreement on a preliminary economic study of the joint utilization of the waters of Lake Titicaca	Bolivia Perú	February 19, 1957	Lake Titicaca

(continuation)

TREATY NAME	COUNTRIES	DATE	TREATY BASIN
LAKE TITICACA – POOPO			
Preliminary convention concerning a study of the joint utilization of the waters of Lake Titicaca	Bolivia Perú	July 30, 1955	Lake Titicaca
Exchange of Diplomatic Notes establishing a joint commission for study of the Puno-Guaqui railway line and joint use of the waters of Lake Titicaca	Bolivia Perú	April 20, 1955	Lake Titicaca

LIST OF REGIONAL WATER PROGRAMMES

- Inter-American Network of Academies of Sciences – IANAS Water Programme;
- Organization of America States / Unit of Sustainable Development and Environment (OAS / USDE);
- Comité Regional de Recursos Hídricos (CRRH);
- Global Water Partnership / South American Technical Advisory Committee (GWP / SAMTAC);
- International Hydrological Programme (IHP – UNESCO);
- Hydrology for International Environmental and Network Data;
- Flow Regimes from Integral Experimental and Network Data (FRIEND);
- ISARMAC / Americas – Internationally Shared Aquifer Resources Management;
- World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP);
- Centro del Agua para Zonas Aridas y Semiáridas del ALC (CAZLAC);
- Centro del Agua para el Trópico Húmedo del ALC (CATHALAC);
- Project for the Environmental Protection and Sustainable Development of the GUarani Aquifer System;
- Strategic Action Programme for the Binational Basin of the Bermejo River;
- Development and Implementation of Mechanisms to Disseminated Lessons Learned and Experienced in Integrated Transboundary Water Resources Management in Latin America and Caribbean – DELTAmerica;
- The Integrated Watershed Management Practices for the Pantanal and Upper Paraguay River Basin Project;
- Inter-American Water Resources Network (IWRN) – UNESCO.

It is important to mention that nine of the twelve South American countries have severe fresh water deficits, reflected on the 25.4% arid or semiarid land of the continent. The hydro deficit territories cover a great variety of ecosystems and agro-productive systems. Due to different circumstances, a strong desertification process has begun and is causing a decrease in the biodiversity and the agro-systems productivity and an increase highly damaging erosion processes. It also has caused a strong unbalance in the hydrological cycles of the basins. Extreme weather events, like severe droughts and floods, as well as metropolitan pollution have helped to accelerate this negative and highly concerning situation.

SUMMARY

TRANSBOUNDARY WATER MANAGEMENT IN WESTERN PART OF JORDAN CHALLENGES & SOLUTIONS

Nisreen D. AL-Hmoud[1]
Khaled S. Abu Samhadaneh[2]
Mufeed Batarseh[3]

[1] Princess Sumaya University for Technology, Amman, Jordan.
[2] Princess Sumaya University for Technology, Amman, Jordan.
[3] Mutah University, Karak, Jordan.

ABSTRACT

Although Jordan and Jordanians were able to deal with water shortage for a few decades, the demand rates have far exceeded supply rates due to uncontrolled internal and external variables. During the previous sixty years the per capita availability of water has sharply dropped from 3600 to 145 cubic meters per year. Recently, things have reached a critical point where Jordan's neighbors seized all the surface transboundary waters, which led to a great pressure on groundwater resources. Consequently, these resources have strongly been depleted; where ten basins out of twelve have serious deterioration due to having exceeded 170% of safe yield. In the current study, many scenarios were suggested to get a clear picture of the water status in Jordan for the next decades, taking into account all variables which might affect water availability in Jordan such as different levels of population growth, urban development, migrations and the expected effects of climate changes. According to national water strategy 2008-2022, the water deficit in coming years will be constant at about 50%, or will even decrease to 0.0065, if Red - Dead Sea canal project become implemented by 2022. Through the analysis of available data, it was found that there will be a huge deficit in water supply in the coming years; when deficit rate would increase to about 217%. It is no longer possible to continue using the traditional water management tools, where the maximum saving by using wastewater treatment and water harvesting systems on a large scale in the Kingdom will save about 5% of water demand according to 2010 readings. A set of different scenarios were developed assuming the possibility of linking water resources in the Middle East together as a single state in terms of water resources. According to these scenarios, the per capita availability of water per year in every country would be between 1632 - 2547 cubic meters according to the 2011 population numbers, and it would be between 1322 – 2093 cubic meters by 2025. Currently, the per capita of water in Jordan is less than 145 cubic meters, and it is expected to decrease to 90 cubic meters in 2025 (according to Water for Life-Jordan's Water Strategy 2008-2022). The results of this study emphasized that the cooperation among countries of the region in the water field could achieve the best returns to all countries in the region; where each country has always something to share with the others. In this respect, Jordan is considered one of the richest countries in terms of oil shale reserves. Moreover, Jordan also enjoys a distinct geographical location which qualifies it to be one of the most prominent countries in solar energy production, which is considered the best choice to desalinate water in the long term.

1 INTRODUCTION

The Middle East is the key or the gateway of world political and security stability, due to its strategic geographic location. Water was and still is the most important reason for conflict in the area; where the United Nations warned that climate change harbors the potential for serious conflicts over water (BARNABY, 2009). So, it is important to find radical solutions to water shortages in the region to avoid new conflicts and wars.

The importance of this study stems from the fact that the subject of this research (Trans-boundary Water in Western Part of Jordan) forms the major water resource of many countries in the region as well as represents half of Jordan's water needs. Jordan was depending heavily on the Jordan River system (Figure 1), since there are no other important sources of fresh water available to Jordan who suffered from water shortage (MIRIAM, 1995).

Figure 1 - Satellite photo of the Jordan River basin

What will happen to a country which has lost half of its water resources, and is classified among the absolute water scarcity countries?

A significant increase in population has led to a sharp decrease in per capita water availability in Jordan, which dropped from 3,600 cubic meters in 1946 to 145 cubic meters in 2008. The rates of demand far exceeds supply rates due to uncontrolled internal and external variables; natural population growth, migrations, climate change effects, and Jordan's neighbors who seized all the surface transboundary waters, which led to great pressure on groundwater resources.

1.1 MAIN TRANSBOUNDARY WATER RESOURCES IN JORDAN

Currently, the Yarmouk River is the largest source of external surface water, which accounts for 40% of the surface water resources of Jordan, including water contributed from the Syrian part of the Yarmouk basin; it is the main source of water for the King Abdullah canal, and is thus considered to be the backbone of development in the Jordan valley. Other major basins include Zarqa, Jordan river side wadis, Mujib, the Dead Sea, Hasa and Wadi Araba.

In 1997, the total amount of surface waters in Jordan was about 600-680 MCM/Y, of which the Yarmouk River and Jordan River were the main resources; side wadis and Zarqa River formed the rest of surface water resources.

According to the Jordanian-Syrian agreement, in 1953 Jordan's share of Yarmouk River was 370 MCM/Y; according to the Johnston plan 1953-1955, the Jordan's share of the main stream of Jordan River was 100 MCM/Y, while side valleys and Zarqa River contribute with 130-200 MCM/Y.

1.1.1 Yarmouk River

Yarmouk River originates from southwestern Syria and flows southwest to its confluence with the Jordan River. For most of its total course of about 80 km, it forms the boundary between Jordan and Syria, and the border between Israel and Jordan close to the Jordan Valley (JORDAN'S WATER STRATEGY, 2008). More recent measurements indicate a decline in the river discharge due to the increase of extractions from the groundwater in the catchment's area, and because of upstream (Syrian and Israeli) development works which were done in the 1980's, in addition to the decrease in precipitation in the last five decades, which led to the decline in the base flow.

The Jordan's share of Yarmouk River decreased from 370 MCM in 1950 to just 15 MCM in 2010 according to the Ministry of Water and Irrigation in Jordan. Though there were several factors which led to this tragic outcome, the most prominent of them was the dominance of neighboring countries militarily, economically and geographically.

1.1.2 Jordan River

With about 1,400 MCM, the Jordan River is the smallest major watershed in the region. However, because of its geopolitical position, this river has been described as "*having witnessed more severe international conflict over water than any other river system in the Middle East and remains by far the most likely flashpoint for the future*" (ANDERSON, 1988).

Jordan River is the smallest transboundary river of the Middle East; its basin drains an area of 18,300 km^2 in five countries: Jordan, Palestine, Lebanon, Syria and Israel (Figure 2). With an annual flow of 1.4 km^3/y, the Jordan River constitutes the smallest basin in the region.

Figure 2 - Jordan River Basin Boundaries
Source: NSU

Many plans were proposed for the distribution of Jordan's river water, but no agreement was ever signed. Johnston plan was subject to many modifications, finally reaching a final plan which was named the “Unified Plan”, Table 1.

Table 1 - The Unified Plan of Jordan River Basin

Source	Lebanon	Syria	Jordan	Israel	Total
Hasbani	35	-	-	-	35
Banias	-	20	-	-	20
Main Jordan stream	-	22	100	375	497
Yarmouk	-	90	377	25	492
Side Wadis	-	-	243	-	143
Total	35	132	720	400	1,287

1.1.2.1 Main Water Distribution Plans of the Jordan River Basin

For many centuries, there was no need to develop plans for sharing water in the Jordan River basin. For hundreds of years, since the Jordan River basin was part of the Islamic state, there had been harmony between people and nature, where natural population growth did not affect the natural balance in the region. The plans for the development of the Jordan River basin began with the start of Jewish interest in Palestine as a potential homeland for them in the region. The main objective of these plans was to secure sufficient water for the high numbers of Jewish immigrants who would be brought from different parts of the world. One of the first plans related to the Jordan River was the Franghia Plan in 1913 (NAFF; RUTH, 1984), which proposed the use of the Jordan River system for irrigation and electricity. Sponsored by the Ottoman Empire, the plan stalled with the fall of the Empire after World War I (KLIOT, 1994). In 1944, the United States recommended the Lowdermilk Plan, which proposed the irrigation of the Negev Desert with the waters of the Jordan and Litani rivers, and the refilling of the Dead Sea through a canal from the Mediterranean Sea (KLIOT, 1994). The plan was abandoned following the change of circumstances in the Jordan River basin after the World War II with the creation of Israel and the influx of large numbers of refugees. The previously mentioned efforts to reallocate the Jordan River waters were never ratified. In 1953, US special envoy to the Middle East, Ambassador Eric Johnston, proposed an allocation scheme based on the previous proposals. Johnston's Jordan Valley plan is the product of Eric Johnston's negotiation with representatives of Israel, Lebanon, Syria and Jordan for 2 years, which finally led in 1955 to a unified plan; which in his view reconciled the demands of all the riparian (ALLAN; MALLAT, 1995; SALIBA, 1968). The plan was never adopted or ratified, partly because the Arab states (especially Jordan) did not need a comprehensive water development program that directly involved Israel in order to achieve their immediate development goals. In addition to the political considerations of not recognizing the legitimacy of Israel in the region, the Arabs did not agree with the criteria that were used for dividing the shares among the parties (PASSIA, 2002; PHILLIPS et al., 2007). Consequently, the Arab project was the response to the Johnston plan, which was based on the principle that the plan for using the water of the Jordan River basin should take into account the political boundaries of the basin. On that basis, the Arab plan allocated 20% of water to Israel (also called the occupied zone project) and 80% of water to the Arab countries. The proposal did not accept the storage of water in the Tiberias Lake. According to the Arab plan, 880 acres would be irrigated of which 335 acres were located in Israel; the generation of electrical energy would be divided between Arabs and Israelis by 80% to the Arabs and 20% to the Israelis.

The plan was completed in March 1954 and revised a few months later for submission to the Arab League. The preservation of cultivated lands in the basin meant the allocation of water shares for Israeli cultivated lands in the basin, which in turn meant an initial promising sign of Arab acceptance of Israeli shares in the waters (HADDADIN, 2002).

In its final form, the Arab plan allocated water shares to all the riparian states, including Israel. The Arab plan emphasized the irrigation of lands inside the river basin, and opposed the transfer of water outside it. Obviously, the Arab plan adopted the emerging principle of "*integrity of the river basin*". The Arab technical committee recommended that maximum storage of the Yarmouk River water should be made through a dam on the river at Maqarin and only about 60 MCM, as surplus water, should be stored in Lake Tiberias (HADDADIN, 2002). Their decision was justified by the higher salinity in the lake, which would aggravate an already saline soil in the Jordanian side of the Jordan Valley, and by the higher evaporation losses from the wide lake compared to the narrow and deep Maqarin reservoir (PHILLIPS et al., 2007).

In 1954, J. S. Cotton, an American engineer who was working as a consultant to Israel at the time, reviewed the plans and came up with another version (HADDADIN, 2002). The main idea of the Cotton plan was to bring as much water to Israel as possible, regardless of the source. Cotton, is his plan, proposed the withdrawal of the Litani water from outside of Jordan River basin in order to maximize Israel's share of water, which implied that a much greater volume of water was available for allocation in the Cotton plan. The water resources allocated by the Cotton plan to both Syria and

Jordan were also significantly lower than those cited in the main plan or (especially) the Arab plan. Cotton assumed the exportation of 400 MCM/Y from the Litani basin to the Jordan River catchment's area, with a slightly greater volume (451 MCM/Y) being retained for use in Lebanon. This increased the total available water resource in the Jordan River basin to about 1895 MCM/Y. It is important to note that the total amount of water in the Jordan River according to Cotton plan without Litani water was about 1500 MCM, in comparison to the 1213 MCM as per Johnston Plan and 1431 MCM as per Arab plan. Another implicitly indicator shows that the water amount of Jordan River was much greater than what had been mentioned in the Johnston Plan figures (LOWI, 1995).

Table (2) demonstrates water allocations to riparian of Jordan River system under different plans. Water is measured in MCM/Y, and area is measured in dunums.

Table 2 - Annual Allocations Under the Different Plans (MCM)

Plan/Country	Johnston 1953		Arab Technical 1954		Cotton*** 1954		Revised 1955	
	Water	Area	Water	Area	Water	Area	Water	Area
Jordan / West Bank	774	490	975	490	575	430	720*	
Syria	45	30	132	119	30	30	123	119
Lebanon	-	-	35	35	450.7	350	35	35
Israel	394	420	289	234	1290	1790	400**	
Totals	1213	940	1431	878	2345.7	2600	1278	

Source: Environmental Profile for the West Bank, V2: Jericho District 1995
* = an estimate 243 Palestine share; 377 from Yarmouk River; 100 from Lake Tiberias.
** 375 from Jordan River, 25 from Yarmouk River.
*** Including the Litani River as part of Jordan River basin.

1.1.2.2 Main water agreements of the Jordan River Basin

It is difficult to subdue environmental and natural resources to the political boundaries which are man-made. Whatever the degree of hostility between any two states, at the end, there should be an agreement or understanding to regulate the uses of shared resources.

Since it was founded in 1948, Israel has controlled all the main water sources in the region. Its biggest concern was to get as much water as it could. Water was the main reason for most wars carried out then. In 1967 by occupying the Golan Heights and the West Bank, Israel by using its military dominance, worked on changing the geographical reality of the region in order to control the headwaters of the Jordan River; and thus, became upstream and the controlling state of the most important water resource in the region.

In fact, since Israel had full control over Jordan River basin, the Israelis were not interested in any agreement unless such agreement was achieved based on the following conditions:

- First: any agreement provides a legitimate cover for the Israeli occupation of the water and land in the region.
- Second: any agreement that provides an access to new water sources.

In the 1980s, a discreet agreement was reached between Jordan and Israel, to make arrangements on the Yarmouk River for sharing its waters.

The most important agreements were the Jordanian-Syrian agreements (1953 and 1987) and Wadi Araba peace treaty which was signed in 1994 between Israel and Jordan. According to these treaties, Jordan's share of water from Yarmouk and Jordan Rivers was defined.

1.1.2.2.1 Jordanian-Syrian agreements on the Yarmouk River water (1953 and 1987)

The first Syrian-Jordanian Agreement was signed in 1953, which relates to the use of the Yarmouk River for both irrigation and hydroelectric power generation. Based on this agreement, Syria would use the higher springs of the River for irrigation while the balance of the water would flow downstream into Jordan and generate hydroelectric power for both (Khori, 1981); Jordan's share of Yarmouk River waters should not be less than 315.36 MCM/year (YAROMUK WATER TREATY, 1953).

Based on the development of the situations on the ground in terms of growth of water demand in the region, the 1953 agreement was modified by the 1987 agreement, where under this agreement Jordan gave more than one-third of its share of the Yarmouk River waters to the Syrians. *Note that Jordan needs to increase its share not to decrease it, because it does not have any water resources substitutes, and Jordanians are still living under water crisis*.

The historical Jordanian share from Yarmouk River was equal to one-third of the Kingdom´s water consumption (MWI, 2010). Jordan's share of Yarmouk River water decreased dramatically from 377 MCM/year to 15 MCM/year (Figure 3).

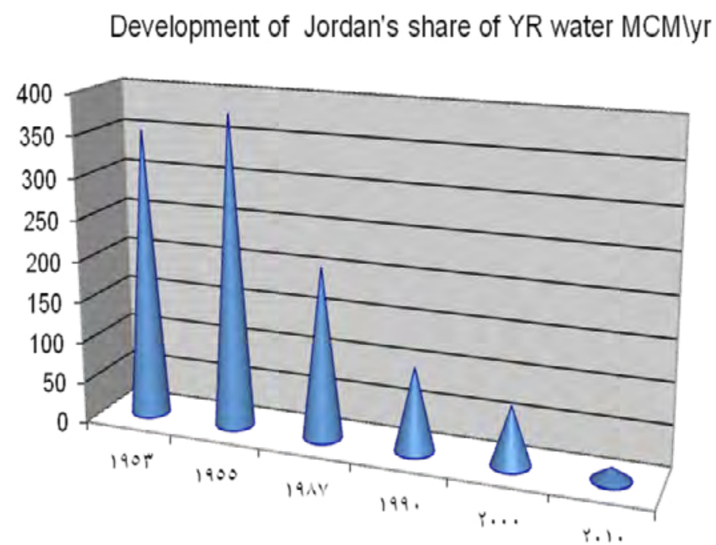


Figure 3 - The development of the Jordan share of Yarmouk River water 1953-2010
Source: The Ministry of Water and Irrigation of Jordan, and water treaties on Jordan River Basin

Three main reasons led to this bad end for the Yarmouk River in Jordan, where any drop of water has extreme value: power balance; the geographical location, where Jordan was not only classified as an arid to semi-arid region but also as a downstream country; the effect of climate change, where this phenomenon had a strong effect on the region, which led other countries to capture any water resource.

1.1.2.2.2 Jordanian-Israeli agreement on the Yarmouk and Jordan Rivers water, Peace treaty 1994 (Wadi Araba Peace treaty)

In October of 1994, Jordan and Israel signed a Peace Treaty. As part of this treaty, the two countries agreed to settle their differences with regard to the claims both countries had on the waters of the Jordan River basin.

The result was that Israel was to keep all the waters of the upper Jordan basin, totaling more than 600 MCM/year. In the lower part of the River basin Jordan got a small share of the waters from the mainstream, together with a more sizeable proportion of the flow of the Yarmouk. The volume of water which Jordan now has access to is considerably less than the water allocations of the Johnston Plan of the 1950s, which was an independent attempt to divide the waters of the Jordan River in an reasonable manner. On the other hand, Israel's share is considerably greater. *Overall, the treaty was particularly favorable to Israel*.

As for the impact of these agreements on the water situation in Jordan,

- Jordan waived one third of its legal share of the Yarmouk River to the Syrians and bear very expensive costs to establish Al Wehdah Dam; although an agreement and a joint committee exist, the amount of water in the Yarmouk River has decreased and almost disappeared.
- Although the Wadi Araba Peace treaty was not fair for Jordanians and their water rights, the Israelis showed cooperation in the implementation side concerning the quantities' provided. For the water quality there were several issues.

2 METHODOLOGY

To address the water crises in Jordan, a simple methodology was adopted that can be summarized by answering three questions in three parts;

- In the first part, the following question was answered: What will be the direction of the water balance in the coming period under expected conditions?
  - This part consisted of seven scenarios which could be used to examine a wide variety of variables and challenges that Jordan would face in terms of water, up to 2025.
  - These variables would be population growth, water demand, potential impacts of climate change on water availability, and impacts of migrations.
- In the second part, while keeping in mind that Jordan stands somewhere between Zero and 1000 cubic meter/y on the water poverty line: *What is the maximum effect of applying the administrative measures with regards to the 145 CM/capita/year*?

- To answer this question the study examined the effects of applying different alternative tools in managing water issues, such as wastewater treatment and water harvesting systems, on a large scale in the Kingdom.

• In the third part, after knowing the direction of water deficit under all expected conditions, and the effect of using various administrative tools, the potential impact of the application of one of the important sustainability principles in the water field, a regional cooperation was examined. The final question was: Is it possible to change Jordan movement's direction along water poverty line through regional cooperation?

- At this step, five scenarios were developed. Each scenario includes a number of countries in the region that could cooperate among them in the water issue. In each scenario a group of regional countries was selected, and was considered as a single entity; on this basis, the calculations of Population growth rates and the quantities of renewable water was carried out.

3 RESULTS AND DISCUSSION

3.1 PART I: SCENARIOS OF FUTURE CHALLENGES OF THE WATER SECTOR IN JORDAN

According to the different scenarios used, it was found that the water deficit will increase to a rate that cannot be controlled.

In the first group, the potential effects of variant factors which could affect water availability in Jordan under different conditions were examined; it was found that Jordan will face continuous water deficit regardless of the classical water management tools that are used (Table 3).

Table 3 - Water Deficit According to Different Potential Scenarios 2007– 2025

Scenario	Deficit Average MCM/Y	Deficit rate to Available amounts
Scenario 1	542	55%
Scenario 2	616	58%
Scenario 3	871	77%
Scenario 4	1062	120%
Scenario 5	1102	130%
Scenario 6	1405	165%
Scenario 7	1551	187%

3.2 PART II: MANAGEMENT OPTIONS. IMPACT OF APPLYING TRADITIONAL MANAGEMENT TOOLS ON DOMESTIC WATER SECTOR SCALE IN JORDAN

- Comprehensive water management on a family scale.
- Wastewater treatment on a large scale in the Kingdom.
- Water Harvesting System (WHS).

The total saving by using all above mentioned management tools was about 6% of the amounts of water available. Taking into consideration the non-revenue water, the maximum saving would not exceed 4% of the (246 MCM) which are used by the domestic sector.

3.3 PART III: THE EFFECTS OF THE APPLICATION OF REGIONAL COOPERATION

The last group of scenarios, by applying regional cooperation, it was found that Jordan's share of water, for example, would rise immediately to 2000 cubic meter/capita (currently, it is 145 cubic meter/capita), while it would reach 1300 cubic meter/capita (instead of 90 cubic meter/capita according to MWI, 2009)in 2025.

In addition, the per capita/year for every country in the region was between 1632 - 2547 cubic meter according to the 2011 population numbers, and it would be between 1322– 2093 cubic meter by 2025.

Moreover, it was clear that regional cooperation in terms of water would achieve water security for all countries, with the lowest costs, which would reflect on all other sectors, especially the energy field and environmental protection, achieving more welfare and social security to the region's countries.

4 CONCLUSIONS

The environment does not recognize political boundaries. So, the sustainable solution for natural resources scarcity depends on this principle. The cooperation of the region in the water field will achieve good returns to all countries in the region, especially if it is accompanied by the establishment of common markets. The existence of common interests among nations, would contribute to avoiding conflicts, which would direct the capability of these countries into development efforts, which would expand the concept of sustainable development to include a larger number of states and people.

REFERENCES

Allan, J. A. and Mallat, C. (eds.) (1995), Water in the Middle East. Legal, Political and Commercial Implications Tauris Academic Studies, London, New York: I.B. Tauris Publishers.

Anderson, E.W. (1988), Water: The Next Strategic Resource. In: Starr, J.R. & D.C. Stoll (Eds). The Politics of Scarcity: Water in the Middle East. London: Westview.

Barnaby, W. (2009), Do Nations Go to War over Water? Nature. 458(7236): 282-3. http://www.rivercenter.uga.edu/education/8990/documents/barnaby.pdf.

Haddadin, M. (2002), þDiplomacy on the Jordan: International Conflict and Negotiated Resolution, Springer.

Khori, R. (1981), The Jordan Valley: Life and Society below Sea Level. Longman Group Ltd. London and New York.

Kliot, N. (1994), Water Resources and Conflict in the Middle East. London & New York: Routledge: (The role of water in conflict resolution in the Middle East).

Lowi, M. R. (1995), Water and Power: The Politics of a Scarce Resource in the Jordan River basin (Cambridge University Press, 1993/95).

Ministry of Water and Irrigation. MWI, (2008), Water for Life, National Water Strategy, 2008-2022.

Naff, T. and Ruth C. M. (1984), Water in the Middle East: Conflict or Cooperation? (Boulder, Colo.: Westview Press, 1984). Pp. 253.

Phillips, D.J.H., Attili, S., McCaffrey, S. and Murray, J.S. (2007), The Jordan River Basin: 2. Potential Future Allocations to the Co-riparians. Water International, 32 (1): 39-62.

Saliba, S. N. (1968), The Jordan River Dispute. The Hague: MartinusNijhoff.

SUMMARY

TRANSBOUNDARY WATER COOPERATION: COOPERATING TOWARDS PEACE IN THE LAC REGION THROGUH THE WORK OF UNESCO

Zelmira May[1]

[1] UNESCO-IHP LAC.

ABSTRACT

Cooperation should be seen as the joint work of the various actors towards achieving a commong good: the sustainable human development in its boradest sense. Upon the designation of 2013 as the International Year of Water Cooperation under the leadership of UNESCO, the UN recognized the critical importance of water not only as a crucial resoruce for human development, but also as a catalyst for cooperation. Therefore, UNESCO shall put at the service of its Member nations all its knowledge on water resources, fostering collaborative efforts at all levels. The following analysis is build on the data and information gathered by UNESCO and the UN System as a contribution to the International Year of Water Cooperation, as well as a collaborative effort of several ot its programmes, projects, and initiatives worldwide.

1 BACKGROUND

In December 2010, the United Nations General Assembly declared 2013 as the United Nations International Year of Water Cooperation calling UNESCO to take lead this particular commemoration taking advantage of the Organization's unique multidisciplinary perspective that includes the view of the natural and social sciences, education, culture and communication.

This International Year shall be an opportunity for raising awareness on the potential for increased cooperation on water and the central role of water in the promotion of cooperation. In addition, it will be an ocassion for discussing the challenges faced by water management in the context of increasing demand for water access, allocation and services. The framework provided by the UN nations throuth this partciular international year will provide the chance for highlighting successful stories on water cooperation; national, regional and global initiatives; as well as helping identifying burning issues on themes such as water education, water diplomacy, transboundary water management, financing cooperation, and legal and institutional frameworks.

The Millennium Development Goals have clear linkages and ties with cooperation on water resources, and the coming assessment of the achievements of the MDGs and its successor in the post-2015 agenda will be fed by the 2013 discussion. This way, the benefits and ouputs of sound cooperation will find a space in the will of the nations towards sustainability.

2 THE GLOBAL CONTRIBUTION OF WATER TO COOPERATION AND COLLABORATION

As we are entering in the International Year of Water Cooperation, working in cooperation will be an imperative with the common goal of not only preventing and resolving potential conflicts arising from the management of shared water resources but also promoting cooperation at all levels ensuring a sustainable water use.

Moreover, water security can only be attained via the development of adequate human and institutional capacities, both within and outside of the water sector. UNESCO will reinforce existing partnership with both public and private partners, as well as build new strategic partnerships to successfully address the complex challenges at stake related to water security. The most important global driver that will significantly change water-related risks in the near future is population growth. On the other hand, other drivers such as land use changes, urbanization, energy issues, food production etc. are all originated from population change and economic development.

The high level of interdependence is illustrated by the number of countries sharing each international basin; the dilemmas posed by basins like the Danube, shared by 19 European countries, or the Nile, shared by 11 African countries, can easily be imagined.

Strikingly, the territory of 148 nations falls within international basins and more than 30 countries are located almost entirely within these basins. In all, there are 276 international basins. These cover around 45% of the Earth's land surface, host about 40% of the world's population and account for approximately 60% of global river flow. Thus, cooperation is the key to preserving water resources and protecting the environment, but also to fostering and maintaining peaceful relations within and among communities.

While water supplies and infrastructure have often served as military tools or targets, no states have gone to war specifically over water resources. Since 1820, more than 680 water treaties and other water-related agreements have been signed, with more than half of these concluded in the past 50 years.

The historical record proves that international water disputes do get resolved, even among enemies and even as conflicts erupt over other issues. Some of the world's most antagonic neighbours have negotiated water agreements or are in the process of doing so and the institutions they have created often prove to be resilient, even when

The major task, which the international community is facing today in the field of water resources, is the transfer of committed obligations into concrete actions that need to be implemented on the ground for the benefit of people, ecosystems and the biosphere as a whole. Therefore, nurturing the opportunities for cooperation in water management among all stakeholders and improving the comprehension of the challenges and benefits of water cooperation can help build mutual respect, understanding and trust among countries and promote peace, security and sustainable economic growth.

Water resources management issues must be addressed at the local, national and at appropriate regional and international levels. All stakeholders, including those in government, international organizations, the private sector, civil society and academia, should be engaged, paying special attention to the livelihoods of the poor and most vulnerable people. Water management choices must also be consistent with other government policies and vice-versa. All the while, social, political and economic decisions must be made in a way that seeks to balance and fairly distribute the allocation of natural resources while keeping in mind the biophysical limits of the environment.

Mobilizing politicians will and commitment to address water issues worldwide remains crucial. Equally important are forward thinking and a willingness to consider innovative ways to approach local, regional and international cooperation. Open discussion of the issues shaping our water resources today and strong citizen participation in decision-making can stimulate cooperative action and political commitment. Promoting a culture of consultation and increasing participative capacities will help to deliver benefits in all areas, including collaborative water management.

Given the basic necessity of water to sustain life and its central role in the provision of a wide range of services, water is a crucial and cross-cutting factor at the heart of all the MDGs. Consequently, the active participation and cooperation of all sectors, levels of government, and civil society are critical for ensuring better management and allocation of water resources. While recognizing the differentiated responsibilities between developed and developing countries, each nation must take ultimate actions to meet the MDGs.

At the international level water appears to provide reasons for transboundary cooperation rather than war. Looking back over the past 50 years, there have been some 37 cases of reported violence between states over water — and most of the episodes have involved only minor skirmishes. Meanwhile, more than 200 water treaties have been negotiated. Some of these treaties — such as the Indus Basin Treaty between India and Pakistan — have remained in operation even during armed conflict.

One clear message from the record is that even the most hostile enemies have a capacity for cooperation on water. Most governments recognize that violence over water is seldom a strategically workable or economically viable option. The institutions that they create to avert conflict have shown extraordinary resilience. The considerable time taken to negotiate the establishment of these institutions bears testimony to the sensitivity of the issues.

Nevertheless, disaster can be a catalyst for cooperation. Upon the disaster in Chernobyl that caused that radioactive caesium deposits made present in reservoirs and increased risk of exposure to radioactivity all the way down to the Black Sea, the governments responded to the challenge of improving river quality. Where cooperation fails to develop or breaks down, all countries stand to lose—and the poor stand to lose the most. Failures in cooperation can cause social and ecological disasters, as in Lake Chad and the Aral Sea. They also expose smaller, vulnerable countries to the threat of unilateral actions by larger, more powerful neighbours.

The history of water-related violence includes incidents between tribes, water use sectors, rural and urban populations and states or provinces. Some research even suggests that, as the geographic scale drops, the likelihood and intensity of violence increases. Throughout the world, local water issues revolve around core values that often date back generations. Irrigators, indigenous populations and environmentalists, for example, all may view water as tied to their way of life, which is increasingly threatened by new uses for cities and hydropower.

Those regions of the world that rely heavily on declining water supplies for irrigation overlap significantly with those that currently concern the security community: the Middle East, North Africa and Central Asia. When access to irrigation water is cut off, groups of unemployed, disgruntled men may be forced away from the countryside into the city, contributing to political instability. When migration is cross-boundary, it can contribute to interstate tensions.

Water problems can thus contribute to local instability, which in turn can destabilize a nation or an entire region. In this indirect way, water contributes to international and national disputes, even though the parties are not fighting explicitly over water. Therefore, while no 'water wars' have occurred so far, the lack of clean fresh water or the competition over access to water resources has occasionally led to intense political instability that resulted in acute violence on a small scale.

At the national and local levels, it is not the lack of water that leads to conflict but the way it is governed and managed. Many countries need stronger policies to regulate water use and enable equitable and sustainable management. Especially in developing countries, water management institutions often lack the human, technical and financial resources to develop comprehensive management plans and ensure their implementation.

Although, there is a crucial need of exceeding the previous global targets of halving the percentage of population without sustainable access to safe drinking water, by understanding ecological impacts of water projects but also for industrial water use, irrigation, quality and related environment links. The principal aim is to re-arrange water quality and ecosystem purposes, including storm water management, human and industrial water management, flood loss reduction, sedimentation and pollution control, improvement of water quality, recreation, education and introduction of natural or manmade cropping systems suitable for local conditions.

3 THE WORK OF UNESCO

The International Hydrological Programme (IHP) is a UNESCO´s intergovernmental scientific cooperation programme in water research, water resources management, education and capacity-building. It is, moreover, the only science programme of the United Nations system in this area with a broad focus in its different aspects. Its aims are principally to support its Member States with sound scientific knowledge, to cooperate with professional and scientific organizations and individual experts that can upgrade their knowledge of the water cycle and thereby increase their capacity to better manage and develop their water resources. This network shall support by developing techniques, methodologies and approaches to better define hydrological phenomena; improving water management, locally and globally; acting as a catalyst to stimulate cooperation and communication in water science and management; and serving as a platform for raising awareness on global water issues.

During its VII strategical phase (2008-2013), the IHP promoted and coordinated international hydrological research, providing education, increasing capacities and improving the management of water resources under the overall theme "Systems under stress and societal responses". It is now widely recognized that water, in its many forms, is a major concern for most sectors of the economy of all countries, and therefore becoming a critical factor for global sustainability. Likewise, freshwater has a vital role for human health, successfulness and security, with crucial importance for a sustainable development of both human beings and ecosystems. It is the common denominator of today's most pressing global challenges, such as health, agriculture, energy, and urbanization.

Freshwater flows freely, unconfined by political boundaries. For example, it has been evaluated that the world has 276 river basins with at least one tributary crossing an international boundary, being thus transboudnary in nature. These transboundary basins cover an estimated 46% of the Earth's land surface, which host about 40% of the world's population. Communities sharing freshwater resources may have competing needs or claims, requiring that traditional stakeholders in freshwater management -- namely, scientists, governments, policy makers -- join forces with individuals or organizations outside this "water box", such as sociologists, ministries for women or indigenous peoples, community activists and civil society. The above mentioned calls for concertated efforts for administring a resources that is vital to all of us.

Water - as a necessary resource - has a definite objective and it is part of the post-2015 sustainable developments goals. Unfortunately, it is a finite resource irregularly distributed and often poorly managed and known. Water resources are under severe pressure enhancements from climate and other global changes, which in combination with the current economic and financial crisis compromised the significant progress achieved over the last decades. The present water systems are faced with several challenges and categorized in different parts: technical, institutional, political and financial. These are further combined by global and regional change pressures and are due to the lack of capacities to administer water rather than to the lack of water resources. Thus, in the near future sustainable water management needs to reach these problems efficiently. A significant step should be to elaborate a global water quality evaluation framework to decrease the information gap and support decision-making and management procedures.

Around 80% of the world's population is exposed to high levels of threat to water security, understood as the capacity of a population to safeguard access to adequate quantities of water of acceptable quality for sustaining human and ecosystem health on a watershed basis and to ensure efficient protection of life and property against water related hazards. Water security is essential to sustainable development, and vital to building inclusive, peaceful societies. Yet billions of people remain vulnerable to water scarcity, deteriorating water quality and such water-related disasters as floods and droughts. Women, children and those living in poverty suffer the heaviest burden. As highlighted in the 2012 MDG Report, women are disproportionately affected by water scarcity. For example, in Sub-Saharan Africa, 71% of the water collection burden falls on women and girls; this heavy burden is also the case in other parts of the world.

The International Year of Water Cooperation (IYWC) may be taking place over the course of 2013, but its fundamental goal is to start paving the path for a more peaceful and sustainable future. According to the UN, the projected world population increase from 7 billion today to 9 billion in 2050 will intensify demand for freshwater, boosting global agricultural consumption by 20% and hydroelectricity & other energy needs by 60%. Contrary to popular belief, people are not more likely to fight over water when there is less of it. Cooperation is more frequent than conflict when it comes to water, having outnumbered conflicts by 2 to 1 over the last 70 years.

The benefits of water cooperation, in economic, social and environmental terms, are considerable. Contrary to common belief, examples of cooperation greatly outshine conflict. For example, gains from cooperation can include the costs averted by reducing tensions and disputes between neighbours. Strained interstate relations linked to water management can inhibit regional cooperation across a broad front, including trade, transport, telecommunications and labour markets.

Cooperation at the basin level can promote efficient techniques for water storage and distribution, expanding irrigation acreage. The Indus Waters Treaty of 1960 was the precursor to the massive expansion of irrigation works in India, which in turn played an important role in the green revolution.

Likewise, cooperation between municipalities and private providers can stimulate resource mobilization. The Tamil Nadu Urban Development Fund, established by state authorities in 1996, developed the Water and Sanitation

Pooled Fund—a 300 million rupee facility generated through bond markets for 14 small municipalities — with a partial credit guarantee from the US Agency for International Development.

Therefore, water cooperation is multi-dimensional in nature and encapsulates cultural, educational and scientific factors, as well as religious, ethical, social, political, legal, institutional and economic aspects. A multidisciplinary approach is essential in order to grasp the many facets implied by the concept and blend them into one holistic vision. Moreover, for water cooperation to be successful and sustainable, it requires a common understanding of the needs and challenges surrounding the issue of water.

Communities sharing freshwater resources may have competing needs or claims, requiring that traditional stakeholders in freshwater management - namely, scientists, governments, policy makers - join forces with individuals or organizations outside this "water box", such as sociologists, ministries for women or indigenous peoples, community activists and civil society.

The importance of cooperation in managing limited water resources in a world where demand is rapidly growing cannot be underestimated: some 145 countries share a major river basin with at least one other nation.

The good news is that contrary to widely held belief, cooperation is more frequent than confrontation over water. This is illustrated by programs such as the Nile Basin Initiative's Socio-Economic Benefits Sharing Project, the agreement between Argentina, Brazil, Paraguay and Uruguay over the conservation and environmental protection of the Guarani Aquifer, and the Mekong River Basin management programme.

As part of post-2015 development agenda, UNESCO can lead the way in developing national and regional plans to achieve community resilience for water security by fostering the contributions of the sciences and innovation. UNESCO strategic plan - corresponding to the 8th phase of the IHP - has as principal aim to enhance water security in response to local regional and global challenges dealing with all the complexity and the rapid environmental and demographical changes; promoting the transformation of information and experience process; and building competences to meet the challenges of today's global water challenges. It is essential to establish knowledge platforms where all the different entities can exchange and share the decision taking to address water security challenges.

The IHP must ensure that the important role of eco-hydrological services in the system of sustaining life on the planet is addressed in several key areas, most notably water for food security and human survival. It is stressed that the water crisis is essentially a crisis of governance, as is stated in the fragmented nature of water management. Therefore, UNESCO can lead the development of national and regional plans to achieve community resilience to water safety, encouraging the contributions of science and innovation. The main objective in the UNESCO's strategic plan is to improve water security in response to regional challenges and local global deal with all the complexity and rapid environmental change and demographic momentum of the process of transforming information and experience, and building skills to meet the planet's water challenges. Thus, it is essential to establish knowledge platforms where different entities can exchange and share decision-making to address the challenges of water security. Therefore, since water security depends heavily on appropriate policies based on sound science, then the role of UNESCO to achieve water security could become the most important, providing advice to its Member States.

4 THE COOPERATION PROGRAMMES IN LAC

4.1 ISARM – TRANSBOUNDARY AQUIFERS OF THE AMERICAS

The worldwide programme's ISARM (Internationally Shared Aquifer Resources Management) is aimed at improving the understanding of scientific, socio-economic, legal, institutional and environmental issues related to the management of transboundary aquifers. The "Management of Transboundary Water Resources - ISARM" promotes the generation of knowledge on transboundary water resources and the creation of a framework for cooperation in various fields for the sustainable management of transboundary aquifer systems globally and regional levels.

The issue of shared international waters is as old as the national borders that make those waters international. During the last century, a significant progress has been made in regulation of joint management of surface watercourses; many international river-, lake- or basin commissions have been set up and the legal treaties signed. Although some of these activities address "a groundwater component" as well, major comparable efforts related to the invisible groundwater have started just a several years ago with the ISARM Programme.

Along its 10 years of work in the Americas, ISARM, being a cooperative effort itself thanks to a partnership with the Organization of American States, has been able to identify and characterize 73 transboundary aquifer systems, drafting the way towards a vision for the shared management of these systems. This is a major achievement for UNESCO that is widely recognized worldwide.

4.2 FROM POTENTIAL CONFLICT TO COOPERATION POTENTIAL – PCCP

The PCCP (From Potential Conflict to Cooperation Potential) programme was conceived with the idea that, although transboundary water resources can be a source of conflict, their joint management can be strengthened and even used as a means for further cooperation. Thus, PCCP aims to demonstrate that a situation with undeniable potential for conflict can be transformed into a situation where cooperation potential can emerge.

The project focuses on the development of tools for the anticipation, prevention and mitigation of water conflicts. Through research and capacity building activities, the programme brings players engaged in transboundary water management together and helps increase the opportunities for cooperation and development, fostering cooperation between nations by supporting and maintaining peace-building processes.

Moreover, it addresses situations where water users need support to manage their transboundary water resources in a peaceful and equitable manner. It capitalizes on the desire of the concerned parties to successfully manage their transboundary water resources in order to create a foundation upon which peace and cooperation are consolidated. It facilitates multi-level and interdisciplinary dialogues in order to foster peace, cooperation and development related to the management of transboundary water resources.

The Latin America and Caribbean region accounts with several initiatives that had been done regarding this issue. The agreement on peaceful management of hydrological and hydro biological resources in the Lake Titicaca basin is a successful example that should be used as a model to foster transboundary water cooperation.

The Ostua Metapan aquifer was the first transboundary aquifer selected as a case study on cooperation in the LAC region. The study illustrates how cooperation can be established for managing groundwater and making a case for the often neglected and non seen water that in turn might be responsible for the supply of entire populations.

4.3 OTHER EXAMPLES OF SUCCESFULL COOPERATION IN LAC

The Trifinio Plan was formulated from a highly participatory process that included a socioeconomic diagnosis of municipalities, a development strategy as well as priority programs and projects of regional and trilateral development. The aim of the plan is to contribute to the Central American integration, through joint action of Guatemala, El Salvador and Honduras, which tends to integral development, harmonious and balanced development of the border region of the three countries. The process towards this pioneer agreement involved planning institutions and bodies of the three governments, in consultation with leaders and local governments.

The Bermejo´s Binational Watershed Strategic Action Program (Argentina and Bolivia) carried out by the governments from both countries through the Binational Commission for the development of the Bermejo and Tarija River High Watershed. Among its aims are encouraging the Bermejo´s transboundary watershed sustainable development by environmental friendly policies, plans and development programs of the different jurisdictions, setting a watershed and transboundary natural resources management vision, fostering the establishment of regional coordination and public participation mechanism, launching programs projects or actions that prevent and solve the non-sustainable use and environmental degradation of the natural resources.

Upon several years of joint studies with support from the international cooperation, the sharing countries of the Guarani Aquifer (Argentina, Brazil, Paraguay and Uruguay) were able to set scientific basis for the development of a strategic action plan, and constituted the first agremment of this type worldwide. This specific case become an example of cooperation for the shared management of transboundary resources, with the commitments of all the four governments.

5 CONCLUSIONS

These are a few examples on how UNESCO and its Member States could support cooperation for the sake of a better management of water resources that could lead to sustainability. Furthermore, the leading scope of UNESCO in the field of sciences, education, culture, and communication gives a broad basis for the member nations to advance in setting the basis for real and effective cooperation.

Cooperation should also be based on trust, colaboration, knowledge, and political will and commitment, together with participatory processes that allow all the involved parties to contribute to sustainable use of water, independently on their role or their location in the overall basin. UNESCO is in a strategic position to lead the process towards peaceful management of natural resources in the benefits of the world’s nations. Its global mandate and its local actions will help the Organization in the pursual of this ambitious achievement.

SESSION 5

WATER FOR ECONOMIC GROWTH AND DEVELOPMENT

SUMMARY

THE ROLE OF WATER IN ECONOMIC DEVELOPMENT

Henry Vaux, Jr.[1]

[1] University of California, Berkeley.

ABSTRACT

The availability of water is almost always necessary for economic growth and almost never sufficient for growth by itself. The connection between water and economic development in the future will most likely be dominated by the need to develop additional food supplies and by the close relationship between water and agriculture. Other inputs to agriculture such as fertilizers and labor will also be required. While economic growth is frequently measured in terms of Gross Domestic Product it is also important to consider the possibilities for increases in productivity of various factors of production . This is especially true of water. Water is rarely priced according to its true scarcity value. For these is reason important incentives to increase the productivity in agriculture in other sectors are often absent. There are a number of ways in which the productivity of water in irrigated agriculture can be increased. These include: 1) improving irrigation network management; 2) planning irrigation systems optimally; 3) accounting for soil intake uniformity; 4) employing techniques and technologies to monitor water use in agriculture constantly; and 5) devising and employing appropriate pricing schemes for water that reflect its true scarcity value. Innovative institutional arrangements will need to be devised if these possible gains in the productivity of water in agriculture are to be realized.

1 INTRODUCTION

Both the availability of water and the development of water resources have always been thought to have a pivotal role in economic development. Regions beset by extreme aridity clearly have limited prospects for economic growth unless adequate water to support growing populations and growing economies can be found. Experience with arid regions is frequently generalized to more humid areas with the result that public officials and others frequently believe that efforts to develop water supplies to ensure that they are constantly and reliably available are sufficient to ensure economic growth. Yet, the fact that regions with ample water supplies do not always flourish economically despite the ready availability of water offer evidence that water be itself does not guarantee economic growth.

To understand the general role of water in economic development it is important to be clear about the conditions that are necessary for economic growth and to distinguish those conditions from others which may be sufficient to ensure economic growth. As a general proposition, a necessary condition for economic growth, is one that must exist for growth to occur. Without such a condition or factor growth will not occur. By contrast, a sufficient condition is one whose presence is enough to ensure or guarantee that growth will occur. As Hanemann (2006), Howe (1968) and others have shown, the presence of water is virtually never by itself sufficient to ensure or guarantee economic growth. The reliable availability of water of adequate quality and in adequate quantities is clearly a necessary condition for economic growth, however, since without water to support people and economies growth cannot occur. In recent decades This principle has been most importantly confirmed by the World Commission on Environment and Development (1987). This Commission is also known as the Brundtland Commission. Indeed, the distinction between necessary and sufficient comditions is one of those that undergirds its famous report, *Our Common Future*.

Some examples maybe useful in clarifying the distinction. In arid lands or lands where rainfall is absent for long periods of time, agriculture cannot be pursued economically if it must rely on precipitation. Clearly, the need for water for irrigation is a necessary condition for economic growth based upon agriculture in arid lands. Yet, the presence of water for irrigation does not guarantee economic growth. It is not a sufficient condition. This is so because growth based on agriculture requires elements in addition to water if it is to be successful. Efficient transportation systems and other arrangements that will allow growers to get their crops to markets are also necessary conditions as are the availability of seed, fertilizer and a modicum of agricultural know how. Another example is the manufacture of chips for computers and other electronic equipment. The manufacture of computer chips requires reliable supplies of very high quality water although in limited amounts. The availability of such supplies is clearly a necessary condition for economic growth based the manufacture of chips. However, there are numerous other factors that must also obtain such as technical knowhow, proximity to markets for chips and/or adequate transportation networks and so forth. Thus the reliable availability of high quality water supplies does not guarantee and is not a sufficient condition for economic growth based on the production of computer chips.

The fundamental principle holding that the availability of water is a necessary but not sufficient condition for economic growth is frequently ignored or forgotten. One explanation lies with the fact that construction of water storage, conveyance and treatment facilities usually entails substantial levels of investment and creates significant numbers of employment opportunities. The economic benefits of such investments tend to be significant only for the immediate short-term although there may be longer term benefits which are usually smaller. The point here is that the economic growth from such investments tends to be more short term in nature- more in the boom and bust sense. Substantial longer term benefits will usually depend upon the presence of other factors which may or may not be present. So, while the construction of water-based public works projects creates potentially attractive economic growth much of that growth may be short term in nature. In the worst cases, the resulting infrastructure creates few or no benefits for the long-term. Thus, water-based projects that are thought to guarantee economic growth frequently fail to do so in the absence of complementary factors. In short, water is virtually always a necessary condition and virtually never a sufficient condition for economic growth (FAGAN, 2011).

2 WATER AND ECONOMIC DEVELOPMENT IN THE FUTURE

There is ample evidence and documentation of the fact that the future will be characterized by intensifying water scarcity (FAGAN, 2011; JURY; VAUX, 2007; VOROSMARTY et al., 2010). This scarcity is characterized by the fact that global population is expected to grow from its 2000 level of 6.5 billion to over 8.0 billion by 2025 and to 9.5 billion by 2050 leading to increase in consumptive use that could be as high as 50% by 2025. Economic growth in the developed world could cause such increases in the demand for water to be even higher. Simultaneously, trends of global deterioration in water quality, anticipated climate change and the loss of some accustomed supplies which are not sustainable (e.g. mined ground water) will likely lead to some shrinkage of supply even while demands increase. This intensifying global scarcity of water is likely to be manifested unevenly from region to region (VOROSMARTY et al., 2010). The regions that are anticipated to experience the most intense scarcity are the Middle, East, large parts of Africa and Southeast Asia. This is disquieting because these are the regions where the population increases will be concentrated and where the capacity of countries to feed existing populations is in question.

In the discussion that follows, the distinction between blue water and green water is important. Precipitation can be divided between blue water, which is ground and surface water available for withdrawal and storage, and green water, which is stored in the soil profile and is available to support plant evapotranspiration (FALKENMARK; ROCKSTROM, 2006). The importance of the distinction lies with the fact that a significant proportion of precipitation is available as green water to support crop plant growth. Indeed, even where agriculture is routinely irrigated (with blue water) some portion of the water utilized by the crop plant is derved directly from precipitation stored in the soil profile. The potential supply of agricultural water cannot be estimated accurately unless both green and blue water are accounted for. Furthermore, the manipulation of green water to reduce unproductive evaporative losses from the soil surface and the acquisition of additional green water through the conversion of new lands to agriculture are both methods of accommodating water shortage in the agricultural sector.

The Falkenmark Stress Index provides a rough approximation of the relative scarcity that is likely to prevail in various countries now and in the future. The index is based on a classification which relies upon estimates of liquid water resources availability, which is defined as surface water flow plus ground water recharge. 1700 m^3 per capita per year of blue water is defined as the amount required for water self-sufficiency. Countries which have this quantity of water can produce the food needed to feed the population and provide the necessary services to sustain human and ecosystem health. Further, countries which have between 1000 m^3 and 1700 m^3 per capita per year are defined as being under water stress while countries with less than 1000 m^3 are said to suffer from chronic water scarcity. (It should be noted that the term scarcity as used here is simply definitional and differs from the customary definition in several ways.) Although this index is arbitrary it does permit reasonable approximations to be made of blue water availability for different countries, both now and in the future (FALKENMARK; ROCKSTROM, 2004).

Using this definition Jury and Vaux (2007) showed that in 1995 some 18 countries were water scarce and 11 more were water stressed. The combined population of the 29 countries was over 450 million. In the year 2025, the number of water scarce countries rises to 29 and the number of water stressed countries rises to 19. The combined population of these 48 countries is estimated to be 2.9 billion. Thus, in 1995 the number of people affected by water insufficiency was relatively small. By 2025 it will be relatively large. It should be noted that these figures are disproportionately affected by the fact that India is expected to fall into the water stressed category by 2025. Thus, both the number of countries and the affected population become more significant by 2025 than they were in 1995. It can be anticipated that these numbers will grow significantly between 2025 and 2050 (JURY; VAUX, 2007).

This analysis is admittedly arbitrary because the definitions of adequacy, stress and scarcity are all arbitrary. There is no necessary reason why the 1700 m^3 per capita per year or the 1000 m^3 per capita per year figures will remain constant or even indicative of adequacy, stress or scarcity over the coming years and decades. Nevertheless, there is corroborating evidence from a variety of sources that more countries and larger populations will be overtaken by water stress and scarcity in the future. The empirical work of Yang et al (2003) shows that a threshold value of 1700 m^3 per capita per year of blue water was reasonable during the period 1980-2000. Raskin et al (1997) defined water stress in terms of the quantities withdrawn annually as a percentage of available annual supplies with values of 40% or more indicating water stress. Seckler et al. (1998) used this index and estimates of projected increases in withdrawals by 2025 to rate countries according to the degree of water stress and scarcity. Though the specifics vary all of these studies arrived at the same general conclusion that over time, more countries and larger numbers of people will find themselves beset by water stress and water scarcity. More recently, Vorosmarty et al. (2010) have completed a study which concludes that 80% of the globe's population lives in areas where water supplies are not secure. The study conclusions are based on a snapshot of global and regional water supply and demand conditions in the first decade of the 21st century. While the study contains no systematic attempt to look ahead, the authors note that the implications of population growth and climate change for the world's water supply will likely pose daunting challenges.

Evidence suggests that population growth will have its largest water related impacts through the agricultural sector and taken with the impacts of continued economic rowth around the world will combine to drive significant growth in agriculture and agricultural water use (VAUX, 2012). Agriculture currently accounts more than 80% of the consumptive use of water world-wide and this may grow as population grows. Moreover, there is a body of evidence that suggests that scarcity will be most prominently manifested through the agricultural sector and that the most significant arena for water related economic development in the future will be the agricultural sector. This suggests that economic development in the future may focus more intensely and directly on the agricultural sector than has been in the case in decades immediately past. Before discussing the ways in which water can be managed to support such growth a word about the economics of development (and its measurement) is in order.

3 DEFINING AND MEASUREING ECONOMIC GROWTH

Economic growth is frequently measured and reported in terms of changes in Gross Domestic Product – also called GDP. Typically, increases in GDP are interpreted as economic growth although changes in GDP per capita tend to correct for changes in population. Per capita growth is often a better – although still approximate – way of measuring the extent to which a population is better off economically over time. The shortcomings of the GDP and per capita GDP measures are at least two in number. First, goods and services that are not monetized or not traded in reasonably well functioning markets are not included in GDP. The failure to account for such non-monitized values as those for environmental services means that GDP is only a proximate indicator of total economic welfare. Second, GDP itself says nothing about the sources or causes of growth, it is simply a measure of the aggregate impact.

As a general rule the term "economic growth" refers to positive changes in the productivity of various factors of production, including capital and labor. Simply stated, increased productivity occurs either as 1) an increase in output per unit(s) of input, or 2) obtaining a constant level of output with fewer units of input. In either event the result is getting more for less. Increased productivity often results from technical change which improves the productivity of labor and/or capital. An obvious example is the advent and dissemination of small computers which increased labor productivity significantly where they were employed. Similarly, a more educated or highly trained workforce can be associated with increases in productivity. The need to increase productivity in agriculture in frequently expressed in terms of water. Increases in water productivity, sometimes expressed as "more crop per drop," is one major way to address intensifying water scarcity.

Other means of addressing water scarcity have been identified. Virtually all of those envision techniques and technologies which expand the use of green water by agriculture. The techniques that have been proposed include: 1) expanding production to lands that are currently not cropped or in pasture; 2) harvesting rainwater from adjacent lands for use as supplementary irrigation; and 3) importing "virtual" water (FALKENMARK; ROCKSTROM, 2010). It should be noted that all of these entail a transfer of water currently allocated to the environment. While the scale of such transfers would be important, the implications for the production of environmental services and amenities is not clear (VAUX, 2012). Although the use of green water may ultimately be critically important in addressing the intensifying scarcity of water for agriculture, it is not clear that they entail increases in productivity. Inasmuch as increases in producitivty are the focus of this paper no further consideration will be given here to green water availability and uses other than those that involve increases in productivty. One example would be more careful management of water in the root zone, a topic this is treated subsequently in this paper.

Increases in water productivity are most frequently thought of and discussed in physical terms. The pertinent concepts are total physical product, which simply increases as inputs are increased; average physical product, which is the amount of output per unit of input; and marginal physical product which is the addition to output with the addition of another unit of input. The basic relationships between these concepts hold that total physical product is maximized where marginal physical product equals zero; and that maximizing average product, as in more crop per drop, may result in the neglect of economic gains that are frequently available where average physical product is declining. For these reasons, prescriptions such as maximizing yield or pursuing more crop per drop do not always result in optimal economic productivity (VAUX; PRUITT, 1983).

Economic productivity is generally assessed with reference to the prevailing prices of inputs and outputs. The pertinent concept is the value of the marginal product in which the price of the input is multiplied times the marginal physical product as in equation 1) below:

1) $P_y = P_i \cdot MPP_i = VMP_i$

where

P_y = the price of the output

P_i = the price of input i (water)

MPP_i = the marginal physical product of the input (water)

VMP_i = the value marginal product of the input (water)

When this condition holds. It ensures that the return from the last unit produced is just equal to the costs of producing it and ensures that the grower maximizes net return. The effect then is to equate increases in marginal physical productivity. Specifically these means shifting the total physical productivity function so that more output is obtained for less input. It then follows that marginal physical productivity will increase.

In the future, factors of production that lack ready substitutes, such as water, will be the focus of efforts to improve their productivity. With many such factors changes in the price signal rising scarcity provide incentives to increase productivity. Unfortunately, water is rarely priced to reflect its actual or approximate scarcity value. Generally, the price of water reflects the costs of capture, transport and treatment where applicable. No value – or a value of zero – is assigned to the water itself. A price of zero signals producers and consumers that the resource in question, water in this case, is freely available. It is not a scarce resource. Yet, this is at odds with the actual situation. In addition without reform in the way that water is priced increasing scarcity will not be reflected in the value of water itself. The result will be a tendency on the part of existing users to ignore increasing scarcity because they signals, price, do not reflect increases. The existence of perverse incentives means that in the future water's role in contributing to economic growth may be significantly attenuated. Appropriate price signals will facilitate management innovations which increase productivity. A number of such innovations are discussed in the next section.

4 INCREASING THE PRODUCTIVITY OF WATER IN AGRICULTURE

Increasing the productivity of water in agriculture is not a simple matter. The low price of water in many locales; the fact that uncertainties about the availability of supplies prior to the growing season as well as throughout it create incentives to apply more rather than less water and the fundamental variability of agricultural soils and cropping systems all work to discourage improvements in water productivity. In addition, water productivity can be limited by other factors such as the nutritional status of crops, weeds, pests and climatic variables. These factors which both constrain and weaken incentives to enhance water productivity are present in both the developed and developing world. There are, nevertheless, numerous opportunities to increase water productivity. These are not limited to technological and management measures but include important social, cultural and economic factors. Fereres (2011) notes that the possibilities for modifiying crop plant genes and/or the environment in which crops are grown are quite limited. However, there are numerous options for improving the fashion in which water is managed both at the field and basin levels.

Improving Irrigation Network Management Many irrigation systems throughout the world are inherently inefficient. Thus, for example, it has been asserted frequently that more than half the water diverted for irrigation is lost. Clemmons (2006) has shown, for example, that in large systems the irrigation efficiency may typically be less than 50%. There are several explanations for this. Some systems were designed in times and places where water was plentiful and the main objective was simple to ensure that the water was distributed. In other cases, systems do not have the capacity to deliver water on demand. Here, water is simply run in conveyance facilities for set periods of time and irrigators are invited to take whatever quantities they want. Many – even most – systems lack the capacity to monitor and measure flows of water and quantities delivered to the field. In all of these circumstances, improving water productivity may be infeasible because of the constraints imposed by the irrigation systems network. All of these shortcomings create incentives that are perverse to improvement of water productivity. Improvements at this scale could have large water conservation benefits relative to what can be gleaned at the individual field level (FERERES, 2011).

Optimal Irrigation Planning Most irrigators world-wide lack timely and sufficient *a priori* knowledge about the quantities of water that will be available to them over the course of the season. This means that they must behave conservatively or face larger risks in selecting crops and managing risks. What is needed are decision support systems that allow growers to chose the quantities of water to allocate to different crops. At a minimum such decision support systems should include information about how crop yield varies as a function of the timing and quantities of water applied. In different terms, decision support systems and the underlying models which provide growers with more complete and certain information about the implications of the timing of irrigation and the quantities applied for yield reduce uncertainty and tend to lead to decision to better decisions in terms of how water can be used most productiviely (STUDETO; HSIAO; RAES; FERERES, 2009).

Accounting for Soil Intake Uniformity The characteristics of the soil underlying most fields are variable and this means, for example, that the rates at which water is taken in by the soil vary. Typically, growers take a very conservative approach to this class of soil non-uniformity. This means that the apply to the entire field the quantity of water needed by that portion of the field where infiltration rates are lowest. This means that the remainder of the field gets more water than is necessary and results in run-off and deep percolation that may or may not be re-used. In addition, Fereres (2011) shows how the extent of soil intake non-uniformity has very significant Managing water at the field level in ways that accommodate this type of environmental variability can yield significant gains in water productivity. Thus, for example, the use of closed conduit irrigation technology such as drip and microsprinkler systems allows water to be applied at rates that are less than the maximum soil intake rate with the result that the quantitiy of applied water lost to run-off and deep percolation is minimized.

Optimal Irrigation Scheduling Irrigation scheduling techniques are already available but not widely used. Generally, such techniques utilize crop evapotranspiration data and weather data to tell the grower how much water to apply and when to apply it. Largely, it is underutilized because of perverse incentives. One innovative scheduling development which may see expanded use in the future is regulated deficit irrigation (RDI) which can be employed where available water is insufficient to meet crop water demands. RDI when applied to tree and vine crops can maintain growers' income while reducing water use. This is because moisture stress is employed on the crop strategically at stages in the crop life cycle when lack of moisture has the least impact on yield. The key is to ensure that moisture stress is not imposed during the flowering and post flowering stage of the crop life cycle. This helps to ensure that the reduction in crop yield is less than proportional to the reduction in water use. In some instances, crop quality is improved even when the size of the yield is reduced (FERERES; SORIANO, 2007).

Monitoring Irrigation Performance One fundamental problem stems from the inherent variability of soil, crop and irrigation characteristics. Single point estimates cannot adequately reflect the performance of irrigation on an entire field. New remote sensing technologies are becoming available which permit the assessment of field and other properties with enough precision to evaluate performance and identify areas in which improvements can be made. In addition, high levels of water productivity can only be achieved with reasonable precise real time measurements which permit water managers to know the moisture status of both the soil and the crop at any given time. Measuring and monitoring lack political appeal. This is highly unfortunate because without it there is no way of knowing whether productivity is actually being improved as a consequence of some of the measures discussed here.

Social and Economic Constraints on Productivity Improvements There are a variety of social and economic factors that combine to reduce and/or eliminate incentives to enhance and increase the productivity with which water is used in agriculture. First, growers often do not have the information necessary to allow water to be managed with precision at the field level. Behavior in these circumstances tends to be conservative because the risks of under irrigating are almost always than those associated with overirrigation. The response is to do what is necessary to protect yields and ensure that they are maximized subject to the applicable constraints. Such behaviour neglects formal water productivity altogether and results in less productivity than could be achieved under the circumstances.

Water is underpriced virtually everywhere. This is attributable to the fact that it is subsidized in many locales and also to the fact that utility pricing rules sometimes ensure that the prices actually paid for water are less than the true scarcity values. This signals the water user that the resource is more plentiful than it is in fact and discourages behaviour which would economize on use by increasing water productivity. It is similarly important to have well defined water rights as well as some flexibility for transferring water away from low valued uses toward higher valued uses. A further perverse incentive surrounds the fact that it is frequently unclear who has rights to water that may be saved or conserved as a consequence of efforts to improve water productivity. Gleick and others have documented the fact that most such water is simply applied to new irrigated lands and used to expand agricultural production. There are no formal rules requiring this and that lack of clarity about what should and can be done with conserved water surely constrains advances in productivity.

5 CONCLUSIONS

The connection between water and economic growth has long been acknowledged. However, experience shows that development and provision of water supplies is rarely, if ever, sufficient to guarantee economic growth. In usual circumstances, the availability of water is necessary for growth to occur but economic growth itself requires an assemblage of factors for success. Appropriate technology, the availability of labor and the availability of resources and other factors of production that complement water are also necessary.

There are at least two measures of economic growth that are commonly used. Gross Domestic Product (GDP) is one common measure of growth. It is based upon the aggregate value of all goods and services produced in a region or nation. GDP is frequently used to assess and measure rates of economic growth. It has advantage of reflecting overall growth but unless it is disaggregated it fails to reveal the causes of growth. A second measures focuses on the productivity of different factors of production. Labor productivity is the most frequently cited but growth in the productivity of water is pertinent to a situation in which water is projected to become scarce. Water productivity is frequently expressed in terms of physical product but this ignores issues of valuation. Productivity can be measured by weighting physical productivity with the relevant prices of inputs and outputs. The fact that water is not often priced according to its scarcity value means that measures of its productivity may be misstated and that incentives to increase productivity may be weak or distorted.

For the future, the productivity of water in agriculture globally is like to be a key component of economic growth. This is so because population is expected to grow by approximately 3 billion between now and 2050 and economies around the world are also expected to grow. These factors will stimulate the demand for water, and especially the demand for agricultural water, which will be derived from the demand for food. If the world is to prosper economically, enough food will have to be produced to feed the growing population and to accommodate changes in dietary patterns that are associated with economic development. Given that water demands will grow at a time when supplies may be shrinking because of pollution, the economic exhaustion of non-renewable water sources and climate change, it will be essential to increase the productivity of water in agriculture.

There are a number of ways in which such productivity increases can be accomplished. Improving the management of agricultural water distribution networks; better planning for available irrigation supplies and the development of decision support tools to reduce uncertainty about the availability of water are examples of how agricultural productivity can be increased. New management strategies which account for the non-uniform nature of agricultural soils and climatic variation will also be important. Monitoring irrigation performance will be essential to provide the feedback needed to irrigate as efficient and productively as possible. Monitoring will provide growers with a least a portion of the information needed to manage irrigation water with precision. Finally, water will need to be priced according to its scarcity value both to signal users about its relative scarcity and to provide incentives to invest in the techniques and technologies needed to increase the productivity of water in agricultural uses.

REFERENCES

Clemmons, A.J. 2006. Improving Irrigated Agriculture Performance Through an Understanding of the Water Delivery Process. Irrigation and Drainage. Vol. 55. No 3. pp.223-234.

Fagan, Brian. 2011. Elixir: A History of Water and Humankind. (New York, NY: Bloomsbury Press). pp. 384.

Falkenmark, M. and J. Rockstrom. 2010. Integrating Agricultural Water Use With the Global Water Budget. In A. Garrido and H. Ingram, eds. Water for Food in a Changing World. (London, UK: Routledge Press). pp. 103-116.

Falkenmark, M. and J. Rockstrom. 2006. The new Green and Blue Water Paradigm: Break New Ground for Water Resources Planning and Management. Journal of Water Resources Planning and Management. Vol. 123. No. 3. pp. 129-132.

Falkenmark, M. and J. Rockstrom. 2004. Balancing Water for Humans and Nature: The New Approach to Ecohydrology (London, UK: Earthscan). pp. 247.

Fereres, Elias. 2011. Optimizing Water Productivity in Food Production. In A. Garrido and H. Ingram, eds. Water for Food in a Changing World (London, UK: Routledge Press) pp. 13-32.

Fereres, E. and M.A. Soriano. 2007. Deficit Irrigtion for Reducing Agricultural Water Use. Journal of Experimental Botany. Vol. 58. No. 2. pp. 147-159.

Hanemann, W.M. 2006. The Economic Conception of Water. In Peter P. Rogers, M. Ramon Llamas and Luis Marinez-Cortina, eds. Water Crisis: Myth or Reality? (London, UK: Taylor and Francis). Pp. 61-91.

Howe, C.W. 1968. Water Resources and Regional Economic Growth in the United States 1950-1960. Southern Economic Journal. Vol. 34. No. 4. April.

Jury, William A. and Henry J. Vaux, Jr. 2007. The Emerging Global Water Crisis: Managing Scarcity and Conflict Between Water Users. In Don Sparks, ed. Advances in Agronomy. Vol. 95 (New York, NY: Elsevier). pp. 1-76.

Raskin, P., P. Gleick, P. Kirshen, R. Pontiums and K. Strzepek. 1997. Comprehensive Assessment of the Freshwater Reesources of the World. Document Prepared for The U.N. Commission on Sustainable Development. 5th Session. Stockholm Environ- mental Institute, Stockholm, Sweden/

Seckler, D., U. Amarasinghe, D. Molden, R. DeSilva and R. Barker. 1998. World Water Demand and Supply, 1990 to 2025: Scenarios and Issues. International Water Management Institute Research Report 19. International Water Management Institute. Colombo, Sri Lanka.

Studeta, P., T.C. Hsiao, D. Raes and E. Fereres. 2009. AquaCrop: The FAO Crop Model To Simulate Crop Response to Water I: Concepts and Underlying Principles. Agronomy Journal. Vol. 101. No. 3. pp. 426-437.

Vaux, Henry. 2012. Water for Agriculture and the Environment: The Ultimate Trade-Off. Water Policy. Vol. 14. No S1. pp. 136-146.

Vaux, H.J. and W.O. Pruitt. 1983. Crop-Water Production Functions. In D. Hillel, ed. Advances In Irrigation. Vol. 2. (New York, NY: Academic Press). pp. 61-93

Vorosmarty, C.J., P.B.McIntyre, M.O. Gessner, D.Dudgeon, A. Prosevich, P. Green, S.E. Bunn, C.A. Sullivan, C. Reidy Liermann and P.M. Davies. 2010. Global Threats to Human Water Security and River Biodiversity. Nature. Vol. 467. pp. 555-561.

World Commission On Environment and Development. 1987. Our Common Future. Report Transmitted to the U.N. General Assembly (Oxford, UK: Oxford University Press). Chapter 2.

Yang, Hong. Peter Reichert, Karim Abbaspour and Alexander J.B. Zehnder. 2003 A Water. Resources Threshold and Its Implication for Food Security. Environmental Science and Technology. Vol. 37. pp. 3048-3054.

THE ADVANCES OF SCIENCE AND TECHNOLOGY ALLOW USING WATER FOR INCREASING DEVELOPMENT OF MOST COUNTRIES

Maite M. Aldaya[1]
Elena Lopez-Gunn[2]
Manuel Ramón Llamas[3]

[1] Complutense University of Madrid and Water Observatory of the Botin Foundation. Consultant, United Nations Environment Programme.

[2] Complutense University of Madrid and Water Observatory of the Botin Foundation.

[3] Royal Academy of Sciences of Spain. E-mail: mramonllamas@gmail.com. Complutense University of Madrid and Water Observatory of the Botin Foundation.

ABSTRACT

This piece of work provides examples in the last fifty years of scientific and technological innovations that provide relatively easy, quick and affordable means of addressing key water management issues. Scientific knowledge and technological innovation can help enhancing water efficiency and management and coping with physical water scarcity. Four of these tools are discussed in this chapter: a) the opportunities afforded by virtual water trade and the water footprint approach; b) the silent revolution for beneficial use of groundwater; c) salt water desalination; and d) finally the use of remote sensing and GIS. Together these advances are changing the options available to address water and food security that have been predominant for centuries in the minds of most water decision-makers.

1 INTRODUCTION

Even though water resources are unevenly distributed and, in some regions precipitation and drought conditions seem to be increasing, the world's water problems are due to bad governance, rather than physical water scarcity (DE STEFANO; LLAMAS, 2012; ROGERS et al., 2006; UNDP, 2006; LOPEZ-GUNN; LLAMAS, 2008). This affects rich industrialized and poor developing countries alike, but it is usually the poor who suffer most.

Globally, more water is used in food production than in other sectors, accounting for 70 percent of freshwater use, and an even higher percentage in arid and semi arid countries (COMPREHENSIVE ASSESSMENT OF WATER MANAGEMENT IN AGRICULTURE, 2007; UNESCO- WWAP 2009). Any advances made in direct or indirect agricultural water management will translate in gains by other sectors – which often have higher economic returns or added value like industry, urban water supply and sanitation or environmental services- which at present are not benefiting globally from water captured by irrigation.

Scientific and technological advances in the last half century have produced tools to solve many water related problems that a few decades ago seemed unthinkable. This paper in its sections 3, 4 and 5 is to a certain extent an update of the previous work developed by Lopez-Gunn and Llamas (2008), but its section 2 is totally new. The paper in general looks at recent advances in science and technology to address water scarcity. It looks at four options which are cheap, already available and accessible to highlight choices already being taken by different countries to allocate water between competing uses. In particular, the four key options presented to address the water 'crisis' are; 1) the key strategic relevance of virtual water and a country's water footprint particularly for arid countries: virtual water, embedded in agricultural commodities can be 'exported' from water rich countries to irrigation based poor economies, encouraged by the low cost and speed of food distribution; 2) the silent revolution of groundwater use: cheap and easy groundwater abstraction has produced great social economic benefits, providing drinking water and reducing hunger, especially among the poor; 3) desalination, which can turn salt water into fresh water suitable for urban supply and 4) finally - although briefly- the potential of new technologies from the information age, like remote sensing, GIS and internet. The paper discusses these advances in knowledge and technological innovation at the global level. Some theoretically relevant advances that are currently under discussion are not considered. For example, biofuels, the genetic engineering to obtain salinity and drought resistant crops. We have instead preferred to comment only factors that are easily available and relatively cheap.

The mentioned technologies and approaches can for example, help address the use of water by irrigation in semi-arid regions of the world, in order to help achieve the Millennium Development Goals (MDGs), in particular the MDG on combating poverty and hunger. Ultimately, these tools and approaches are helping to ensure global water supply and water-dependant food security.

2 VIRTUAL WATER TRADE AND WATER FOOTPRINT

The concept of virtual water was introduced by Tony Allan in the nineties (ALLAN, 1993, 2011), when he studied the possibility of importing virtual water as a partial solution to problems of water scarcity in the Middle East. The virtual-water content of a product is the freshwater 'embodied' in the product. It refers to the volume of water consumed or polluted for producing the product, measured over its full production chain. For example, it takes about 1,000 litres of water to produce a kilogram of wheat, but 16 times as much to produce a kilogram of beef (ALLAN, 2011). This is a key advance in addressing the current water crisis because it allows calculating fairly accurately the water embedded in the production of any good or service. Quantifying and accounting for water flows within the economy (including environmental needs) and related impacts in the appropriate time and spatial scales, would allow to attain transparent information to develop robust allocation and management systems.

At present, the total global water resources amount to about 110,000 km^3/year, of which *green water* -i.e. water stored in the soil- is calculated at 70,000 km^3/year, whereas *blue water* -i.e. fresh surface and groundwater- account for 40,000 km^3/year (UNESCO-WWAP 2006). Of all global water available blue and green, human water use is around 8%, while environmental water requirements represent about 92% (COMPREHENSIVE ASSESSMENT OF WATER MANAGEMENT IN AGRICULTURE, 2007). Regarding the human water use, agriculture is by far the most important user, with 70% of the total withdrawal, while industry accounts for 20% and domestic water use 10% (COMPREHENSIVE ASSESSMENT OF WATER MANAGEMENT IN AGRICULTURE, 2007; UNESCO-WWAP, 2009; UNEP, 2011a). When considering consumptive use, the agricultural percentage is even higher, reaching the 90% of total water consumption (MEKONNEN; HOEKSTRA, 2011, Table 1). The diffuse pollution in agriculture also seems to be the most challenging when looking at the grey water footprint, which is a theoretical and still controversial indicator to quantify water pollution from an ecosystem perspective (Hoekstra et al., 2011a, Table 1).

Table 1 - Global water footprint (WF) of production (1996-2005)

	Agricultural production					
	Crop production	Pasture	Water supply in animal raising	Industrial production	Domestic water supply	Total
Global WF of production (Gm^3/yr)						
- Green	5771	913	-	-	-	6684
- Blue	899	-	46	38	42	1025
- Grey	733	-	-	363	282	1378
Total	7404	913	46	400	324	9087
WF for export (Gm^3/yr)		1597		165	0	1762
WF for export compared to total (%)		19		41	0	19

Source: Mekonnen and Hoekstra (2011)

As seen in Table 1, most of the global virtual water flows concern agricultural commodity trade. Nowadays it is widely recognized that international trade in agricultural products can contribute to addressing problems related to the unequal geographical distribution of water (ALLAN, 2011; HOEKSTRA, 2010; HOEKSTRA et al., 2011b; JACKSON et al., in press; UNEP, 2011b). In fact, current global virtual water trade has a moderating impact on the demand for irrigation water, as three of the four major exporters (United States, Brasil and Argentina) produce in highly productive rainfed conditions. (ALDAYA et al., 2010; DE FRAITURE et al., 2004; MEKONNEN; HOEKSTRA, 2011) (Figure 1). While major exporters produce under rainfed cultivation, most importers would have relied (at least partially) on their blue water resources. The virtual water trade can efficiently redistribute global water and partially help to address the impacts of production. Virtual water trade, thus, can play a role in ensuring water and water dependent food security in water-short countries.

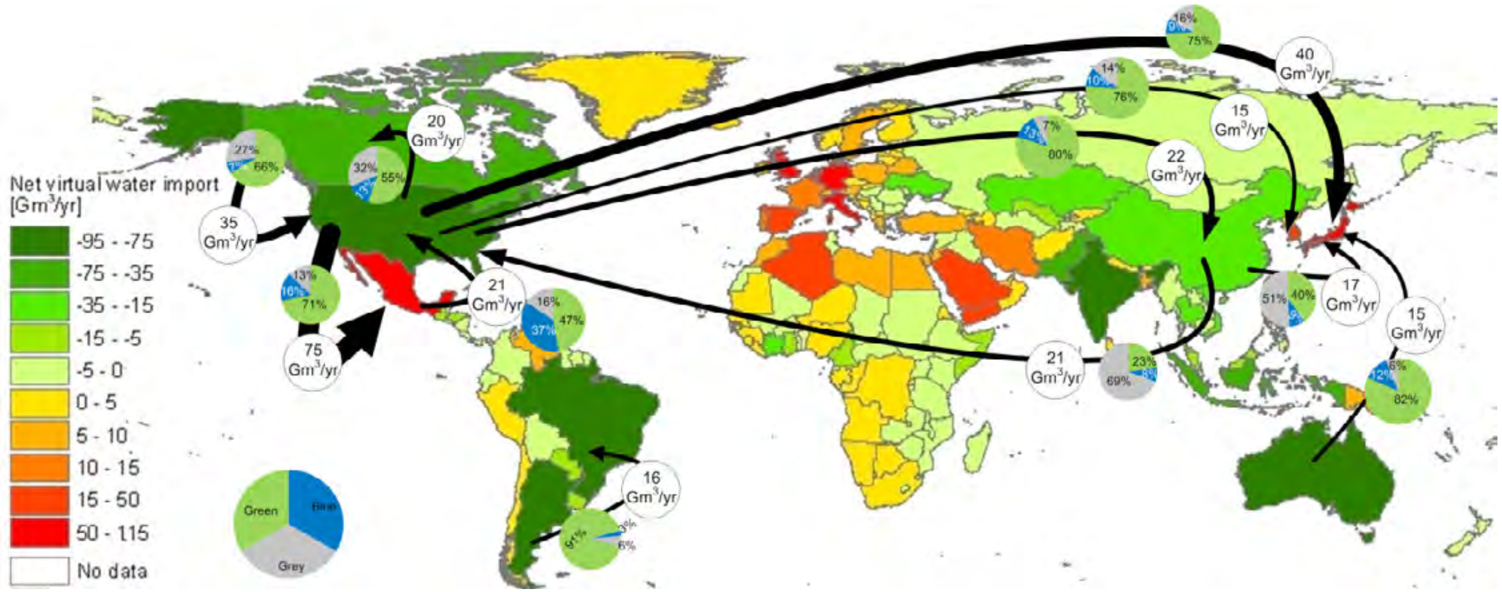


Figure 1 - National virtual water balances. Arrows show gross virtual water flows >15 Gm³/yr (1 Gm³ = 1 Km³)
Source: Mekonnen and Hoekstra (2011)

On the other hand, if effective national and international policies and incentives are not properly developed and implemented, virtual water trade can have negative side effects. International trade in water-intensive commodities takes water in the exporting countries, which can no longer be used for other (domestic) purposes. Besides, the social and environmental costs that are often associated with water use remain in the exporting countries; they are not included in the price paid for the products by the consumers in the importing countries.

It is well-known that water is seldom the dominant factor determining trade in water-intensive commodities. Many factors influence virtual water trade, such as direct or indirect subsidies, availability of land, labor, technology, level of socio-economic development, national food policies and international trade agreements (ALDAYA et al., 2010; ROGERS; RAMIREZ-VALLEJO, 2011). Currently, virtual water flows are mainly subordinated to world trade rules (HOEKSTRA et al., 2011b). The European Single Market and WTO frameworks are suited to address the link between international trade and sustainable water use. Hoekstra (2010) identifies several mechanisms to better ensure that trade and sustainable water use goes hand in hand such as product transparency or an international water pricing protocol. More recently, the WTO has started looking at the WTO interventions that can influence water-related policies on either the production side (irrigation subsidies) or the consumption side (water footprint labeling) (JACKSON et al., in press). More work is needed to clarify key concepts and to enhance transparency in order to have a more comprehensive understanding of the ways in which these rules alter water resource outcomes.

Even if it is not yet widely recognised, the private sector has also a vital role to play in food-water securitization. Private sector food supply chains operate beneath a complex pact between the state and the market. The agents in these food supply chains – mainly farmers - determine whether food-water is managed sustainably and securely (ALLAN, 2012; SOJAMO et al., 2012).

Water and food security is today much more related to economic capacity and trade, than to physical water scarcity. Knowledge about the virtual water flows entering and leaving a country can cast a completely new light on the actual water scarcity of a country. This shift in perception means that it forces a re-consideration of what are the main problems of food security, away from pure physical scarcity and technological fixes. The main issues that have to be addressed globally in relation to food security are: first, the hidden oligopolies that currently exist in the WTO, the potential threat of political embargoes and the need for domestic social changes to be fulfilled.

The water footprint concept was introduced by Hoekstra in 2002 (HOEKSTRA, 2003) when looking for an indicator that could map the impact of human consumption on global freshwater resources. It refers to all forms of freshwater use (consumption and pollution) that contribute to the production of goods and services consumed by the inhabitants of a certain geographical region (HOEKSTRA et al., 2011a).

On one hand, one can talk about the water footprint of a product, which is the amount of water consumed directly (operations) or indirectly (supply chain) to produce the product and is synonym to the virtual water of a product. On the other hand, one can talk about the water footprint of an individual, which refers to the total amount of freshwater used to produce the goods and services (direct and indirectly) consumed by this individual. In the first case, the water footprint of products; the basic information provided by water footprints can be used by the private sector to perform risk assessment, as a planning tool, to identify hotspots in their supply chains or to couple it with tools like Life Cycle Assessment (LCA) methods in order to perform benchmarking of products. In the second case, the WF of individuals or the inhabitants of a given region or country; the basic information provided by WFs can be used by governments, academia, NGO's or other organisations for awareness raising or for understanding changes and trends in consumption patterns as related to water resources. In addition, it can also be used by a third sector, water management, which generally concerns a geographic area. Applying the water footprint for water management purposes allows for the comparison of the water footprints of water consuming and polluting production sectors in a certain geographic area with the availability of water in the specific geographical area to inform water management decision making (UNEP, 2011b). In all the cases a water footprint assessment has four distinct phases: Setting goals and scope, water accounting, sustainability assessment and response formulation (HOEKSTRA et al., 2011a).

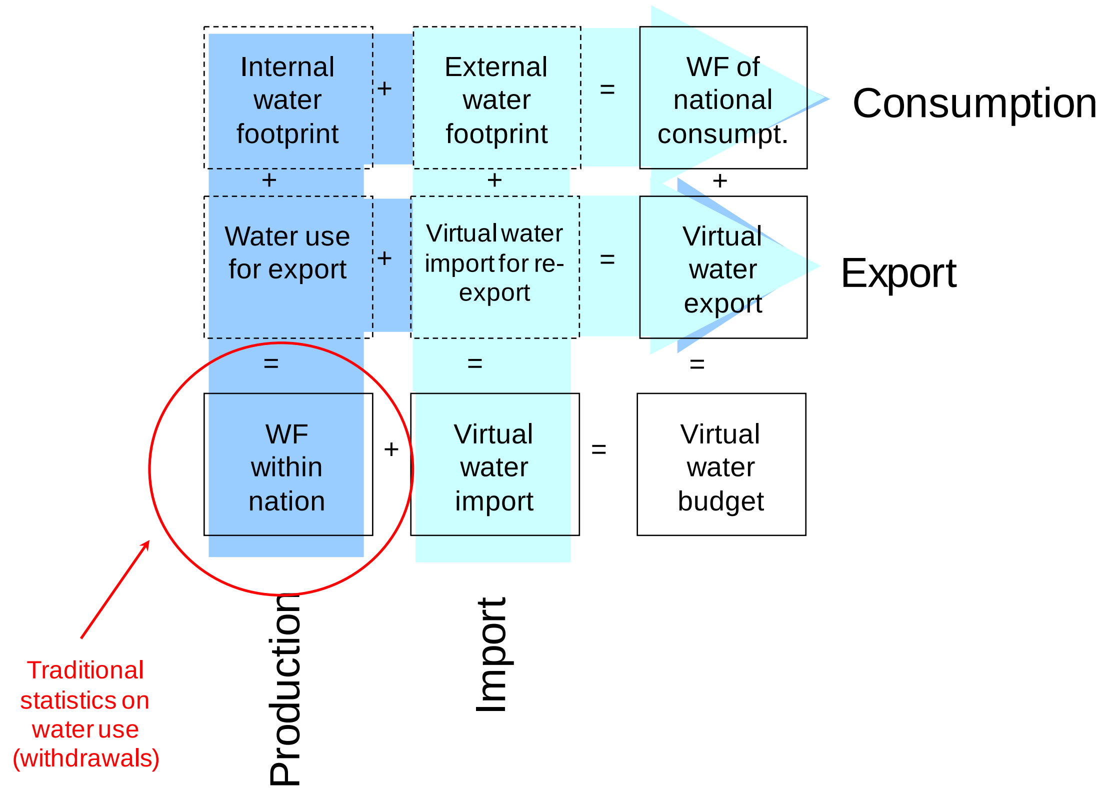


Figure 2 - National water accounting framework
Source: Hoekstra et al. (2011a)

The water footprint indicator provides key new information to policy makers that can complement the classical measure of water withdrawals (Figure 2). Traditional national water use accounts only refer to the direct blue water withdrawal within a country, whereas the water footprint assessment provides information on green and blue water consumption and pollution (grey water) including data on direct and indirect water use (virtual water flows). By looking only at water use in the own country, most governments have a blind spot to the issue of sustainability of national consumption. This makes the water footprint very different from other indicators and very useful for achieving a more Integrated Water Resource Management (IWRM). In order to support a broader sort of analysis and better inform decision making, the national water use accounts could be extended. Making national water footprint accounting a standard component in national water statistics would provide a stronger information basis to formulate a national water plan and river basin plans that are coherent with national policies with respect to the environment, agriculture, energy, trade, foreign affairs and development cooperation (HOEKSTRA et al., 2011a).

More and more are the studies recognizing the usefulness of the water footprint as a green indicator providing part of the information regarding water resource management (FRENCH GOVERNMENT IN MORDANT AND PASQUIER, 2012; UNEP, 2011b). At the national level Spain is the first country that has included the water footprint analysis into governmental policy making in the context of the EU Water Framework Directive (OFFICIAL STATE GAZETTE, 2008) and a sustainable tourism regulation, so-called Plan FuturE (OFFICIAL STATE GAZETTE, 2010). However, there is a need for a systematic, standardized and comprehensive water accounting systems (UNSD, 2012).

Water accounting is necessary but not sufficient to properly manage water resources. There is a need to integrate water accounting information (volumes of consumptive and non-consumptive water use, pollution data) with socio-economic and environmental figures and intangible values along supply-chains (cultural, religious, political, educational and others).

Hitherto, environmental water requirements, mainly green, have rarely been taken into account in water resources management, even if considered the main water user (Comprehensive Assessment of Water Management in Agriculture, 2007). Few are the studies including both the aquatic and terrestrial ecosystem water requirements, even if recent studies imply that this might be crucial (ALDAYA et al., 2010; SALMORAL et al., 2011; WILLAARTS, 2012) (Figure 3).

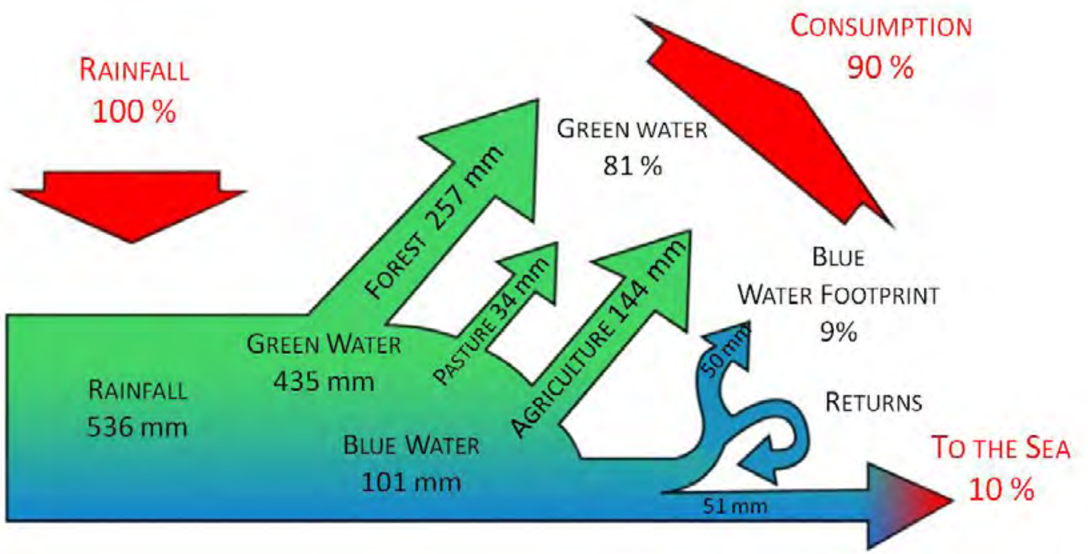


Figure 3 - Water balance in the Guadalquivir river basin
Source: Salmoral et al. (2011)

Another factor to consider is the economic dimension of water management (Figure 4). A water productivity analysis can be useful to make strategic choices by different countries on whether water is used for high value uses such as urban water supply, industrial uses or cash crops (e.g. vegetables, fruit and flowers), or low value ones (like growing cereals or alfalfa) (UNESCO- WWAP 2006).

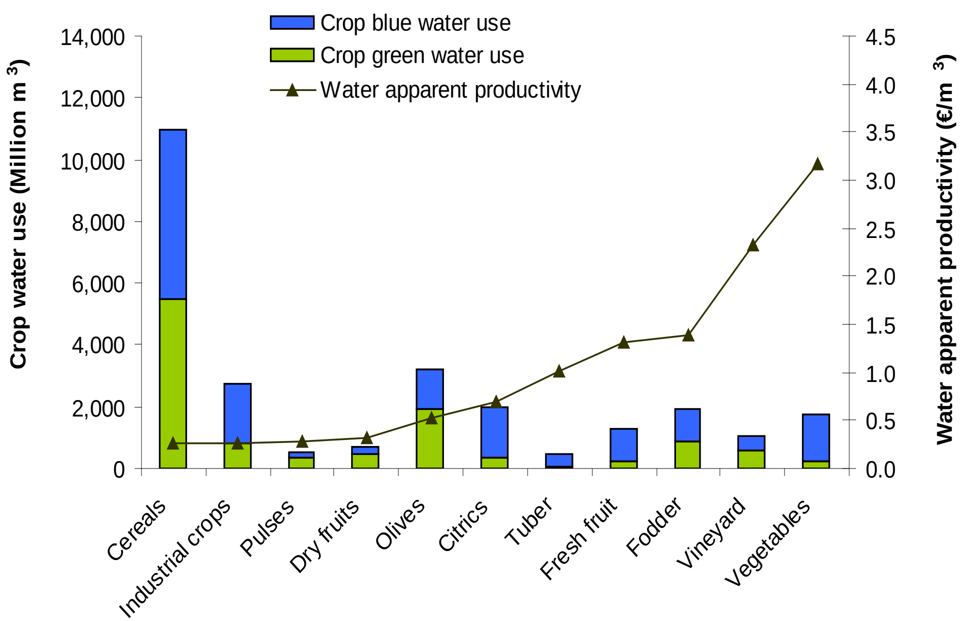


Figure 4 - Water apparent productivity and blue and green water footprint of crop production in Spanish agriculture (2002)
Source: Garrido et al. (2010)

One of the most relevant consequences of the water footprint and virtual water trade knowledge in arid and semiarid countries such as Spain is the change in the water security and food security concepts, paradigms that have hitherto prevailed in the minds of most policy makers. This comes from a food self-sufficiency tradition that will probably change in the near future. Previous works support that water crisis is a problem of water management in relation to various aspects, such as obsolete irrigation systems or excessive blue water use for growing low economic value crops (LLAMAS, 2005A; UNDP, 2006; COMPREHENSIVE ASSESSMENT OF WATER MANAGEMENT IN AGRICULTURE, 2007). Along these lines, the water footprint analysis is providing new data and perspectives that are enabling to form a more optimistic outlook of the frequently spread looming ‘water scarcity crisis’.

3 THE SILENT REVOLUTION: THE INTENSIVE USE OF GROUNDWATER

In terms of re-considering physical water scarcity and the need to question 'technological fixes' largely spearheaded by central or national government, the next great advance is the silent revolution – groundwater use. The silent revolution has happened in the last half century in practically all arid or semi-arid regions across the world (Figure 5). A first wave took place in California, Italy, Mexico and Spain followed by a second wave in Asia, with a large part of India and the North China plains to parts of the Middle East and North Africa (SHAH et al., 2007). It is called a revolution because it has led to dramatic changes in water use and food policy in these regions. It is also called 'silent' because it has been mainly undertaken by millions of small farmers, with little control and planning on the part of the government administration (FORNÉS et al., 2005; LLAMAS; MARTÍNEZ-SANTOS, 2005; LLAMAS, 2006b). It is estimated that global groundwater abstraction rose from a base level of 100-150 Mm^3 in 1950 to about 950-1,000 Mm^3 in 2000. In turn farmers abstract 900 Mm^3 of water to generate $210–230 billion, with a gross productivity of about $0.23–26 per m^3 abstracted (SHAH et al., 2007).

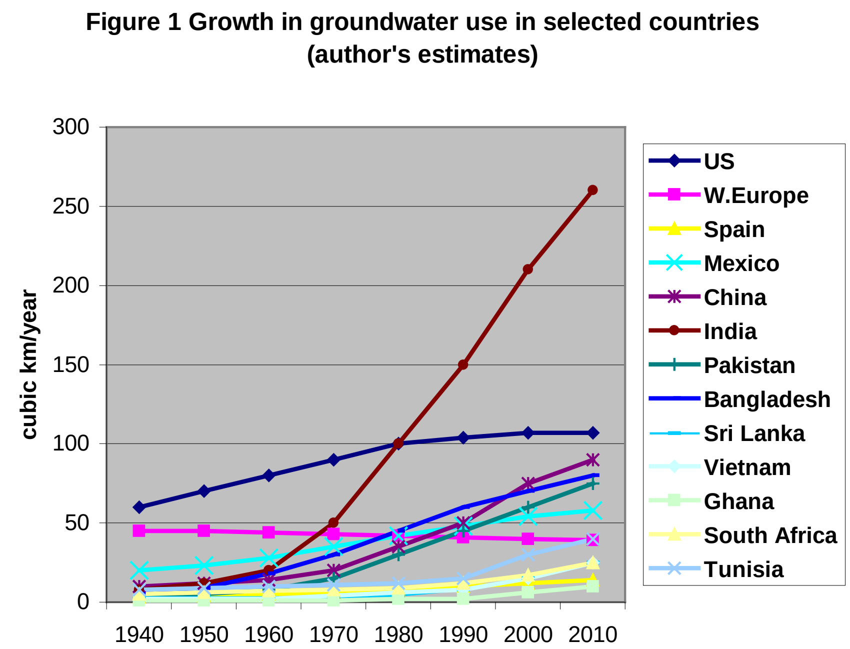


Figure 5 - Growth in groundwater use in selected countries
Source: Lopez-Gunn and Llamas (2008)

The strategic importance of groundwater can be fully appreciated when considering specific data; globally 25% of global irrigation depends on groundwater, although in arid and semi arid areas this percentage goes up to 60% of irrigated agriculture. In terms of hectares the official number is estimated at 69 m ha, although other studies indicate that the actual figure might be closer to 100 m ha (from 30 m ha in 1950) (SHAH et al., 2007; UNESCO-WWAP, 2006). What is also highly relevant is that most of this land and 80% of groundwater abstracted is in some of the most heavily populated countries in the world like Bangladesh, Pakistan, India and China; or otherwise economically crucial for global food trade, like the United States.

Considering that by 2030, over 60% of the population will live in urban areas, claiming an increasing share of water abstraction (UNESCO-WWAP, 2006) it is crucial to appreciate the role of groundwater in public water supply. It is estimated that groundwater systems globally provide 25 to 40% of the world's drinking water (MORRIS et al., 2003). Another estimate calculates that more than half the world's population relies on groundwater for its drinking water supply (COUGHANOWR, 1994). In 2004 more than 2 billion people relied on groundwater for their daily supply (KEMPER, 2004). In terms of scale, groundwater is crucially important in the world's mega cities and hundreds of other major cities which make significant use of groundwater (FOSTER et al., 1998). In Europe for example, a substantial part of the population depends on groundwater for public water supply. Finally, groundwater is a useful back up in water supply gaps during long dry seasons and droughts, offering drought resilience. Managed aquifer recharge, shallow groundwater management, and rain water harvesting and recharge can, in fact, provide more resilient (and safe) drinking water systems in water short communities, especially relevant in the context of climate change.

The main reason for the huge explosion in the use of groundwater resources is technological innovation. The introduction of increasingly cheap tube well and mechanical pump technology and its wide availability has facilitated a social revolution in the use of groundwater, which has produced great socio-economic benefits (see Figure 6) (GIORDANO; VILLHOLTH, 2007). This is probably because of the autonomy and empowerment groundwater offers since it can be developed by individual farmers or small groups. Although operating costs might be higher (due to e.g., electricity costs), initial capital investment is much lower per irrigated hectare. Users can pump groundwater when needed, with precise application (e.g., when crops need water most), which can greatly increase yields (UNESCO-WWAP, 2006). Groundwater has been vital to yield and production increases, and in turn, has helped to reduce rural poverty (MOENCH, 2003). Intensive groundwater use has allowed rural communities to undergo a social transition thanks to improved farm incomes, the education of a younger generation and the migration of most of the family to nearby cities. This is, for example, evident in the Middle East where permanent shifts have occurred (Allan, 2006), and in South Asia where there are flexible and diverse adaptive part-time modes of rural – urban interaction.

There is some evidence that groundwater in fact promotes greater interpersonal, intergender, interclass and more spatial equity than surface water use (SHAH et al., 2007). This is particularly the case in the use of shallow groundwater wells. It is estimated that groundwater is critical to the livelihoods and food security of approximately 1.2–1.5 billion rural households in the poorest regions in Asia and Africa (SHAH et al., 2007).

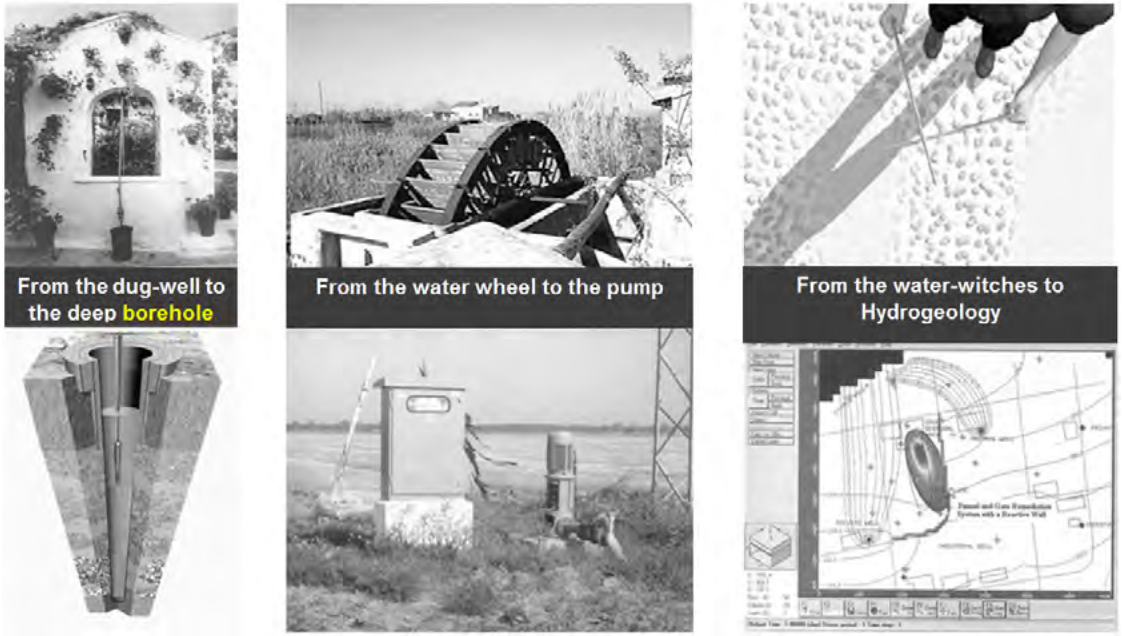


Figure 6 - Technological changes in generating a silent groundwater revolution

Groundwater provides flexible, on demand, irrigation to support vibrant wealth-creating agriculture (SHAH et al., 2007). In India it has allowed 'small' irrigation to truly revolutionize agriculture in the country. This has been achieved mainly through the abstraction of 200 Mm^3/yr, from about 20 million wells to irrigate about 50 million hectares, i.e., 60% of the land (SHAH, 2005). In a recent report of the World Bank, this situation has been described as a 'quiet revolution' (BRISCOE, 2005). These efforts have been mainly undertaken and financed by small farmers or small municipalities, and the pattern extends to most of South East Asia, including Pakistan and Bangladesh (SHAH et al., 2006). In extremely poor countries, with less than 1$/per capita/per day, - where 500 million people live - the NGO International Development Enterprise (or IDE) created in the last 20 years a simple pedal operated pump (POLAK, 2005), which has allowed these areas to evolve in a relatively short space of time to a diesel or electric pump. Meanwhile, in mid-range countries, a potential initial solution will be the intensive use of groundwater (LLAMAS, 2005b; ALLAN, 2007).

Therefore groundwater is a key resource often underestimated in global water budgets in helping meet the Millennium Development Goal on poverty and malnutrition. This is mainly due to its affordability, and low abstraction cost even without 'perverse' energy subsidies. Abstraction costs usually vary between 0.02–0.20 US$/$m^3$. It has allowed significantly 'more crops and jobs per drop' than in-surface water irrigation systems, which in turn has helped the socio-economic transition necessary for other sectors in the economy to take off. Meanwhile in developed countries, more concerned with the green agenda than the brown agenda of environmental issues, the motto is changing to 'more cash and nature per drop' in the context of EU's Common Agricultural Policy. It is important however to note the cash generated per hectare in different contexts, for example, in Spain 60,000 euros/ha can be produced whereas in India, production concentrates on staple foods like cereals and rice, i.e., subsistence farming. However, there is no reason why the pattern adopted in Spain and other countries would not be adopted in the future by countries like India or China, which have shown a spectacular growth in the last decades. An analysis of this situation is going to be prepared now jointly by an Indian and Spanish working group.

Yet the main threat to the silent revolution is not physical scarcity once again, but lack of water governance. Often regulatory frameworks have lagged behind the quick take off of groundwater use (WEGERICH, 2006). Even if regulatory frameworks existed or were developed, their implementation has often been ineffective in controlling and rationalizing groundwater use (KOUNDOURI, 2004). Most regulators have limited understanding and poor data on groundwater situation and value (LLAMAS; CUSTODIO, 2003). It is difficult to say if groundwater governance is better in arid or semi-arid countries where groundwater is privately owned (for example, California, Texas, India, or Chile) or in countries where it is public dominion (for example, Mexico, Libya, and Spain).

In the course of this revolution there have been some significant casualties, mainly environmental. The use of groundwater is so economically salient, that often serious external environmental impacts have been ignored. It is easier for the authorities to turn a blind eye to its chaotic and irrational management due to its key strategic economic importance for agriculture, public water supply and industrial use.

This attitude, which has tended to ignore or disregard groundwater use in water planning, has been called 'hydroschizophrenia', where groundwater management was considered as totally separate from surface water, thus practically ignoring the concept of the hydrological cycle. The dominant view extended to the majority of the public is the 'hydromyth' that groundwater is a fragile resource (LÓPEZ-GUNN; LLAMAS, 2000; CUSTODIO, 2002). Paraphrasing Hamlet: the main strategy adopted is to perceive groundwater as 'frailty, frailty, thy name is groundwater'. Yet this conveniently ignores its widespread use and its enormous socio-economic significance, thus evading the public duty of regulating a key strategic common pool resource.

Groundwater is now a key political issue in many areas of the world due to its strategic socio-economic significance for both irrigation and public water supply and increasingly its competing rival uses like industry or mining. Yet in many countries monitoring of groundwater use has been minimal, with most government and water agencies taking little or no action to assess and control groundwater use.

4 DESALINATION: POTENTIAL AND LIMITATIONS

Desalination is one of the most obvious technological advances in relation to access to 'new' water resources. Desalination is used mainly in arid and semi-arid areas either located inland where the only available water source is saline or brackish groundwater, or in coastal areas. Globally, about 50% of global desalination takes place in the Gulf, followed by North America (16%), Europe (13%), Asia (11%) Africa (5%) and the Caribbean (3%), whilst South America and Australia each accounted for about 1% of the global desalination volume in 2002 according to the International Desalination Association (UNESCO-WWAP, 2006). However, these trends are changing, with other countries considering desalination, particularly for public water supply like China, Mexico, Turkey and North Africa (GLOBAL WATER INTELLIGENCE, 2007). In terms of the uses for desalinated water, municipalities are the largest users (63%), followed by industry use (25%). Additionally — and in view of climate change — desalination is often a key strategic option for many island environments. In terms of future uses, the IDA predicts new demands for desalination for recreation and tourism, the military, and irrigated agriculture (UNESCO-WWAP, 2006).

Technologically, in recent years there has been progress thanks to chemical engineering in membrane technology (Reverse Osmosis) (SERVICE, 2006). This has allowed the removal of all impurities from water at a reasonable (and decreasing) cost to meet the increased demands of water short areas. According to the UNESCO-WWAP (2006), the contracted capacity of desalination plants is 34.2 million m^3/day converting principally seawater (59%) and brackish water (23%).

The main reason for the increased consideration of desalination is that the cost of producing desalinated water has fallen dramatically in the past two decades. Equally, according to Voutchkov (2007) the cost of water production worldwide (from rivers, lakes and aquifers) has increased by 50% to 100% mainly due to limited availability, water quality degradation and more stringent drinking water regulations. During the same time costs for reverse osmosis desalination decreased by 50% to 100% as a result of breakthroughs in technology, energy use, engineering innovation and economies of scale. This means desalination is increasingly becoming an 'affordable' technology, since the energy cost to desalinize one cubic meter of sea water has decreased from almost 20 kwh to less than 4 kwh for a large desalination plant in full-time operation. This is generally the case with no hidden subsidies. The energy consumed to drive the conversion is a significant part of the cost and ranges from 4 to 15 kWh/m^3 depending on factors such as the technique used, the production rate of the facility, and the quality of the equipment. (UNESCO-WWAP, 2006). The cost of desalinated water is about US$ 0.5/m^3 for large plants working almost continuously. The price is lower if desalinating brackish groundwater, where costs decrease to US$ 0.10–0.20/m^3. In most cases this cost is affordable for urban water supply in cities near the coast and also for irrigating cash crops.

At present, desalination is mainly an option considered in arid and semi-arid areas, and particularly in wealthy regions like parts of Australia and California. In the case of Australia, the policy adopted is one of 'security through diversity' (MCCANN, 2007). The desalination market is currently estimated at US$ 150 million a year and according to the private sector predicted to expand by 35% per year for the next four years. These predictions are likely since about 85% of the population in Australia lives on the coast and the other 152 municipalities have a small population. Furthermore, plans for desalinated water are being revised upwards. For example, the Gold coast plans for 50 ml/day by 2050 have now been revised to 125 ml/day on a request from Queensland state government, to cover the water needs of Brisbane and south east of Queensland. Sidney has also issued a tender for a plant in the 250 ml/day range (Degremont/Veolia). Meanwhile, in the USA, population in the state of California is set to increase from 36.5 to 48 million requiring a possible 4 Mm^3/day new water to be put into supply. The California Department of Water Resources established a US$ 50 million desalination plant programme in 2004 aimed at assisting water utilities across the state in implementing brackish water and seawater desalination projects. By 2020 most southern Californian water utilities are planning to supply 10 to 20% of their water from the ocean. However, a recent study by the Pacific Institute (COOLEY et al., 2006) gives some note for caution. For example, the desalination plant in the city of Santa Barbara is being decommissioned for economic reasons.

Meanwhile in the United Kingdom, not traditionally perceived as a water scarce country, due to the heavy concentration of population in the south east, a private water company has invested £300 million (US$ 539 million) in a reverse osmosis plant to treat water from the tidal estuary of the River Thames to serve 900,000 customers in London, producing up to 150,000 m^3/day for the public water supply (UNESCO-WWAP, 2006).

In developing countries like China, Turkey and Mexico there is growing interest in desalination. For example, in China the lack of access to traditional water sources is making desalination an option. This is the case, for example, in coastal north China where four coastal provinces, which account for 25% of China's GDP, have an estimated demand gap of 16.5 to 25.5 billion m^3/yr by 2010. In addition, new tight regulatory controls on groundwater abstraction and the use of surface water are forcing consideration of other water supply options. At present the interest is mainly for industrial purposes, but by 2010–2015 when convergence between cost of desalination and municipal water tariffs is likely to happen, there will also be interest for the public water supply. At present the installed capacity is 380,000 m^3/day, yet the forecast for 2012–2015 is 2.5 Mm^3/day (GLOBAL WATER INTELLIGENCE, 2007).

The reason why desalination has been discussed in this paper is because it is a technology that is already providing solutions to urban water supply in coastal areas, where much of the world's population currently live and many more millions are likely to live in the coming years. It is also a technology that could be used for irrigation of high value crops, thus freeing up other cheaper water resources for such uses as the public water supply of the poorest sectors of the population, which cannot afford to pay for desalination, and for small scale irrigation schemes.

5 THE ROLE OF GIS AND THE INTERNET IN INCREASING

Possibly one of the most important problems in water conflicts is the illusory accuracy of data, and in many cases as the saying goes: 'Half-truths are worse than open lies'. Yet advances in the use of the internet, GIS and remote sensing can increase transparency and increase participation of multiple users. This in turn can facilitate monitoring and control a classic sign of 'healthy' water management systems, which makes water managers and users mutually accountable. Rapid developments in communication technologies can help record and disseminate experience, and strengthen social learning in decision-making processes, through information, knowledge and stakeholders participation (UNESCO-WWAP, 2006). The application of satellite information and modeling can have a substantial impact on water resources monitoring in lower-income countries.

Generally transparency and availability of water data is scarce. Key data where information tends to be lacking or is most inaccurate are on the one hand, irrigated area and types of crops and on the other, inventories of groundwater uses and rights. Yet relatively new technologies like remote sensing can help provide these data in a fast and affordable way. An additional advantage in the use of GIS and remote sensing is that it can facilitate the increased participation of different water users and stakeholders at different levels. For example, there is already a case in Bolivia where the use of a GIS-based programme allowed comparison of the efficiency of water allocation of customary uses vis-à-vis proposed allocation arrangements based on formalising water rights. This use of GIS in effect highlighted that the existing process was not less efficient that the proposed changes.

GIS, internet and remote sensing can encourage increased government transparency and make information accessible to civil society at large. This is because GIS and internet allow elaboration and dissemination of data to the general public with a relatively small investment. Information transparency can prevent corruption, clientelism and inertia, whilst taking decisions that sometimes are politically difficult yet necessary. It brings about deliberative democracy in water management, essential to achieving sound water governance (INNES; BOOHER, 2000; LOWNDESS et al., 2001; BULKELEY; MOL, 2003).

Remote sensing, GIS and the internet are cheap, available tools that can play a crucial role in order to achieve a participatory management. The incorporation of methods and techniques such as GIS, remote sensing and other quantitative, digital or statistical forms of data can provide a vehicle for increased participation. This is particularly the case with new trends towards participatory GIS research or so called Public Participation GIS (PPGIS) with its capacity to empower by incorporating diverse forms of local knowledge. GIS is particularly powerful because of its visualization potential, and its ability to communicate complex data in a user friendly, accessible format. It also opens up decision-making since it can force a dialogue between different types of knowledge, namely rationalist, expert or scientific, which is often granted greater legitimacy and other more localised, grounded and experiential knowledge. In this case, the process itself can become as important as the end product itself (i.e., GIS maps) since in the production of GIS maps a dialogue can occur e.g., with marginalised sectors of society. Through collaborative efforts, it can help transform certain political or institutional cultures. PPGIS can help make transparent the constant process of negotiation and knowledge production that is often obscured in expert systems, and which are then often distrusted by those it is supposed to benefit (ELWOOD, 2006). There are still some questions on the digital divide i.e., the uneven distribution worldwide of communications technology and access to, and use of information, although hardware and software costs are dropping increasingly.

Whereas it was once difficult to map a community, it is now relatively easy with the use of satellite imagery and geographic information systems. In today's market, satellite images are no longer expensive. This development, coupled with a UN-HABITAT programme to provide GIS capability in up to 1,000 cities globally, makes it feasible to bring this technology to local authorities. The use of GIS by local authorities, commonplace in high-income countries, provides a basis for collecting the kinds of spatial information needed for pro-poor governance (UNESCO-WWAP, 2006).

6 CONCLUSION

This paper has shown that there are already cheap and feasible technologies and approaches, which are helping to prevent the often quoted 'water crisis'. These include new data or new perspectives (i.e. the case of virtual water and the silent revolution of groundwater) and technological innovations (like desalination and the use of GIS and remote sensing). These advances are helping to ensure global water supply and water-dependant food security. However, this chapter has also highlighted that these 'revolutions' generated thanks to scientific and technological innovation should not occur in a vacuum and it is the responsibility of states and other actors to carefully assess their full potential and limitations.

It seems clear that the introduction of key concepts like virtual water and water footprint have generated new ways of looking at old problems, like the traditional concept of food and water security, and the concern that humanity will shortly be 'water stressed'. Trade in virtual water constitutes a key element in helping to eliminate or at least soften the global water crisis. However, it is not a panacea, methods have to be further developed, data has to be improved and the side effects or unintended consequences - economic, social, geopolitical and ecological, better studied.

The quantification of water uses, including virtual water and water footprint assessments, and their monetary value is a first important step in understanding how reallocation of water among users could help mitigate many current water problems. However, such reallocation among users or from users to nature is far from simple. Initiatives heralded as the solution to the water governance problem - e.g. water trade, improved water use efficiency, users' collective action, public participation - are not without difficulties or shortcomings. There is a growing need for maintaining our planet's natural capital and the human component of water governance - people's needs, wishes, (vested) interests, aspirations - that often determine the outcome of decisions.

Taking into account that globally approximately 70% of water is used for agriculture, the decisions on which crops are grown (and its embedded water use), and which foods are imported as virtual water, have a much substantial impact on the country's or catchment's water budget. Equally, ignoring the huge boom in groundwater use can only lead to the mismanagement of a key strategic resource that has already been instrumental in lifting millions of people out of poverty, in line with the MDGs. Desalination, although still out of reach for poor countries, is increasingly becoming affordable to wealthy farmers and large mega cities, thus freeing up other traditional water resources like groundwater for other sectors. Last but not least the revolution in information technology (internet, GIS and remote sensing) can bring much needed transparency and accountability to a sector that has been traditionally mired by its problem of water being a natural monopoly and what this entails (STALGREN, 2006).

The current competition over water resources requires innovative solutions to old problems, this translates in a portfolio of appropriate solutions to specific problems, instead of the old mentality where one size fits all, i.e. where water infrastructure was advancement in technology *'the'* solution to *'the'* problem of water scarcity'. Science and technological innovation already offer cheap, accessible options to areas under so called 'water stress', but like any and knowledge it has to be grounded in the equitable and efficient allocation of water. We have enough fresh water to produce food for the global population now – and in the future. But world leaders must take action now by embracing transparency and using the available tools and approaches.

REFERENCES

Aldaya, M.M., Allan, J.A. and Hoekstra, A.Y. (2010) Strategic importance of green water in international crop trade, Ecological Economics, 69(4): 887-894.

Allan, T. (1993) Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible. In: ODA, Priorities for water resources allocation and management, ODA, London, pp. 13-26.

Allan, T. (2006) Virtual Water, Part of an invisible synergy that ameliorates water scarcity. in Water Crisis: Myth or Reality? Rogers, Llamas and Martinez-Cortina edts, Balkema Publishers.

Allan, A. (2007) Rural economic transitions: groundwater uses in the Middle East and its environment consequences. The agricultural Groundwater Revolution: Opportunities and threats to development, CAB International, Cambridge, MA. USA, pp.63-78.

Allan, T. (2011) Virtual Water: Tackling the Threat to Our Planet's Most Precious Resource. I. B. Tauris. 384 pp

Allan, T. (2012) Food-water security: beyond hydrology and the water sector, in B. Lankford, K. Bakker, M. Zeitoun and D. Conway (eds). Water Scarcity. London: Earthscan.

Briscoe, J. (2005) India's Water Economy: Bracing for a Turbulent Future. Washington DC, November 28, The World Bank.

Bulkeley, H. and Mol, A. (2003) Participation in environmental governance: consensus, ambivalence and debate. Environmental Values 12: 143-154.

Comprehensive Assessment of Water Management in Agriculture (2007) Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. London: Earthscan, and Colombo: International Water Management Institute.

Cooley, H., Gleick, P.H. and Wolff, G. (2006) Desalination, with a Grain of Salt: A California Perspective . Oakland, California, Pacific Institute: 88pp.

Coughanowr, C. (1994) Groundwater Paris; UNESCO, IHP, Humid Tropics Program Series No. 8.

Custodio, E. (2002) Aquifer overexploitation: What does it mean? Hydrogeology Journal, 10: 254–277.

De Fraiture, C., Cai, X., Amarasinghe, U., Rosegrant, M. and Molden, D. (2004) Does International Cereal Trade Save Water? The Impact of Virtual Water Trade on Global Water Use. Comprehensive Assessment Research Report 4. Comprehensive Assessment Secretariat. Colombo, Sri Lanka.

De Stefano, L. And Llamas, M.R. (2012) Water, Agriculture and the Environment in Spain: can we square the circle? Taylor & Francis Group, London, UK, 316 pp.

Elwood, S. (2006) Critical issues in participatory GIS: Deconstruction, reconstruction and new research directions. Transactions in GIS, 10(5): 693–708.

Foster, S., Lawrence, A. and Morris, B. (1998) Groundwater in Urban development Assessing management needs and reformulating policy strategies World bank Technical Paper No. 390

Fornés, J. M., d. l. Hera, A. and Llamas, M. R. (2005) The Silent Revolution in Groundwater Intensive Use and its Influence in Spain". Water Policy 7(3): 253-268.

Garrido, A., Llamas, M.R., Varela-Ortega, C., Novo, P., Rodríguez-Casado, R. and Aldaya, M.M. (2010) Water Footprint and Virtual Water Trade in Spain: Policy Implications. Springer, New York.

Giordano, M and Villholth, K. (2007) The agricultural groundwater revolution: opportunities and threats to development CAB international, Oxford.

Global Water Intelligence (2007) Desalination Report 2007, London.

Hoekstra, A. Y. (ed) (2003) Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade, 12–13 December 2002, Value of Water Research Report Series No 12, UNESCO-IHE, Delft, Netherlands, www.waterfootprint.org/ Reports/Report12.pdf

Hoekstra, A.Y. (2010) The relation between international trade and freshwater scarcity, Working Paper ERSD-2010-05, January 2010, World Trade Organization, Geneva, Switzerland.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. and Mekonnen, M.M. (2011a) The water footprint assessment manual: Setting the global standard, Earthscan, London, UK.

Hoekstra, A.Y., Aldaya, M.M. and Avril, B. (eds.) (2011b) Proceedings of the ESF Strategic Workshop on accounting for water scarcity and pollution in the rules of international trade, Amsterdam, 25-26 November 2010, Value of Water Research Report Series No. 54, UNESCO-IHE.

Innes, J. and Booher, D. (2000) Public participation in planning: New strategies for the 21st century. Working Paper 2000-07, University of California: Berkeley.

Jackson, L.A., Pene, C., Martinez-Hommel, M.B., Hofmann, C. and Tamiotti, L. (in press) Water Policy, Agricultural Trade and WTO Rules. Martinez-Santos, P., Aldaya, M.M. and Llamas, M.R. (in press) Integrated Water Resource management. Taylor and Francis, London.

Kemper, K. (2004) Preface: Groundwater from development to management 12 3-5.

Koundouri, P. (2004) Current issues in the economics of groundwater resource management Journal of economic Surveys Vol. 18 No. 5 pp 704-740.

Llamas, M.R. (2005a) Los Colores del Agua, El Agua Virtual y los conflictos Hídricos. Discurso Inaugural del Curso 2005/2006. Revista de la Real Academia de Ciencias Exactas.

Llamas, M.R. (2005b). Groundwater and Human Development. in Groundwater and Human Development. Bocanegra and Usunoff , eds. Leiden, Balkema Publishers. Selected Papers on Hydrogeology, No 6,: 3-8.

Llamas, M.R. (2006) Avances científicos y cambios en viejos paradigmas sobre la politica del agua, Revista Empresa y Humanismo, IX(2): 67–108.

Llamas, M. R. and Custodio, E. (2003) Intensive Use of Groundwater: Challenges and Opportunities. Dordrecht, Holland, Balkema Publishing Co.

Llamas, M.R. and Martínez-Santos, P. (2005) Intensive groundwater use: Silent revolution and potential source of social conflicts. Journal of Water Resources Planning and Management. American Society of Civil Engineers, September/October: 337–341.

López-Gunn, E. and Llamas, M.R. (2000) New and Old Paradigms in Spain's Water Policy. Water Security in the Third Millennium: Mediterranean Countries Towards a Regional Vision. UNESCO U. S. F. P. Series. Vol. 9: 271-293.

Lopez-Gunn, E. and Llamas, M.R. (2008) Re-thinking water scarcity: can science and technology solve the global water crisis? Natural Resources Forum 32 September 228-238.

Lowndess, V., Pratchett, L. and Stoker, G. (2001) Trends in public participation: Part 2 — Citizens. Public Administration, 79(2): 445– 566.

McCann, B. (2007) Lessons from Australia's resource rationale, Water 21: magazine of the International Water Association: 18–20.

Mekonnen, M.M. and Hoekstra, A.Y. (2011) National water footprint accounts: the green, blue and grey water footprint of production and consumption, Value of Water Research Report Series No.50, UNESCO-IHE.

Moench, M. (2003) Groundwater and poverty: Exploring the connections. In: Llamas, M.R., Custodio, E. (eds) Intensive Use of Groundwater: Challenges and Opportunities, Balkema Publishing Co.: Dordrecht, Holland.

Mordant, G. and Pasquier, J.L. (2012) An estimate of the water footprint for France. Ministère de l'écologie, du développement durable et de l'énergie – Service de l'observation et des statistiques. Government of France.

Morris, B. L., Lawrence, A. R. L., Chilton, P. J. C., Adams, B., Calow, R. C. and Klinck, B. A. (2003) Groundwater and its Susceptibility to Degradation. A Global Assessment of the Problem and Options for Management. Early Warning and Assessment Report Series, RS. 03-3. United Nations Environment Programme/DEWA, Nairobi, Kenya.

Official State Gazette (2008) Approval of the water planning instruction. Ministry of the Environment and Rural and Marine Affairs. Official State Gazette 229. September 22, 2008. Available from: http://www.boe.es/boe/dias/2008/09/22/pdfs/A38472-38582.pdf.

Official State Gazette (2010) Plan Future. Ministry of the Environment and Rural and Marine Affairs. Official State Gazette 28. January 22, 2010.

Polak, P. (2005) Water and the other three Revolutions needed to end rural poverty. Water Science and Technology 8: 133-146.

Rogers, P. and Ramirez-Vallejo, J. (2011) Failure of the virtual water argument. Hoekstra, A.Y., Aldaya, M.M. and Avril, B. (eds.) (2011b) Proceedings of the ESF Strategic Workshop on accounting for water scarcity and pollution in the rules of international trade, Amsterdam, 25-26 November 2010, Value of Water Research Report Series No. 54, UNESCO-IHE.

Rogers, P., Llamas, M.R. and Martinez-Cortina, L. (2006) “Forword” in Water Crisis: Myth or Reality? (Rogers et al. (eds.). Taylor and Francis Group. London, pp. IX and X, ISBN: 100-415-36438-8.

Salmoral, G., Dumont, A., Aldaya, M.M., Rodríguez-Casado, R. Garrido, A. and Llamas, M.R. (2011) Análisis de la Huella Hídrica Extendida de la Cuenca del Guadalquivir. Fundación Marcelino Botín, Santander. Papeles de Seguridad Hídrica y Alimentario y Cuidado de la Naturaleza (SHAN): 3.

Service, R. (2006) Desalination freshens up, Science, 313: 1088–1090.

Shah, T. (2005) "Groundwater and Human Development: Challenges and Opportunities in Livelihoods and Environment." Water Science and Technology 8: 27-37.

Shah, T., Singh, O. P. and Mukherji, A. (2006) Some aspects of South Asia's groundwater economy: Analyses of a Survey in India, Pakistan, Nepal Terai and Bangladesh. Hydrogeology Journal 14: 286-304.

Shah, T., Burke, J. and Villholth, K. (2007) Groundwater: a global assessment of scale and significance in David Molden et al Water for Food, water for life: a comprehensive assessment. IWMI/Earthscan, London.

Sojamo, S., Keulertz, M., Warner, J. and Allan, T. (2012) Virtual water hegemony: the role of agribusiness in global water governance, Water International, 37:2, 169-182

UNDP (2006) Human Development Report 2006. Beyond scarcity: Power, poverty and the global water crisis. United Nations Development Programme, New York.

UNEP (2011a) Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication. United Nations Environment Programme . Available from: www.unep.org/greeneconomy

UNEP (2011b) Water footprint and corporate water accounting for resource efficiency, United Nations Environment Programme, Paris.

UNESCO- WWAP (2006) Water- a shared responsibility. The UN World Water Development Report 2

UNESCO- WWAP (2009) Water in a Changing World. The UN World Water Development Report 3

UNSD (2012) SEEA-Water: System of Environmental-Economic Accounting for Water. United Nations. United Nations Statistics Division, Department of Economic and Social Affairs Statistics Division. New York.

Voutchkov, N. (2007) California turns to the ocean. Water 21: Magazine of the International Water Association: 22–24.

Wegerich, K. (2006) Groundwater institutions and management problems in the developing world. In: Tellam (ed) Urban Groundwater Management and Sustainability, Holland: Springer, pp. 447–458.

Willaarts, B. (2012) Linking land management to water planning: Estimating the water consumption of Spanish forests. In: De Stefano, L. y Llamas, M.R. (Eds.). Water, agriculture and the environment in Spain: can we square the circle? CRC Press.Taylor and Francis.

WATER, A "WICKED" PROBLEM: THE NEED FOR EFFECTIVE INFORMATION MANAGEMENT

Salmah Zakaria[1]
KK Aw[2]
Jin Lee[3]

[1] Fellow, Academy of Science Malaysia (ASM) and Senior Water Resources Specialist, ESCAP.
[2] Director, Multicentric Technology Sdn Bhd.
[3] Director, GLS Haidro Sdn Bhd.

ABSTRACT

Persistent water management challenges, as seen in current practices and approaches in water resources and services management, constitute a complex combination of economic, social and environmental issues which can therefore be termed "wicked". Climate change impacts and the required adaptation is another specific example of a wicked problem within the water resources management domain.

1 INTRODUCTION: the "wicked problem"

The phrase "wicked problem" was first introduced to analyze social or cultural problem that is difficult to solve because of incomplete, contradictory and changing requirements, due to its systemic and social nature. A good example of a wicked problem in water is the challenge of managing floods within the constraints of the need to protect the changing human habitats within a river corridor that is subjected to a changing acceptable probabilistic flood protection level with increased urbanization over time.

Rittel and Webber (1973) identified ten characteristics of the "wicked" problem as given below, which can be related to the challenges of flood management:

I. **Wicked problems have no definitive formulation.** Formulating the problem and the solution is essentially the same task. Each attempt at creating a solution changes your understanding of the problem;

II. **Wicked problems have no stopping rule.** Since you can't define the problem in any single way, it's difficult to tell when it's resolved. The problem-solving process ends when resources are depleted, stakeholders lose interest or political realities change;

III. **Solutions to wicked problems are not true-or-false, but good-or-bad.** Since there are no unambiguous criteria for deciding if the problem is resolved, getting all stakeholders to agree that a resolution is "good enough" can be a challenge, but getting to a good enough resolution may be the best we can do;

IV. **There is no immediate or ultimate test of a solution to a wicked problem.** Since there is no singular description of a wicked problem, and since the very act of intervention has at least the potential to change that which we deem to be the problem, there is no one way to test the success of the proposed resolution;

V. **Every implemented solution to a wicked problem has consequences.** Solutions to such problems generate waves of consequences, and it's impossible to know, in advance and completely, how these waves will eventually play out;

VI. **Wicked problems don't have a well-described set of potential solutions.** Various stakeholders have differing views of acceptable solutions. It's a matter of judgment as to when enough potential solutions have emerged and which should be pursued;

VII. **Each wicked problem is essentially unique.** There are no "classes" of solutions that can be applied, *a priori*, to a specific case. "Part of the art of dealing with wicked problems is the art of not knowing too early what type of solution to apply";

VIII. **Each wicked problem can be considered a symptom of another problem.** A wicked problem is a set of interlocking issues and constraints that change over time, embedded in a dynamic social context. But, more importantly, each proposed resolution of a particular description of a problem should be *expected* to generate its own set of unique problems;

IX. **The causes of a wicked problem can be explained in numerous ways.** There are many stakeholders who will have various and changing ideas about what might be a problem, what might be causing it and how to resolve it. There is no way to sort these different explanations into sets of correct or incorrect answers;

X. **The planner (designer) has no right to be wrong.** Scientists are expected to formulate hypotheses, which may or may not be supportable by evidence. Designers don't have such a luxury they're expected to get things right. People get hurt, when planners are wrong Yet, there will always be some condition under which planners *will* be wrong.

Persistent water management challenges, as seen in current practices and approaches in water resources and services management, constitute a complex combination of economic, social and environmental issues which can therefore be termed “wicked”. Climate change impacts and the required adaptation is another specific example of a wicked problem within the water resources management domain.

2 CHALLENGES - MULTIPLE ISSUES WITHIN THE WATER SECTOR

2.1 GOVERNANCE OF CROSS CUTTING ISSUES

Water is the most basic of all resources, underpining all socio-economic activities and environmental sustainability. Civilizations, such as those surrounding the basins of Indus, Tigris and Euphrates, and current economic development grow or wither depending on its availability.

As water flows across the land surface to form rivers and replenish other water bodies such as lakes/reservoirs and aquifers, management and thus governance of this precious and limited resources must take into cognisance landuse of nation states. There are also issues of upstream and downstream interests, river basins and adjacent coastal and marine environments; new emerging issues of rapid population growth, rapid urbanisation and acute pollution of water bodies; global warming and climate change impacts and others. Extreme conditions of floods and droughts need to be managed; and with climate change impacts, these extreme conditions will become more extreme, more intense and with changing frequencies of occurrences.

Globally, there are also large numbers of shared trans-boundary water bodies. Some of these are the Amazon and Parana rivers in South America, the Danube and Rhine rivers in Europe, the Nile, Niger, Congo and Zambezi rivers in Africa, the Tigris and Euphrates rivers in the Middle East and the Aral Sea, Ganges-Brahmaputra-Meghna, Indus, and Mekong rivers in the Asia Pacific. The existence of trans-boundary aquifers not necessarily running parallel to the river basins on the surface, add to the complexities of water resources management. Thus, multilateral cooperation is needed for these shared water resources. Water resources do not recognize political borders; however, their effective management requires cooperation between governments. The management of all these resources is dependent on coordinated efforts among a range of stakeholders.

Managing water resources is just not about managing water but also the landuse. It is also not just about managing the natural resources of land and water but also about understanding human systems, cultural nuances, and the conflicts that will arise when limited resources are shared among stakeholders. There are competing needs, inherent vulnerability and gender balancing to ensure equity of allocation, which in turn can have implications on political stability and consequently human survival.

Invariably this critical resource must have an adequate governance structure and workable institutional arrangements, cutting across multiple sectors, technical, environment, economics, social and legislations. As such awareness and knowledge on the implications of inadequate management among policy makers are prerequisites to the development of commitment and establishing effective legal frameworks for the management of water resources and the concurrent provision of services related to water.

2.2 NEW EMERGING ISSUES–CLIMATE CHANGE IMPACT, RAPID POPULATION GROWTH, URBANISATION AND ACUTE POLLUTION OF WATER BODIES

Climate Change Impact: In the past decades, climate change has become the great equalizer, affecting the economies of both developed and developing nations, and threatening the health and well-being of millions across the globe (UNESCAP, 2012). The impacts of climate change are even more challenging for vulnerable developing countries struggling to address climate change issues with severely stretched natural and financial resources.

Climate change is anticipated to have widespread and unpredictable impacts on water resources through changes to the hydrological patterns and freshwater systems. Impacts include reduced availability of water in regions affected by falling annual or seasonal precipitation, reduction in some crop yields, generally increased evaporative demand from crops as a result of higher temperatures, reduced storage of precipitation as earlier melting of snow shifts peak runoff away from the summer season. With increasing climate variability impacts on surface water availability, there will be increased dependence on groundwater to cope with water scarcity, drought and rainfall irregularity. Access to clean water will become a major concern as climate change has created multiple water hotspots or areas identified as having significant water security issues, including access to water supply for personal and economic activities, and protection from water-related disasters such as pollution of water bodies, water borne diseases, floods, cyclones, droughts, forest fires, and desertification.

Climate change will primarily affect ecosystems and people through water-related issues. Clean freshwater will become increasingly scarce as available water resources become more unevenly distributed over time and space. Climate change will have varying impacts among the different areas and countries in different regions. Climate change adaptation policies for water management will urgently be needed as the risks from climate change continue.

Rapid population growth: The world's population has grown at an unprecedented rate in the last 50 years as shown in **Figure 1**, below.

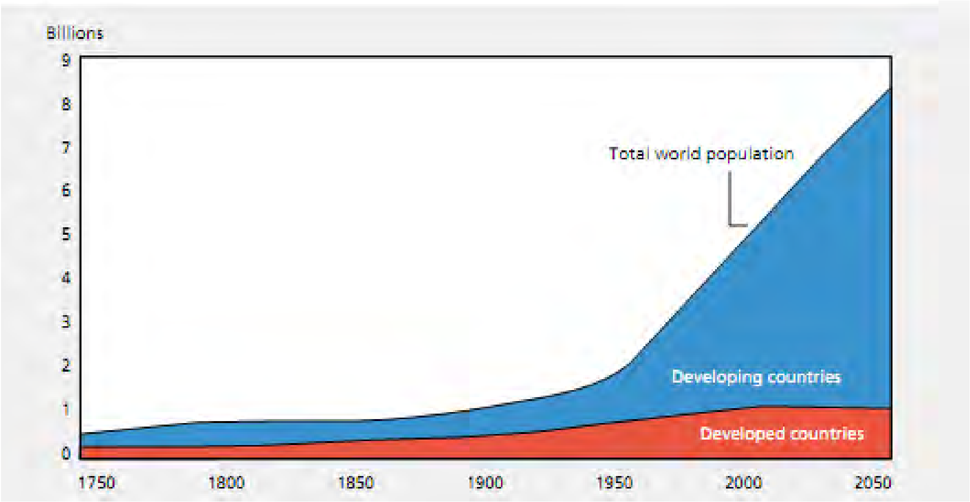


Figure 1- World Population, 1750-2050
Source: <*http://www.worldbank.org/depweb/beyond/beyondco/beg_03.pdf*>.

With such a rapid increase in population, the pressure and demand on land and water for food and basic survival will also be unprecedented. Water is not only required for households and industries but is critical for all crops which require and transpire massive amounts of water during the growing season. In total, agricultural production consumes more fresh water than any other human activity. Specifically, about 87 per cent of the world's fresh water is consumed or used up by agriculture and, thus, is not recoverable (PIMENTEL et al., 1996).

Rapid ubanisation and acute pollution of water bodies: As the world urbanize, cities increasingly compete with farms for land and water resources. Striving for increased food security has resulted in the over-abstraction of groundwater resources in some subregions, an issue that has significantly impacted India and the northwest of China, with falling water tables. Increasing urban contaminants and agricultural chemicals are making their way into surface waterways and groundwater, resulting in increasingly polluted water bodies (ASM, 2009). As populations and economies grow, the quality of water resources has declined in many areas and in some cases has become unusable for domestic, industrial and agricultural uses.

Urbanization also increases impermeable areas as more roads and buildings are constructed to meet the increasing demand for housing, businesses and the necessary utilities. This invariably result in increasing surface runoff and couple with the increasing intensities and occurrences of floods from climate change impacts will result in inevitable flash floods occurrences.

2.3 DATA, INFORMATION, INNOVATION AND TECHNOLOGY

Data and information are essential for planning, developing, and managing water resources as well as for policy deliberations. The amount of information that are already available and that are required for decision-making are tremendous. Their effective analysis and management for the different needs are important for effective monitoring and evaluation of policies, programs and projects aimed at improving water-use efficiency and availability. The analysis should include identifying emerging trends and predicting future development as keys to the formulation of responsive policies and management actions. Efforts are needed and are carried out continuously in the different regions to increase data collection, access, and comparability on water resources availability, quantity and quality, and usage at regional, national, and local levels.

Innovation in information technology and development continues to offer new and faster ways to manage, analyze and organise the increasing data and information to make them into usable knowledge.

3 THE WAY FORWARD

3.1 EFFECTIVE INFORMATION MANAGEMENT TO ADDRESS THE WATER MANAGEMENT “WICKED PROBLEM”

The discussions above show the complexities of water resources and services management with its many systemic issues and subjective stakeholders' requirements that are inter-connected, and thus make it a “wicked problem”. It is difficult for policy and decision-makers to appreciate the complexities and inter-relationships between the numerous and disparate information on the various inter-related systemic issues. Thus, a key challenge in tackling wicked problems is effective information management. The ability to systematically identify the key issues, facts, ideas and solutions relating to each of the inter-related systemic areas of concern, and to document them in a comprehensive way in a neutral platform so that they can be studied and viewed from different perspectives is important. This is especially so, as the problem has to be revisited from time to time, since the systemic conditions and stakeholders’ perspectives will also change with time.

3.2 CASE STUDY – ACADEMY OF SCIENCE MALAYSIA (ASM) TASK FORCE ON CLIMATE CHANGE ADAPTATION’S PROJECT

The Academy of Science Malaysia (ASM) set up a Task Force on Climate Change Adaptation (ASM, 2010) to steer a project to develop strategies and recommendations to address climate change impacts in Malaysia. At the initial stage of the project a consultancy baseline study was commisioned to review the status of climate change impacts on Malaysia. The study reviewed both international and national levels key documents and presents the current status, gaps and recommendations, in seven thematic areas. They are briefly, as follows:

I. Governance and Institutional Capacity

Climate change has just recently become an important national consideration in Malaysia, and thus *"a decision-making framework and process relating to climate change and water"* need to be developed.

II. Climate Change (CC) Projections and R & D Capacity

The gaps identified for this theme are the inherent CC uncertainty, a low understanding of uncertainties and limitations of climate change projections and scenarios for effective communication with decision makers and end users, and also the lack of procedures, application and data in some areas.

III. Information Management Capacity

The Study recommendations for this thematic area include enhancing and strenghtening the Malaysian national climate services through the setting up, among others; sector-specific water and climate change information management unit, national climate observation committee, national water and climate change information repositories and the need to publicise and disseminate climate information.

IV. Stakeholder Awareness and Participation

The recommendations for this thematic area are to create or improve "climate change awareness and participation" among and between government agencies and department, disaster-relief agencies and communities.

V. Water Bodies Management Capacity

This thematic area looks at water bodies such as rivers, lakes, aquifers/groundwater and coastal areas. For rivers the need to assess the increased river flow variability on the stability of river banks, impacts of sea level rise and the breeding grounds for malarial vectors were identified. For lakes, there is a need for more extensive monitoring and research, particularly for lakes that have important socio-economic implications. For aquifers the recommendation is to monitor the recharge characteristics of important aquifers so as to identify the potential negative impacts. For coastal areas, there is a need to assess the impacts on erosion, saltwater intrusion and ecosystems, such as mangrove forests, mudflats and the bio-diversity they support in the absence of many critical data.

VI. Water Use Management Capacity

The major gaps identified for this thematic area covers the management of potable and agriculture water supply, hydropower, river navigation, fisheries water ecosystems and competing uses of water. They are the lack of an effective framework to suport the implementation of IWRM/IRBM principles and approach in land use planning, water resources planning, management and use. The recommendations include the development of strategies and reviewing of existing and future development plans, including water infrastructure, planting periods for crops and the vulnerability of each to the impact of climate change.

VII. Water Management Capacity

This thematic area covers floods, water pollution, water scarcity/drought and human health. For floods, the recommendations are to update the existing hydrological procedures, manuals and studies to include projected rainfalls, latest flood maps and consequently to review the design of dams, drainage and flood mitigation structures. For pollution, the recommendation is to increase the monitoring on the effects of temperature increase on water quality in rivers and lakes. There is also the need to develop and implement an integrated drought management system and to reduce the per capita demand of water and to improve irrigation efficiency in crop production. For human health, while research on vector diseases are ongoing, little is yet known on the impact of climatic factors on morbidity and mortality.

Following the baseline Status Report study a national conference and a series of stakeholders workshops for each of the seven thematic areas were organised. The objectives of the conference and workshops are to identify the set of desired strategic action plans for adaptations, that are discussed, agreed and endorsed by all stakeholders, so that they can be submitted to the appropriate government agencies for adoption and implementation.

Since the volume of water related information compiled in the Status Report is already huge, and with the additional information arising from the national conference and seven thematic workshops, the ASM decided to use an innovative information management web application known as the “Multicentric Issues-Based Information System (MctIBIS)” to present and manage both the existing information for the seven thematic areas, compiled from the baseline study report, together with those that were presented and discussed in the seven thematic workshops. The seven workshops were designated as ASM Strategic Consultative Labs on Climate Change and Water Resources. There are international interests in the use of the MctIBIS methodology for managing the multi-stakeholders, multi workshops information management since many global complex issues remain unmanageable using the conventional workshop and information management approaches.

3.3 THE MCTIBIS AND MYWCCIBIS WEB APPLICATIONS

The ASM Strategic Consultative Lab on Climate Change and Water Resources has been piloted using the MctIBIS web application (http://prezi.com/ewekl1bgkisi/tackling-wicked-problems-collaboratively-the-mctibis/) to support the workshop participants in their workshop deliberations. A specific "Malaysia Water and Climate Change IBIS (MywccIBIS)" web application (*http://mywccibis.mcthosting.net*) was developed using the MctIBIS. The MctIBIS is a Malaysian implementation of the Issue-Based Information System (IBIS) concept introduced by Horst Rittel, a design theorist in the 1970s. MctIBIS, allows the issues, facts, positions, ideas, solutions and argumentation to be arranged into an Issue Map, a graphical structure similar to the mind map, to help users make sense of the many interrelated issues. The issues may be conflicting and at the same time competing for resources.

Figure 2 shows the content model of a typical MctIBIS web application, where the issue/dialogue map of all the different types of entries (issues, facts, ideas, solutions, etc.) are linked to their respective contributors, and are also grouped under their respective subject headings.

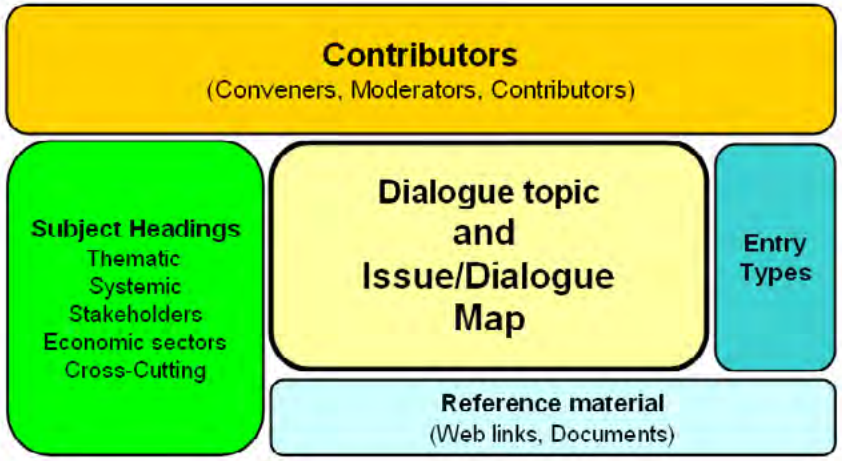


Figure 2 - Content Model of MctIBIS

MctIBIS allows the users to explore the issue map from different perspectives. It also provides a customizable subject headings list containing thematic, physical, biological, socio-economic and management issues for further clustering the information. The subject headings allow the information presented in the issue/dialogue map to be reorganized and presented based on the subject headings for different views on the information resources.

The value of the MctIBIS developed Issue Map goes beyond the duration of the workshops. It can remain accessible on the web as a ready reference for authorized users interested in the subject of the consultative labs. Whilst the IBIS concept was convincing, it has still not gained widespread usage. Early implementation of the IBIS concept focused on the graphical issue map, ignoring the other elements proposed by Horst Rittel. MctIBIS is a comprehensive implementation of Rittel's proposal based on information relationship management concepts.

3.4 WORKSHOPS GROUP DYNAMICS

Whilst MctIBIS provides the technical platform for documenting the issues, ASM recognizes the importance of developing a methodology that will support and promote the group dynamics in the workshops required to encourage participants feedback systematically.

Figure 3 illustrates and describes how the consultative issue map were developed systematically over a 3-stage process.

The first stage is the development of the initial Issue Map for the seven thematic areas which is based on the information compiled in the baseline status report prepared by the ASM WCC task force. The second stage is the inclusion of the workshop presenter's contributions to the baseline Issue Map. Thus, the role of the workshop presenters should be to confirm, expand or add new information into the Issue Map based on their experience and area of expertise. The third stage is get the contributions and agreement of the workshop groups on the outputs from the first two stages through the dialogue and deliberation process so as to clarify the outputs of the first two stages, and evaluate the ideas and solutions through the argumentation process. The ultimate objective of the MctIBIS-supported workshop process is to develop a comprehensive and integrated map of the related issues, facts, ideas and solutions so that strategic policies or plans can be formulated to address them.

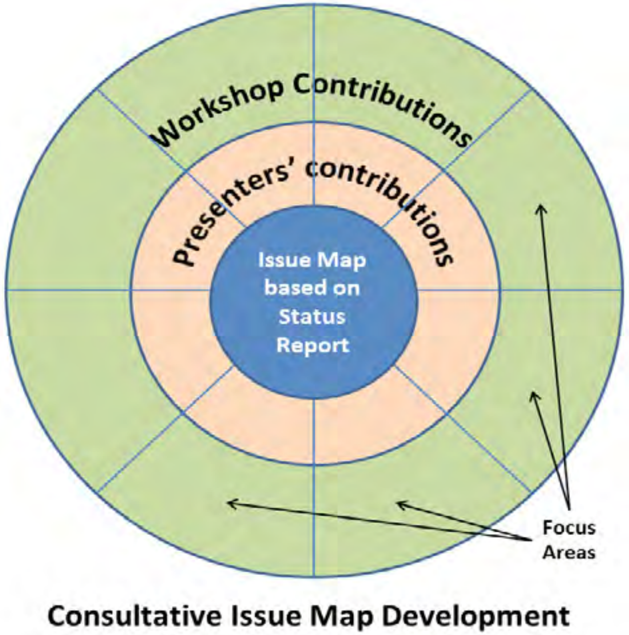


Figure 3 - Consultative Issue Map Development

4 CONCLUSION

The seven ASM Strategic Consultative Lab (SCL) on Climate Change and Water Resources has been completed as shown below:

1. SCL1 - Information Management – 3rd Sept 2012;
2. SCL2 - Stakeholder Awareness and Participation – 4th Sept 2012;
3. SCL3 - Climate Change Projections and R & D Capacity – 9 Oct 2012;
4. SCL4 – Water Resource and Water Use Management Capacity – 3rd Dec 2012;
5. SCL5 - Governance and Institutional Capacity – 4th Dec 2012;
6. SCL6 - Water-related Hazard and Risk Management Capacity – 14th Dec 2012
7. SCL7 - Water-related Landuse Management Capacity – 13th Dec 2012.

ASM is still finalising the contents of the MywccIBIS and analysing the results of the pilot project for the effectiveness of the MctIBIS tool.

Several gaps in the MctIBIS implementation and the workshop methodology used were identified as part of this pilot exercise. The information collected is considered too voluminous for use by policy and decision makers. The need to summarize the important issues and the thematic subject matters will be necessary. In addition, the issues need to be ranked so that readers can focus on the critical and more important issues.

The methodology of ranking issues based on pertinent criteria will also help in reducing trivial issues been included in the issue map in future work.

5 ACKNOWLEDGEMENT

The authors would like to thank the Chair, Tan Sri Shahrizaila Abdullah, and the secetariat of ASM WEHABE (Water, Energy, Health, Agriculture, Biodiversity and Emerging Technologies) for facilitating the works of the MalaysianTask Force on Climate Change Adaptation that lead to this paper.

REFERENCES

ASM (2009). *Advisory Report on the Study on Lakes of Malaysia,* ASM Malaysia, Kuala Lumpur

ASM (2010). *Study on the Status of Climate Change Impact on Water Related Issues (Final Report),* ASM Malaysia, Kuala Lumpur

Isenmann, S., and Reuter, W.D., *IBIS - a convincing concept... but a lousy instrument?* http://dl.acm.org/citation.cfm?id=263602.

Rittel, H.W.J. and Webber, M.M., (1973). *Dilemmas in a General Theory of Planning,* Elsevier, Amsterdam

Pimentel, D., Huang, X., Cordova, A., and Pimentel, M. 1996. *Impact of Population Growth on Food Supplies and Environment* http://www.dieoff.org/page57.htm

Pimentel, D., J. Houser, E. Preiss, O. White, H. Fang, L. Mesnick, T. Barsky, S. Tariche, J. Schreck, and S. Alpert. 1996. *Water resources: agriculture, the environment, and society*. BioScience.

UNESCAP (2012). *Climate Change Adaptation for water management in a green economy- Discussion Paper*, UN Publication, Thailand http://www.unescap.org/esd/publications/water/2012/cma/Climate-Change-Adaptation.pdf

Whelton, M., & Ballard, G., (2002).*Wicked Problems in Project Definition,* Brazil 2002

World Bank (1) http://www.worldbank.org/depweb/beyond/beyondco/beg_03.pdf

SESSION 6

MANAGING WATER IN URBAN AREAS AND METROPOLITAN REGIONS: AN EVER-GROWING CHALLENGE

SUMMARY

URBAN WATER SUPPLY; THE HARARE CASE STUDY

Christopher H.D. Magadza[1]

[1] University of Harare, Zimbabue.

ABSTRACT

Harare is the capital city of Zimbabwe, with a population estimated at some five million. The city's water supply is from two reservoirs on the Manyame River watershed. Because the city is located on the crest of a high altitude plateau (approximately 1500 m above sea level), as the city grew large water supply reservoirs have had to be built downstream to the city location. Consequently the city effluent is discharged upstream of the water supply reservoirs. With the southern African region experiencing a general decline in precipitation supplying adequate potable water to the city poses hydrological and water quality management problems. Overlaying these supply issues are issues of management by the city authorities. An economic meltdown and poor management have resulted in severe water supply and water quality problems. The paper examines the structural cause of the problems and the possible future remedy to them.

1 INTRODUCTION

The early settlers of the now Zimbabwe established their main settlements along the high ridge watershed, separating the south flowing rivers draining to the Indian Ocean via the Limpopo River and those draining northwards into the Zambezi. Generally, these settlements are above 1000m a.m.s.l. with the capital city Harare averaging 1500m a.m.s.l. This settlement pattern was determined by the distribution of insect borne diseases such as malaria and Trypanosomiasis, which occur in lower altitudes. Hierologically this means these settlements were located at the low stream order end of the hydrological system. At this elevation, most of the drainage channels are seasonal. This situation together with the fact that annual rainfall is about 800 mm per annum, means that the drainage density if low. Consequently, Zimbabwe has a large number of reservoirs to store water for dry season use. This paper briefly presents the issues of urban water supply and management for Harare City, the capita of Zimbabwe. Figure 1 is a Google overview of the City of Harare and Chitungwiza, showing the main streams and reservoirs. Note that Lake Chivero, the City's water supply reservoir, is downstream to the major wastewater treatment plants.

2 CONTEXTUAL SETTING

2.1 THE ECONOMY

Towards the end of the 1980s, Zimbabwe had been removed from the category of developing countries to that of economies in transition. However, by the mid 1990s the economy began to decline. IMF advised economic programmes, the Economic Structural Adjustment Programme resulted in widespread retrenchments and poverty. Next came the land reform during which white owned frames were forcibly and violently acquired. This resulted in a complete breakdown of the economy. Inflation was in was in trillion percentages. Industry ground to a halt and there was mass unemployment service. Public service delivery, such as water and sanitation, collapsed. The HIV/Aids pandemic further exacerbated the human condition. A beleaguered government turned against its people, resulting in untold suffering. There was mass emigration to neighboring countries, particularly of well qualified technical workers. Current unemployment stands at 95%.

Eventually, in response in response to world outcry the Southern Africa Development Community, SADC, intervened. The Zimbabwe currency ceased to be legal tender and a "multi-currency" fiscal strategy adopted. However, this relief came only after a near complete breakdown of infrastructure.

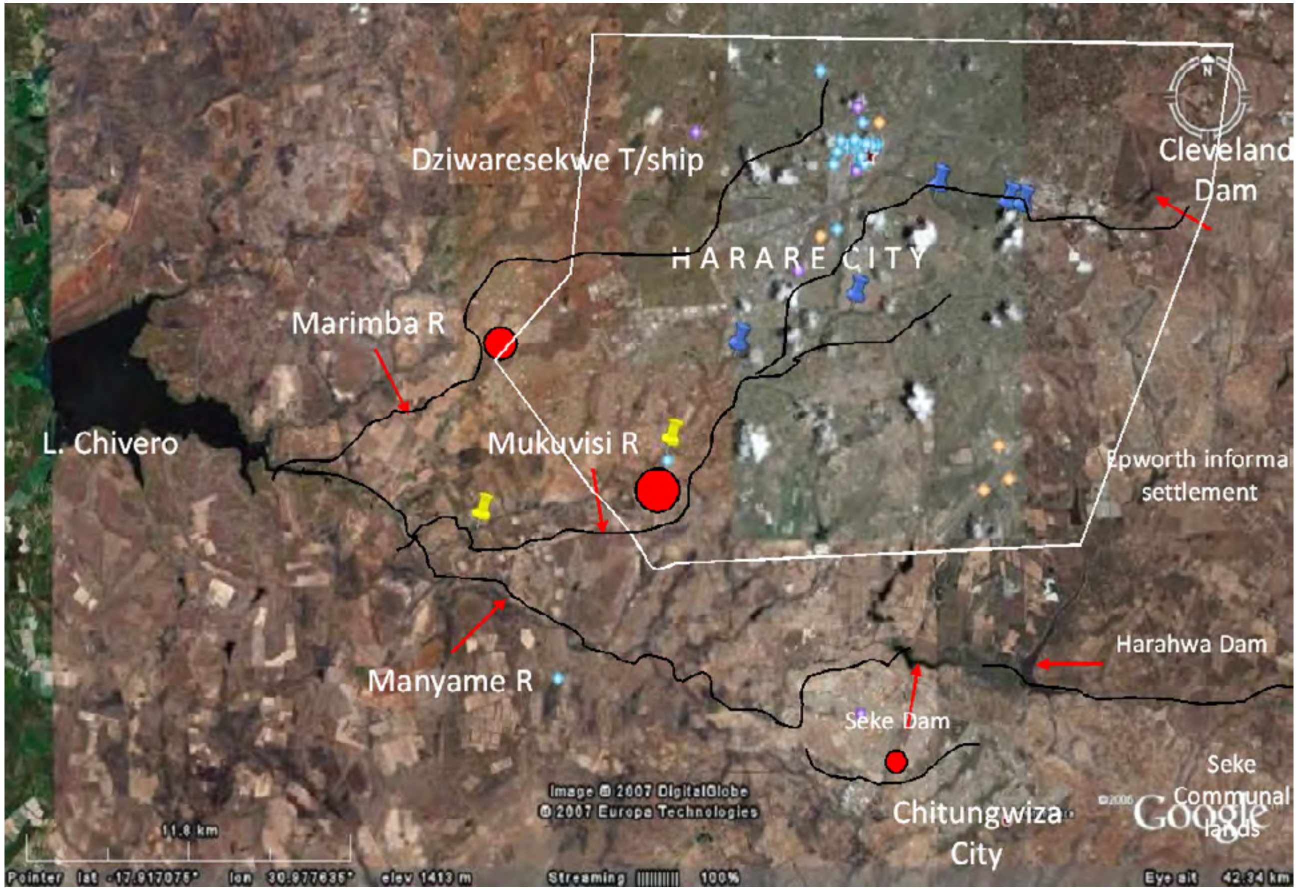


Figure 1 - Google earth view of L. Chivero watershed with overlays

Widespread poverty, particularly in the rural subsistence economy areas intensified the urban drift, resulting in overcrowding in the high density townships as well as the mushrooming of informal peri-urban settlements, with no amenities services.

Figure 2 is a reconstructed population growth of Harare, based on pre 2000 data. This figure suggests that the population Greater of Harare is close to 5 million, a figure city engineers also suggest is closer true population in contrast to the officially quote 2 million. Harare Municipality also supplies water to Norton, Ruwa and Chitungwiza city, and Epworth. Thus, in total, Harare supplies water to close to 7 million inhabitants, i.e. close to half of the Zimbabwe population.

The colonial administration designated separate residential areas for the different races, mainly Caucasians and Negroid. Now these areas have been renamed low-density suburbs and high-density suburbs. The colonial land act set aside certain areas, designated native reserves, for the indigenous peoples. It is only here that indigenous people had the right of abode, though they had no property rights, even in theses reservations.

In the urban areas, the indigenous people were regarded as migrant workers. Their dwellings were property of the municipality and could not own real estate in municipal jurisdictions. It was taken for granted that their standard of living as were expectations would be lower than that of the Caucasian races. Asiatic were an insignificant minority whose areas were close to the Caucasians, but nevertheless, separate.

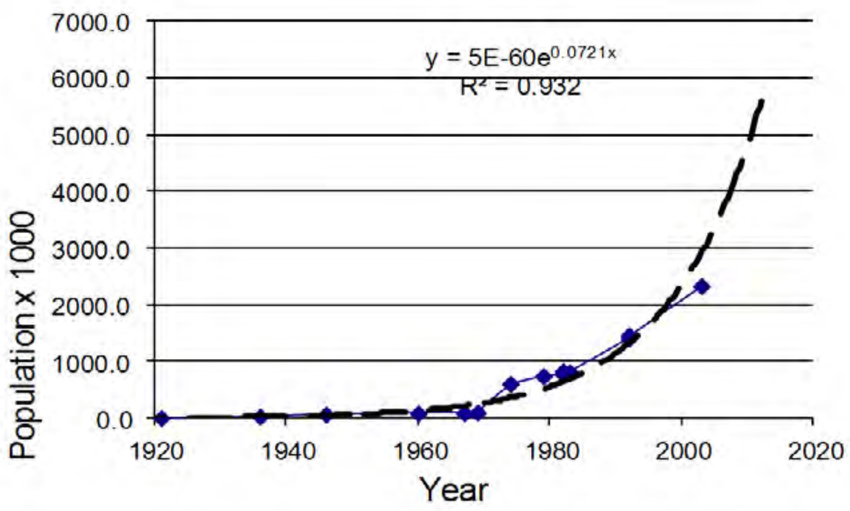


Figure 2 - Reconstructed Harare population: doubling period ~12 years

2.2 URBAN POPULATIONS

Worried about the burgeoning black populations in the cities, especially in the then Salisbury, the state sought to provide employment for the black labour force outside the white cities. Thus near Harare the now City of Chitungwiza (two million inhabitants) was established, in the Lake Chivero catchment, originally as a small settlement exclusively for black employment seekers. The plan was to establish industry in this settlement, away from the white city. Because of the then rising political tensions, only a few industries were relocated at Chitungwiza. Since by law black people could not own real estate property, their dwelling units were non-ratable and the administrative authority's income was only to recover water and electricity supply costs. The result is that that an urban settlement with no substantial income to provide services grew to be a city; a city with no significant source of revenue.

At its establishment, Chitungwiza was provided with a trickle filter sewage plant for removal of BOD, suspended solids and bacteria. Aware of the role of the injurious role phosphorus and nitrogen in sewage effluent to reservoirs the effluent from the Chitungwiza sewage plant was to be pumped out of the Lake Chivero water shed into the adjacent one.

However, by the mid 1980s the pumping station could no longer cope with the growing effluent volume, and hence discharged partially treated sewage into the Lake Chivero catchment, only abbot 15km away from the lake. By the mid 1990s, the city was discharging upwards of 50 ML per day. By 2011 one of three sewage outlets were discharging 25 ML untreated sewage per day, i.e. circa 75 $Meld^{-1}$ from the city. A Biological nutrient removal plant installed by the Japan International Cooperation Agency (JICA) in 2000 was no longer operational because of the city's financial limitations.

Thus in summary

- Harare City, Formerly Salisbury, as shown a very high rate of population growth, with an estimated doubling period of about 12 years;
- The city's waterworks also has to supply other urban settlements: Vis Chitungwiza, Norton, Ruwa and Epworth. In all the Manyame Lakes;
- Because black people could not own property in the urban municipalities, and indeed anywhere else, the black settlements were non-ratable. However the greater percentage of the city's population consisted of residents who could not contribute meaningfully to the city's income;
- The establishment of other settlement in the Lake Chivero watershed has increased the wastewater discharge in the watershed;
- In all cases, the additional settlements have a high component of non-ratable properties.

2.2.1 Hydrology and climate

Table 1 - is a summary of the characteristics of Lake Chivero

Hydrological and morphometric features of Lake Chivero	
Full supply volume	250 x $10^6 m^3$
Full supply surface area	26.30 km^2
Catchment area	2227 km^2
Shoreline length	74 km
Maximum depth	27.43 m
Mean depth	9.4 m
Maximum breadth	8.0 km
Mean breadth	1.68 km
Length	15.7 km

The IPCC AR4WG1 notes that the southern Africa shows a drying trend. A Magicc-Scengen model, using CISIRO, set for the A1b-New emission scenario and the reference scenario of 450NFB model, gave a temperature rise projection of close to 2℃ for the period 2050, while precipitation ranged from between 5% and 10% increase in summer precipitation for the IPCC default ensemble, but the CSIRO-30 model projected precipitation deficits of up to between 5% and 9 %. By 2075, the region could have warmed up by close to 3℃. However, though the precipitation projections show a wide range, the warming projections appear consistent. Given that for a rise of 1℃ in the tropics evaporation losses are likely to increase by some 10%, the indications are that the area in which the Lake Chivero Catchment is located is likely to suffer from frequent water deficits. Magadza (2011) has noted that time series analysis of climate data from more than thirty meteorological stations in Zimbabwe show the area to have been warming by an average of 0.3℃ per decade in the forty years between 1960 and 2000.As a cororally several river basins in the region suggest reduced net runoff.

Figure 3 show the half-normal probability plot of runoff on the Manyame catchment of Lake Chivero. The data show that the frequency of low flows is above the expected frequencies, while high flow frequencies are below expected values. In Figure 4, these data are represented as normalised deviations, together with a six-year moving average of the deviations. These data suggest that, in line with the general trend to reduced runoff in the regions, the Lake Chivero hydrological income is reducing. Figure 5 is an estimate of the proportion of Lake Chivero's hydrological income that comprises returned sewage. The component of return wastewater recorded here is from only two of the inflowing rivers, the Mukuvisi and Marimba Rivers, both of which have major sewage treatment plant on them.

However, these data do not include outflow Chitungwiza City. Due to operational breakdowns, no wastewater discharge data were available from this urban settlement. Thus, the Nyatsime flow was estimated by proportionality with respect to the total Manyame flow gauged below the confluence of the two streams, using a few measurements made manually at the Chitungwiza sewage outflow.

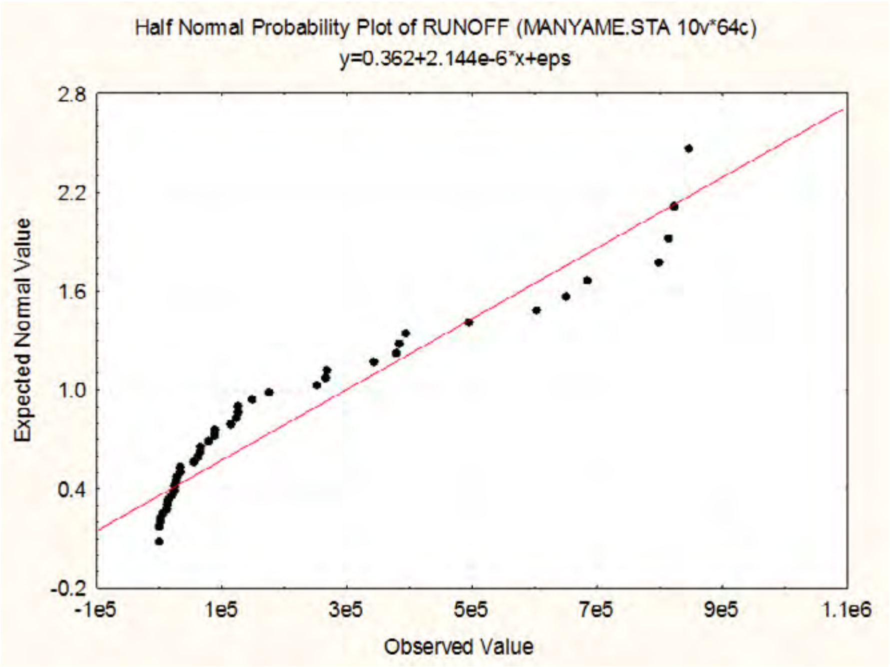


Figure 3 - Half-normal plot of the Manyame River runoff

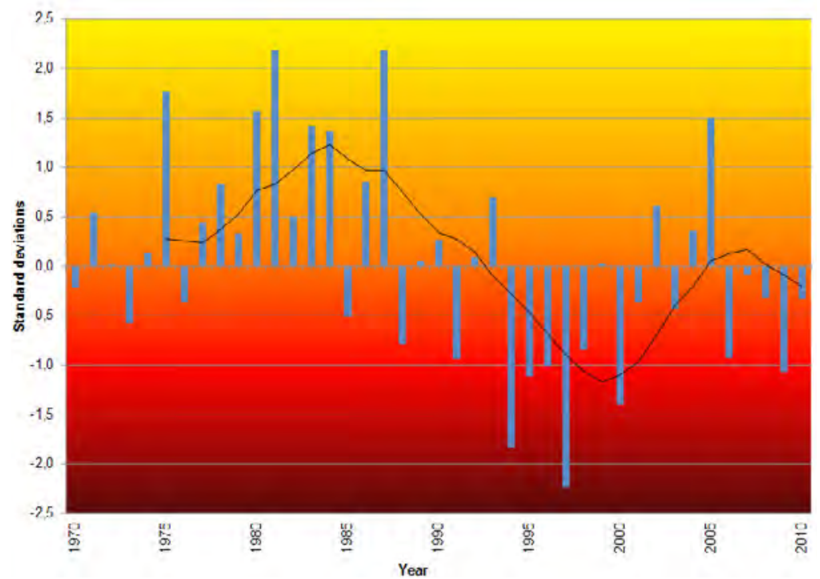


Figure 4 - Standardised annual runoff; Manyame River, with six yr moving average

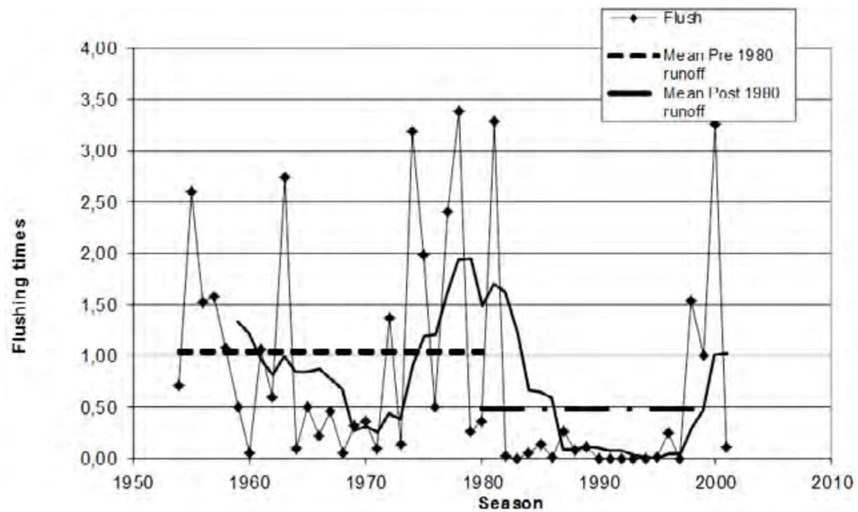


Figure 5 - Flush rate per anum

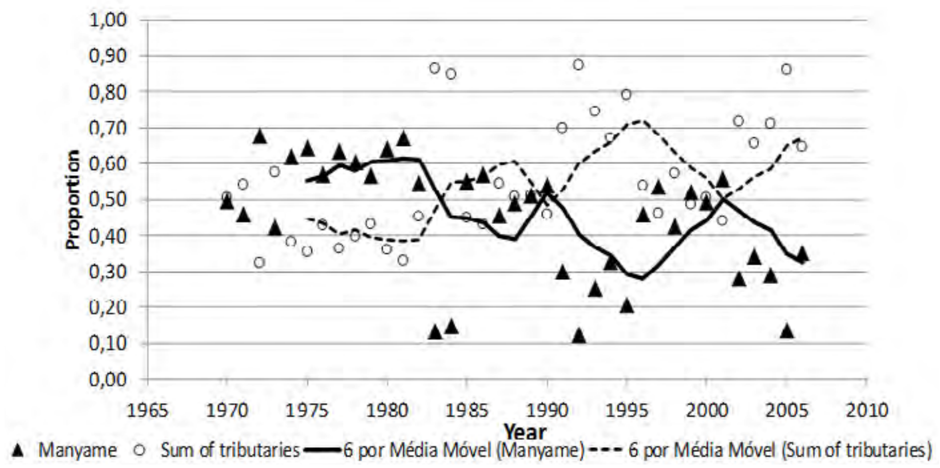


Figure 6 - Proportionate flows of sewage bearing streams and Manyame runoff

Small to medium sized reservoirs can periodically be cleansed of pollution loads by flushing during high inflow periods. In the period from the 1960s to the 1980s, the inflow into Lake Chivero was large enough to flush the lake as much as twice in a rainy season. Figure 5 shows comparative flushing rated of Lake Chivero in the periods prior to 1980 and thereafter. The data show that while in the pre 1980 period the lake , on the average, flushed out once every rainy season, with occasions when the inflows was more than twice the lakes capacity. In the post 1980 period, however, it now takes about two years to replace resident water in the reservoir. Thus, pollutants entering the lake now have a longer residence in the lake.

On the other hand, Figure 6 shows comparative proportion of the Lake Chivero inflows. The data clearly indicate that while contribution from the Manyame River has been declining, that from wastewater bearing streams has proportionately increased. Indeed in some years, runoff contribution from the watershed ceases in midyear, leaving the city to depend on recycled wastewater. In drought years, as in the 1991-92 severe drought, wastewater returns contributed as much as 90% of the lake's inflows. These observations stress the need to process the wastewater effluent from the urban settlements in the Lake Chivero catchment to the highest standard as the sewage outfall is now a significant source of the settlements' water supply.

3 WATER QUALITY

Sixteen years after Lake Chivero was commissioned it became hypereutrophic, dominated by the blue green alga *Anabaena flos aquae.* During that period phosphorus peaked at 27.4 gm^{-2} in 1967. In 1970, the municipality installed a biological nutrient removal (BNR) plant for the treatment of the wastewater. By 1978 the phosphorus loading had declined to 1.5 gm^{-2} (THORNTON, 1982) demonstrating the efficacy of the BNR technology. The lake reverted to a metastable condition (MAGADZA, 1994). However, by the 1990s, ten years after Zimbabwe attained majority rule, maintenance of public works began to falter. Thus, by 1996, P loading had risen to 14 gm^{-2} and rose to 223 tones p.a. by 2010 the aerial loading was 20 gm^{-2} (NYUMBU, 2012). In addition to wastewater sources from treatment plants the lake was also subjected to increasing diffuse source pollution, with a total output, estimated in year 2000, of 272.81 tones p.a. an amount equivalent to a P loading of 11 g m^{-2}.. These results were up to date in 2002. The situation would worsened by 2012. Thus the city authorities are in a situation where investment in point source wastewater treatment, i.e. bigger sewage plants, will no longer the same result that the BNR technology produced in the 1970s. The source of this non point source of nutrient loading in the lake is threefold:

- Poor city sanitation, resulting on thousands of tones of uncollected garbage;
- Poor maintenance of wastewater transport systems, i.e. broken sewers that could run for months without repairs due to an economic meltdown (2000-2009);
- Urban agriculture that converted wetlands to fertilised croplands.

More recently more attention is now given to infrastructure maintenance, but the rehabilitation of millions dollars worth of dilapidated sewage works will take a few years to accomplish. In the meantime, the bulk of the wastewater discharged into the lake is untreated sewage. There is yet no policy for management of diffuse source pollution.

Table 2 - Sewage treatment plants servicing the city of Harare

Wastewater treatment plant	Design Capacity ML/day	Current Capacity ML/day	Received flows ML/day	Capacity utilization (%)
Firle	144	60	150	42
Crowborough	54	5	120	9
Hatcliffe	2.5	1	3	45
Donnybrook	12	3	7	30
Marlborough	7	3	7	
Total	219.5	72	287	45

Source: Harare Water (2010)

In Figure 6 above, it has been shown that over the years the hydrological income of Lake Chivero has increasingly consisted of wastewater. From 1995 maintenance of wastewater treatment plants began to deteriorate culminating in the current situation where the bulk of wastewaters enters the lake untreated, not only from Harare Municipality, but also from dysfunctional BNR plant of the satellite settlement of Chitungwiza. In addition, Ruwa and Tafara / Mabvuku discharged wastewater from oxidation ponds

Table 2 shows the capacity and status of wastewater treatment facilities. The table clearly shows that the installed capacity, when fully functional, would only treat some 70% of total wastewater output from Harare. By 2002, the Chitungwiza BNR was no longer functioning. The overall picture then is of two cities discharging either untreated of partially treated sewage into Lake Chivero.

Table 3 shows estimates of non point source pollutants from various suburbs of Harare. Apart from the Umwisindale the rest are part of the Manyame reservoirs catchment, with Gwebe entering Manyame Lake below Lake Chivero. In this study, the total P output was 179 tonnes and 11722 tones of nitrogen per rainy season. The P loading to the lake is 7gm^{-2} in comparison to the recovery phase when the loading was 1.5 gm^{-2} P. In other words, non point sources can now maintain the hypereutrophic state of Lake Chivero.

Table 3 - Diffuse source Phosphorus and Nitrogen exports from Harare suburbs: dry season

Catchment/ Suburb	Type	Phosphorus		Nitrogen			Total export	
		Tonnes km^{-2}	Kg $capita^{-1}$	Tonnes km^{-2}	Kg $capita^{-1}$	N:Ratio	P-Tonnes	N-Tonnes
Gwebe	Low	0.02	0.04	0.16	0.42	5.81	0.99	9.31
Muwisindale	Low	0.07	2.31	1.22	41.39	5.99	5.24	93.96
Kuwadzana	Medium	0.08	0.17	0.47	0.96	3.89	2.88	16.75
Mukuvisi	High/Industrial	10.28	1.00	39.98	3.89	3.61	98.99	385.04
Marimba	High/Industrial	0.13	0.77	0.86	4.98	3.68	9.28	60.31
Budiriro	High	2.30	0.23	13.77	1.35	9.42	22.08	132.17
Epworth	High	3.38	1.11	12.20	4.00	17.95	103.12	371.88
Glenview	High	0.30	0.39	1.09	1.44	6.50	30.23	111.39

Source: adapted from Mufaro (2001)

Note that most of the diffuse source output is from the high-density suburbs. Here sanitary services (garbage clearance, street trash accumulation, sewer breaches) are most prominent. These data do not include similar emissions from the satellite settlements in the Lake Chivero catchment. However, again there is indication that engineering fixes to treat piped wastewater will no longer be sufficient in the restoration of Lake Chivero. The estimated diffuse source from Harare alone is equivalent to a phosphorus loading of 6.9 gm^{-2}.

Table 4 shows the historical phosphorus loading in Lake Chivero. The lake recovered to metastable mesotrophic state in the early 1980s (MAGADZA, 1994) at a loading of 1.5 gm^{-2}. Thus, diffuse source emissions to the lake, from only the Harare suburbs would maintain the lake in a highly eutrophic state, more so if emissions from other settlements were factored in. The estimated loading of 6.9 gm^{-2} is based on data from year 2000. Since then these emissions would have increased substantially.

These observations emphasize the need to factor diffuse source emission from the Lake Chivero watershed. Rehabilitation and expansion of the wastewater treatment capacity is indeed an essential requirement, but that alone is no longer adequate to restore water quality in Lake Chivero.

Table 4 - Historical trend in P loading to Lake Chivero

Variable	1967	1978	1996	**2010**
P concentration (mg/l)	2.8	0.13	1.8 (Manyame)	**2.77**
P load g (m^2)	27.4	1.5	14	**27.8**
P load (tonnes/pa)	685.0	39.6	350.0	**697**

Source: Magadza (2003) and Nyumbun (2012)

Figure 7 illustrates, using the phosphorus lake concentrations, the impact on the lake water quality of the emissions discussed above. The figure shows the exponentially worsening state of the Lake Chivero water quality. Similar trends can be shown for other pollution indicators, such as high TDS, high salinity, reduction in DO, high levels of NH_3^+ etc. Water Secchi disk transparency is only a few centimeters. In order to render the water potable the Municipality now has to treat it with a combination of at least eleven chemicals, resulting in piped water that is measurably corrosive due to high chlorine content. It is noteworthy that the exponent for the growth rate of the phosphorus concentration in the lake (0.18) is higher than that of the population growth (0.07), indicating that the eutrophication of the lake is proceeding disproportionately to the population growth.

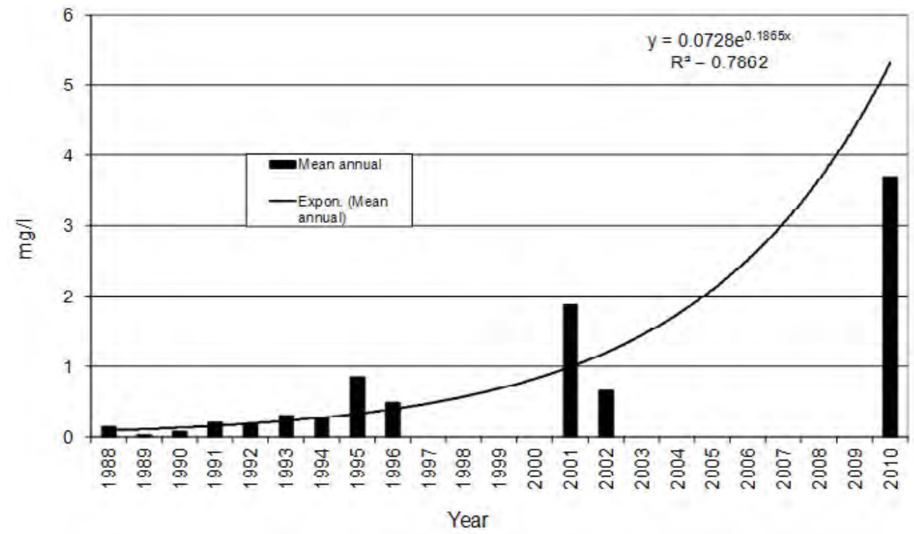


Figura 7 - Annual mean phosphate: 2010 data after Nyumbu (2012), 1988 - 1994 Harare Minucipality, other data by author

4 HEALTH IMPACTS

The health hazards in the Harare water supply arise from microbial contamination of the lake as well as toxins from cyanobacteria and *microcystin*, in particular (NDEBELE; MAGADZA, 2006). Nyumbu (2012) has recorded incidences of enteric diseases in Harare and Chitungwiza. Her data show that there have been significant out breaks of diarrhea incidences in both Harare and Chitungwiza, affecting mainly the high-density suburbs. There are periodic outbreaks of cholera and more recently typhoid fever. Figure 8 shows the growth of incidences of deaths due to enteric diseases. Between 1995 and year 2000, the incidences of liver cancer rose from 0.4 per thousand to 0.8, peaking at just over one death per thousand in 1999. Dalu et al. (2011) found significant loads of intestinal parasites in fishes from Lake Chivero. These parasites are transferable to humans who consume the fish. In the current economic hardships in Zimbabwe fish products from Lake Chivero constitutes a significant source of protein for low-income groups in the high-density suburbs. Besides parasites, the fish have also been found to contain significant levels of heavy metals.

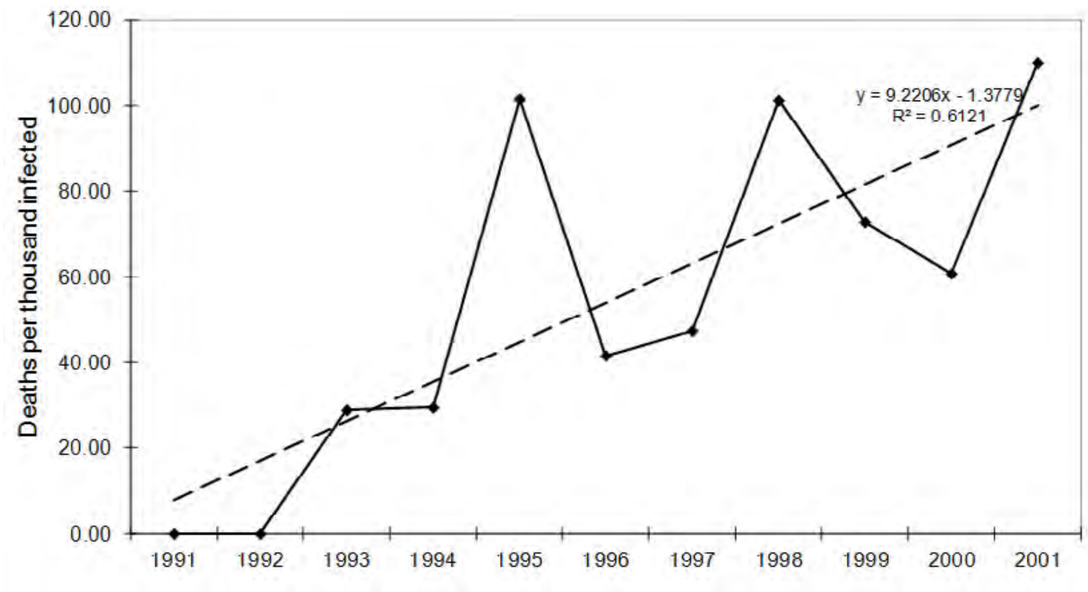


Figure 8 - Enteritis deaths per thosant infected

Zimbabwe, like many developing countries, lacks the protocol for linking human health to the environmental status. Thus, the health implications of the condition of Lake Chivero are largely unknown. One pointer is that the municipality sometimes boasts of the number of chemicals they now have to use in the water purification process. The health implication of this is also unknown, but what is evident is that the water thus treated can be very corrosive

The need to chlorinate the Lake Chivero heavily to kill pathenogenic microbes, in the presence of high levels of organic matter and decaying vegetation creates chlorinated biphenyl as well as possible dioxin compounds. These aspects of possible toxic effects of Harare water have not been investigated, but under the circumstances should be given consideration.

5 RESTORATION

In restoring Lake Chivero, there are two complementary issues, which must be addressed together. The first is the issues of the population of the City of Harare and satellite settlements Currently the Harare waterworks can only produce

60% of the total demand, and of this some 20% is said to be lost through leakages. There are plans for constructing another water supply reservoir, the proposed Kunzvi dam. This will be located in a different catchment from Chivero, but nevertheless, will eventually be subject to the same stresses as Lake Chivero from the expanding city. Further, the new reservoir's catchment will include communal lands with highly erosive soils and poor watershed management.

The approach of the city fathers is that more householders means more revenue, hence plans for further expansion of the city. However, the municipality is unable to meet the water demands of the current population. The country's second largest city, Bulawayo is in a similar water scarcity situation.

The reason for the country's population concentration in cities has already been discussed above as the former colonial policy of segregating the country into communal lands for the native population and restricting commerce and property rights to areas formerly reserved for the white inhabitants. Thirty years after majority rule there are no proactive policy for the economic development of the rural areas. Formal employment is still largely found in the cities and former white commercial farms, even though here too unemployment is high due to the recent economic collapse when the Zimbabwean dollar became worthless.

Thus to relive Harare and Bulawayo of water scarcity problems the communal areas must be developed to participate in the nation's economic activities. This requires massive injections of capital investment in these areas. However, investment is predicated upon security of property rights and an enabling state and social environment. This entails fundamental policy review in property rights in the communal lands; review that has consistently been resisted by government. The impacts of global warming on water resources in southern Africa will impose limits to growth of many cities. The appropriate adaptive measure is to spread the stress more evenly in the country by making economic activity more widely spread in the country instead of concentration in the cities.

The second approach to the restoration of Lake Chivero is the management of the wastewaters, both point sources and diffuse sources. In the early 1950s, when the lake became eutrophic it was at the dawn of eutrophication concepts e.g. National Academy of Sciences (1969). Sewage was traditionally treaded by the Trickle Filter, which removed BOD and suspended matter, while releasing nutrient rich effluent back into the lake. At low human population and low effluent emissions, the dilution factor of receiving waters was traditionally used to lower the concentrations of pollutants in those receiving waters. However, the rapid population growth of Harare city and satellite settlements has now overpowered these old traditional means of waste disposal. By the late 1960s, Lake Chivero had a foetid odour and covered with blue green algal scum. The lake had lost its aesthetic values and water purification for potable water supply costs increased.

A combined research effort between the University and the municipality resulted in the design of one of the earliest Biological Nutrient Removal wastewater treatment plants. The water act was amended to limit levels of phosphorus discharge to public streams to a maximum of 1 mgl^{-1}. The lake quickly recovered and by the late 1970s-early 1980s phosphorus loading had decreased from 27.4 gm^{-2} to 1.5 gm^{-2} (Table 4.)

However in the post 1980 to current period sewage plant failures and poor maintenance, insufficient funding for the water section with an overlay of rapid urban population growth reversed the recovery trends recorded in the early 1980s (MAGADZA, 2006, THORNTON, 1981). Currently the phosphorus load stands at 27.8 gm^{-2}, when the Chitungwiza city is included.

Table 5 shows the wastewater management capacity of the installed plant in Harare. The table shows that at the turn of the century Harare Municipality had a wastewater treatment capacity deficit of 221 ML per day... Had the plants been maintained and operated at design capacity the deficit would have been only 2ML per day. This cleanly shows the role of management in clean potable water supply. The processing deficit capacity indicates untreated sewage entering the public streams and ultimately the water supply reservoirs.

Table 5 - Status of wastewater treatment facilities in Harare

Wastewater treatment plant	Design Capacity ML/day	Current Capacity ML/day	Received flows ML/day	Deficit	Capacity utilization (%)
Firle	144	60	150	90	42
Crowborough	54	5	120	125	9
Hatcliffe	2.5	1	3	2	45
Donnybrook	12	3	7	4	30
Marlborough	7	3	7	4	45
Total	219.5	72	287	221	

Source: Harare Water (2010)

However, only Firle and Crowborough plants are BNR type. Thus even if these were fully operational a total of about 20 ML per day of high nutrient effluent would still find its way to the water supply lakes. This level of effluent is comparable to what eventually lead to the eutrophication of Lake Chivero in the mid 1960s. To make matters worse, these data do not include effluent from Chitungwiza city. This city now discharges an estimate 20 ML of untreated sewage from a non-functional BNR plant, with a total P output of some 133 tonnes.

Thus in summary the wastewater management situation in Harare is as follows:

- Dysfunctional wastewater treatment plants that are discharging hundreds of tones of P to Lake Chivero;
- A municipality hamstrung by lack of funding to maintain operations;
- A diffuse source of nutrients that is loading the lake to a level past experience shows is sufficient to keep it hypereutrophic;
- A burgeoning city population, consisting of non revenue generating sectors (i.e. the 90 % unemployed);
- A large watershed of 2227 km^2, consisting of three urban settlements and a large rural area administratively disconnected to the issues of Lake Chivero, but contributing to both the hydrology and dissolved and suspended matter transport to the lake;
- A water ministry largely restricted to developing water resources, i.e. building dams;
- A water Act that has up to now no water policy derivative. This is now being developed.

Nyumbu estimated that the current phosphorus loading of Lake Chivero is 45.1 gm^{-2}, 38% (17 gm^{-2}) of which originates from diffuse sources in Harare. The diffuse source component of the phosphorus loading is similar to the total loading in 1996 (14 gm^{-2}) when the lake had already reverted to a hypereutrophic state. The traditional method of managing wastewaters from Harare municipality has been to develop more capacity at the wastewater treatment plants. The current findings indicate that if all piped sewerage is treated to the legal standards this is unlikely to register as s reduction in eutrophication in the Manyame lakes, and Lake Chivero in particular.

This situation calls for new strategies of integrated water resources management. So far, the most popularly used concept is the Integrated Water Resources Management (IWRM). This strategy, evolved from the Dublin Principles. Dublin Principles state:

Principle 1: Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment
Principle 2: Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels
Principle 3: Women play a central part in the provision, management and safeguarding of water
Principle 4: Water has an economic value in all its competing uses and should be recognized as an economic good

These principles essentially deal with ethical and equitable distribution and access to water, among different societies and the environment, such as wetlands.

The international Environment Committee (ILEC) has, for several decades now, been concerned with not only the issues of access to water, but water of acceptable quality to humans and the environment. Communities can be denied water, not because of its scarcity, but its degraded nature, where the cost of treating it to acceptable level can be prohibitive. ILEC has concentrated on lakes because lakes integrate all the impacts of human activities in the watershed. After several years of studying the responses of lakes and reservoirs to various pressures worldwide ILEC gradually developed strategies for managing water quality in lakes and reservoirs. At this juncture, I would like to pay tribute to the work of the late Professor Tauto Kira, one of the founders of ILEC, whose vision inspired many scientists in the water sector.

In March 2003, ILEC launched the World Lake Vision (WORLD LAKE VISION COMMITTEE, 2003) as the template for management of lakes and reservoirs. This vision is underpinned by seven simple principles:

1. A harmonious relationship between humans and nature is essential for the sustainable use of lakes;
2. A lake drainage basin is the logical starting point for planning and management actions for sustainable lake use;
3. A long-term, preventative approach directed to preventing the causes of lake degradation is essential;
4. Policy development and decision making for lake management should be based on sound science and the best available information;
5. The management of lakes for their sustainable use requires the resolution of conflicts among competing use of lake resources, taking into account the needs of present and future generations and of nature;
6. Citizens and other stakeholders should be encouraged to participate meaningfully in identifying and resolving critical lake problems;
7. Good governance, based on fairness, transparency and empowerment of all stakeholders, is essential for sustainable lake use.

To implement this vision ILEC, under the leadership of Nakamura and Rast (2011) developed the Integrated Lake Basin Management (ILBM) initiative. The strategy identifies “six pillars” of lake basin governance for sustainable water resources management. These are:

1. Infrastructure

As we have noted above one of the reasons behind the collapse of the water provision services has been a breakdown in infrastructure. Wastewater treatment works and water purification facilities need rehabilitation and augmentation.

2. Policies

Zimbabwe has a water Act, but this is not underpinned by a water policy (now being developed). One reason for this anomaly is that the Ministry of water has seen its role as primarily that of developing water resources by constructing dams or sinking boreholes. Issues of water quality are lodged in the Ministry of Environment.

3. Participation

Zimbabwe has a top down style of government. In the issue of water supply and sanitation, the municipality merely advises consumers what the levies are. There is a ratepayers association, but the municipality makes decision without consultation to ratepayers. Indeed the public is barred from visiting any of the water public works installations.

4. Technology

Ironically, Zimbabwe has an adequate supply of very competent engineers. Hence, the main thrust in managing the crisis has been seen only as engineering fixes.

5. Information

In accordance with the top down governance style the municipality of Harare has found no need of appraising city residents of the difficulties encountered in the water delivery effort, nor to educate them on how water arrives in their taps and where it comes from and how their activities impact on the water supply.

6. Finance

The underpinning cause of the Harare water services failure has been gross underfunding. This is due to under budgeting as well as political interference. In the case of the satellite city of Chitungwiza, the city lacks an industrial business base to generate revenue to fund services.

Figure 9 - Amount of litter in the streets of Harare

The University of Zimbabwe, recognizing the complexity of the Harare water situation, invited ILEC for collaborative effort to formulate a strategy for the restoration of the Manyame River lakes. The agreed strategy is to formulate a multidisciplinary programme, based on the ILBM platform to tackle the Harare water conundrum multisecorally. To date several workshops have been held to bring all possible contributors to buy into the proposed programme...

The issues to be addresses are.

1. Diffuse source pollution

In Table 3 above, we have shown the contribution of only Harare suburbs to the phosphorus loading of Lake Chivero. The sources of non point source pollution include:

a. Poor city sanitation in which domestic garbage collects in heaps on the streets;

b. During the rainy season the decomposition products of these heaps are washed into the drainage system and find their way to the lake (see Table 3 above., Plate 1);

c. Urban agriculture in wetlands originally set aside for street run of cleansing.

Though illegal, urban agriculture on wetlands has been condoned by politicians and indeed promoted by some donor agencies as a solution to urban poverty. Attempts by the city authorities to stop the use of wetlands have been thwarted by politicians and party activists.

d. Loss of wetlands...

There is a growing encroachment into wetlands for conversion to housing or industrial estates. The most conspicuous one of these is a 600 bed Chinese hotel constructed on a prime wetland. "Development" politicians argue that now they have acquired Chinese technology for building on wetlands, so the engineering restrictions fall away.

Tackling these attitudes towards wetland will fall in the Information pillar. The residents of Harare, and indeed the rest of the watershed, need to be well informed on the role that wetlands play in intercepting pollutants to the lake as well as contributing to the overall hydrological performance of the watershed.

2. Participation

It is now patently clear that without the cooperation of the residents in keeping the streets clean and refraining from damaging wetlands the city authorities have no hope of bringing the level of Lake Chivero pollution under control. City residents need to participate in the safeguarding for their water resources actively. The city residents need to ***own*** the Harare water rather than thinking it belongs to the city and they just pay for it.

3. Technology

A number of studies at the University of Zimbabwe have indicated the possible contribution wetlands can make to the management of water quality in the Lake Chivero watershed. Pollution processing rates of wetlands have been established. Self-purification of a highly polluted stream, the Mukuvisi, has been demonstrated (Machena 1997). It is now possible to attach economic values of wetlands services, when compared their engineering counterparts. Recently Nyumbu (2012) estimated the total wetland area in the Lake Chivero catchment at approximately 40 000 Ha.

Using these data and the model PAMOLARE Nyumbu (2012) ran four scenarios on the water quality of Lake Chivero. As follows

a. Business as usual

Scenario one was projected water quality under current management;

b. Rehabilitation of wastewater treatment plants

Scenario two was use of fully functioning BNR technology only;

c. Use of wetlands

Scenario three was if only wetlands were used and;

d. Wetlands plus BNR

Scenario four was a combination of BNR technology and wet land use.

Figures 9A to 9C (NYUMBU, 2012) show the results of the four scenarios. Under the fourth scenario, the concentration of P in the lake by 2020 would be 0.22 mgl^{-1}, a P load of 1.36 gm^{-2} and a total discharge of only 34 tonnes per annum. However to achieve these results there has to be a basin wide awareness of the issues involved in water supply in the Greater Harare area.

4. Information

The project will explore means of maximizing public awareness in the Lake Chivero awareness. Where do information transfer barriers lie? This is no easy task as Magadza (2010) noted that dam construction creates an upstream catchment society made up of many of social and cultural entities who may have no obvious connection or interest in a downstream reservoir that supplies water to a city which they have empathy with.

5. Finance

Finance issues are linked with issues of governance, and this in turn linked to the political; and legal framework. The project aims at highlighting the linkages between politics, governance and state of the environment, in particular in this forum, that of the potable water supply to the Nation's capital City.

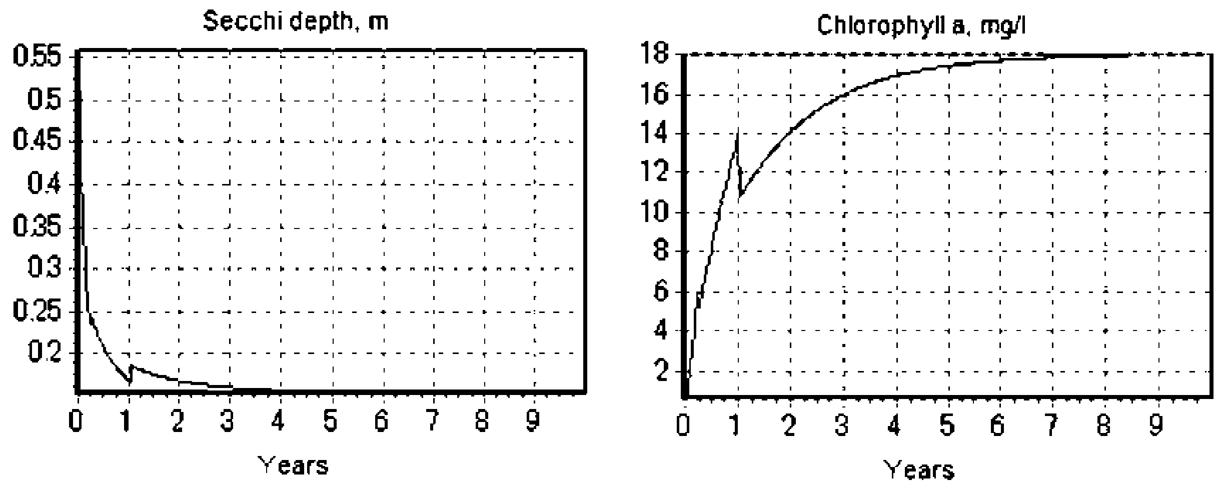


Fig 10A - PAMOLARE Projected Secchi depth and chlorophyll- a levels in Lake Chivero under current wastewater purification

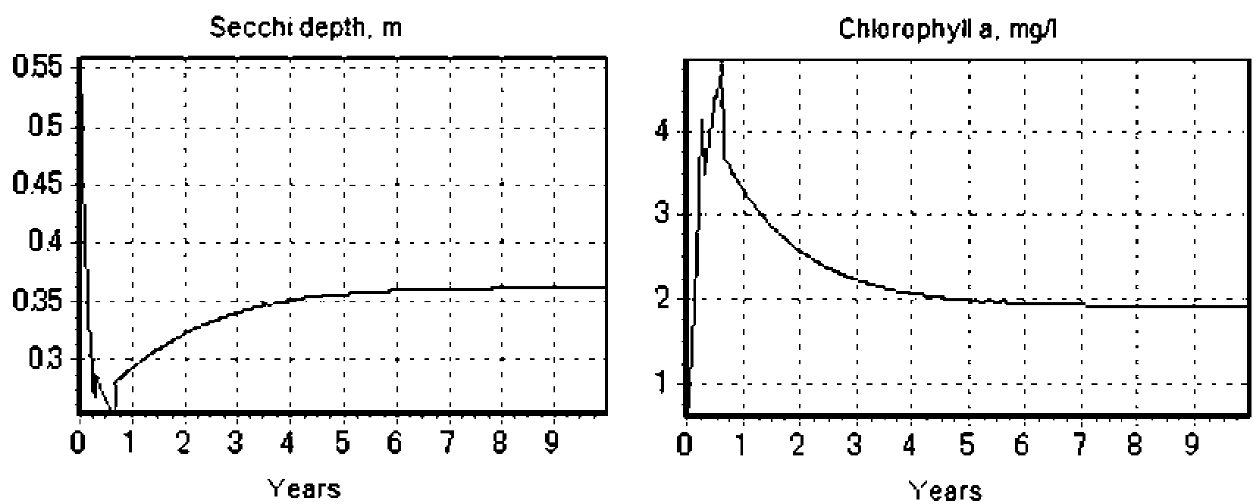


Figure 10B - PAMOLARE projections for Secchi depth and chlorophyll a levels in Lake Chivero under efficient wastewater treatment plants

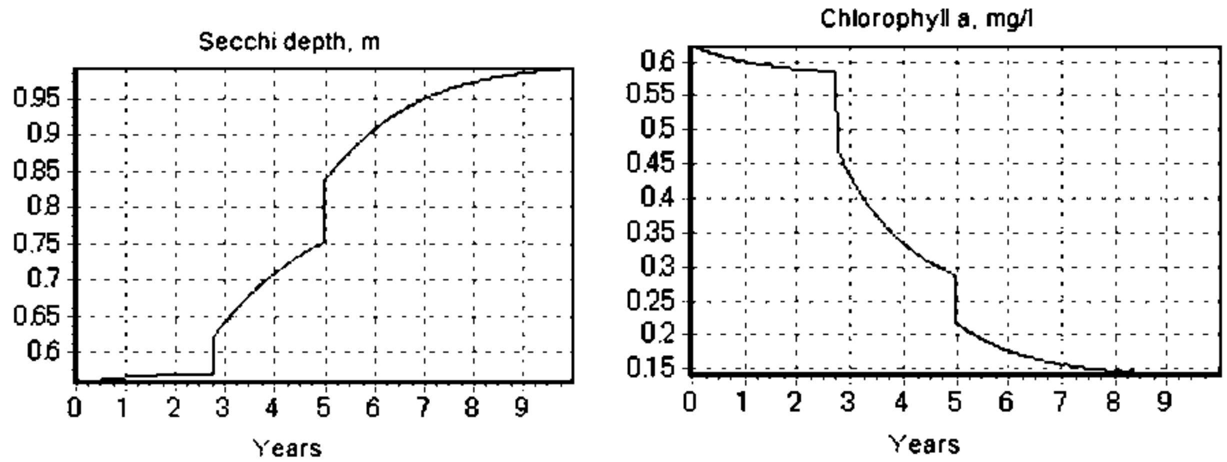


Figure 10c - PAMOLARE Projected Secchi depth and chlorophyll- a levels in Lake Chivero under wetland use and an efficient wastewater treatment system

Table 6 - Historical, current and possible future P loadings in L. Chivero under scenario 4 management strategy.

Parameter	1967	1978	1996	2010-11	2020 (Projections)
P concentration (mgL^{-1})	2.8	0.13	1.8 (Manyame)	2.77	0.22
P load g (m^2)	27.4	1.5	14	22.56	1.36
P load (tonnes/pa)	685.0	39.6	350.0	564	34.1
Conductivity (μScm^{-1})	160	120	800	609	

Source: adapted from Nyumbu (2012)

6 SUMMARY AND CONCLUSION

This presentation has shown a city with substantial water supply problems. The Harare municipality not only supplies water to the City of Harare, but also has to supply other satellite urban settlement (NORTON, RUWA; CHITUNGWIZA) with an estimate population close to two million inhabitants, over and above Harare's estimated five million residents. The population of Harare currently doubles every twelve to fourteen years. All in all the total population of Harare and satellite settlements approaches 50% of the entire population of Zimbabwe. The cause of the concentration of Zimbabwe's population in a few urban centers and Harare in particular is a political legacy form past colonial regimes that confined the indigenous people into non-economic Native Reserves. However thirty years after majority rule attainment this divide into poor rural Native Reserves, now euphemistically called "Communal Lands" and commerce driven society underpinned by property rights has not been redressed. Hence, the rural drift into urban centers, especially by the young, in search of livelihoods. It is recommended here that investment in the Communal areas, guaranteed by property rights, could alleviate Harare's water demand pressure.

In contrast to the burgeoning urban population, the Southern Africa subcontinent is showing reduced precipitation, or at least runoff. To avoid the scourge of malaria and other vector borne diseases, the early settlers established their settlements on the high altitude ridge that runs in the northeast to southwest direction along the center of the country, otherwise known as the high veldt. Because of the high seasonality of rainfall in the region, it is necessary to store water for dry season use in the reservoirs, hence Lake Chivero and other Manyame River reservoirs. However because of the elevated position of the urban settlements reservoirs near the settlements are situated on low order stream segments, therefore highly sensitive to annual variations runoff. Lake Chivero is downstream to the City of Harare. Effluent from the city, including wastewater effluent, now constitutes an important component of the reservoirs hydrological income.

Because of various factors, political and economic, the Harare Municipality's capacity to supply potable water to its clients has been greatly compromised, in terms of both available quantity and quality. The discharge of untreated wastewater to Lake Chivero in particular places enormous strain of the Morton Jeffrey Waterworks to supply safe potable water. Though the delivered water is microbiologically passable, the large number of chemical additives raises other issues of its safety.

There in now a constant threat of waterborne diseases, such as cholera, typhoid and diarrhea. The sources of these are sewer breaches, runoff from decomposing garbage resort to shallow wells where the municipality fails to deliver safe water, especially in the high-density suburbs. Other hidden health hazards are associated with the large amounts chlorine added to the water in the presence of high levels of decaying organic matter, and in particular the possible formation of phenolic toxins.

Given good governance and a buoyant economy, the problems outlined above can be solved by the appropriate technology. However, piped sewerage is not the only source of pollution in Lake Chivero. Data on non point sources of phosphorus and nitrogen clearly show that this source of pollution to Lake Chivero can maintain a hypereutrophic state. On the other hand, research has demonstrated the potential use of natural ecological processes in wetlands, which abound in the catchment, for control of diffuse source pollution.

To address these issues towards the restoration of Lake Chivero the International Lake Environment Committee, ILEC, in collaboration with the University of Zimbabwe and the Harare Municipality are developing a multisector project, based on the ILEC Integrated Lake Basin Management (ILBM) platform.

REFERENCES

Dalu T, Barson M. and T. Nhiwatiwa. 2011. Impact of protozoan parasites on drinking water quality in Harare. Zimbabwe. Journal of Water Sanitation and Hygiene for Development 1:3 153 163.

Machena, C. 1997. The pollution and self-purification capacity of Mukuvisi River. In Moyo N.A.G. Lake Chivero, a polluted lake. IUCN/University of Zimbabwe Publications.

Magadza. C. H. D. 2003. Lake Chivero: A management case study. Lakes & Reservoirs: Research and Management; 8: 69–81.

Magadza C.H.D. 2010. Environmental state of Lake Kariba and Zambezi River Valley: Lessons learned and not learned. Lakes & Reservoirs: Research and Management 2010 15: 167–192

Magadza, C.H.D. 1994. An evaluation of eutrophication control in Lake Chivero, using multivariate analysis of plankton samples. In Dumont, H., J. Green and H. Masundire. Studies on the ecology of Tropical zooplankton. Kluwer Academic Press. London. 295pp.

Magadza, C.H.D. 1997. Water pollution and catchment management in Lake Chivero. In: Lake Chivero: a Polluted Lake (ed.) N. A. G. Moyo. University of Zimbabwe Publications, Harare, Zimbabwe: pp. 13-26

Mukwashi M. G. 2001. Chracterisation of stream outflow in the City of Harare. B. Sc. Honours Dissertation. University of Zimbabwe

Ndebele M R and C.H.D. Magadha. 2006. The occurrence of microcystin-LR in Lake Chivero, Zimbabwe. Lakes and Reservoirs: Research and management. 11 (1) 57-62.

Nakamura Masahisa, Walter Rast. 2011. Development of ILBM Platform Process: Evolving Guidelines through Participatory Improvement" RCSE - Shiga University and ILEC.

Nyumbu T. 2012. Using Planning and Management Model of lakes and Reservoirs (PAMOLARE) as a tool for planning the rehabilitation of Lake Chivero. M. Sc. Thesis. University of Zimbabwe. 124pp

Thornton J. A. (ed.) (1982) Lake McIlwaine: the Eutrophication and Recovery of a Tropical African Lake. Dr W. Junk Publishers, The Hague.

World Lake Vision Committee 2003 World Lake Vision: a call for action. International Lake Environment Committee, Otsu

World Water Council. 1992. International Conference on Water and the Environment (ICWE), Dublin, Ireland, organised on 26-31 January 1992.

THE ROLE OF SCIENCE ACADEMIES IN POLICY AND SOCIETY ADVICE: WATER MANAGEMENT IN URBAN AREAS AS AN EXAMPLE

Henning Steinicke[1]

[1] German National Academy of Sciences Leopoldina, Department Science-Policy-Society, Jägerberg 1, 06108 Halle, Germany.

ABSTRACT

The provision of clean water is one of the most important tasks of a society. In particular urbanised areas have to deal with a number of problems regarding water resource management. The massive growth rates of urbanised areas, especially in developing countries, have increased the demand for innovative solutions to water management. Scientists and engineers have provided a large number of approaches and solutions. However, there is still a large gap between development, dissemination and application of scientific results. Science-based advice to policy and society can fill this gap and enhance the efficacy of application of novel approaches. The role of science academies and their international networks need to be strengthened in this context. As networks of excellence, free of economic or political interests, science and engineering academies can build an interface between science, policy, and society. Scientific approaches tackling the problem of water management in urban areas could here be used as an example, as most countries have to deal with this problem and provide different solutions.

1 INTRODUCTION

Water management in urban areas is an ever-growing challenge. In contrast to other problems, almost all countries have to deal with the societal phenomenon of urbanisation concerning water resource management. Although reasons and mechanisms of urbanisation may differ from country to country, challenges and problems resulting from urbanisation are comparable. Urbanisation led to a tremendous growth of cities and their adjacent urban areas that sometimes had not been planned for so many people. This increase in population, in turn, leads to foreseeable problems, in particular in resource management. The most essential resource that people need to have access to is water. Consequently, in July 2010 the UN General Assembly declared access to clean water and sanitation as a human right (UNEP, 2012). Apart from providing clean water, managing waste water is also a problematic issue. All large urban areas have to deal with these problems to some extent, regardless to climatic range and general water availability. In spite of its advantages, urbanisation itself may be a problem that needs to be faced for a number of reasons. Nevertheless, urbanisation is a reality that implies the need for viable solutions to be developed for any secondary problem caused by it. Especially in areas where urbanisation has already led to scarcity of essential resources, it is necessary to cope with this problem, to develop management plans, and to implement solutions. To make such processes efficient, a strong link between science, policy, and society is necessary.

2 WATER MANAGEMENT IN URBAN AREAS

Today more than half of the world population lives in urban areas. This development will continue (ESA-UN, 2010). For individuals urbanisation comes along with several advantages, leading to this global phenomenon. For the society it leads, on the other hand, to several problems. In particular the fact that urbanised areas have increasing need of resources is one of the main challenges a society has to deal with. Access to clean water and sanitation is the most important demand of people. Water is often scarce, water demand in particular in metropolitan regions is large and, especially in regions of high urbanisation rates, increasing with time. Sustaining a city with high-quality water is a challenging task in arid as well as in humid regions (NAGY et al., 2011). For supply purposes many large cities rely on surface water, but also groundwater plays an increasing role (VÁZQUEZ-SUÑÉ et al., 2005). The impact of cities regarding resource is not only limited to urbanised areas but also includes, surrounding areas, and hinterlands, which play an important role for the supply of resources and the disposal of wastes (BAI, 2007; HUA, et al., 2009; AGUDELO-

VERA, 2011). The catchment area is of particular importance for water resource management. Thus in water resource management urban planning involves not just the local area of a city, but also surrounding areas.

Urban areas and the process of urbanisation significantly affect the natural water cycle in terms of quality and quantity (VÁZQUEZ-SUÑÉ, et al., 2005). The quantity is influenced because cities rely on water and thus use water for a number of purposes. While surface waters play a main role in water provision groundwater can be important for the regional food production, which can lead to increased groundwater utilisation for irrigation in agriculture (NAIK et al., 2008). To what extend an urban area depends on surface waters (e.g. reservoirs) and/or on groundwater (e.g. borewells) depends on climatic, geographical, and geological conditions. The quality of the water cycle can be influenced due to the management of wastes, including solid waste disposal as well as sewage management and clarification. The actual impact of an urbanised area on the natural water cycle however, depends on various specific factors, including geographic location but also economic factors (VÁZQUEZ-SUÑÉ et al., 2005; NAIK et al., 2008).

Beside the direct management of water as a resource urban areas often have to deal with problems related to precipitation. Precipitation plays a particular role in urban areas. While e.g. rain water is an important factor for water provision and groundwater recharge in the surrounding area of a city, in the urbanised area itself it may cause problems. This is especially valid for large agglomerations with high cumulative precipitation amounts and a high amount of extreme weather events. A city can act here as a huge sealed area that is almost impermeable for precipitation. This puts particular importance on management structures, the sewer system, and drainage in general, which need to be able to cope with extreme events. Furthermore, impermeable surfaces reduce surface water infiltration, which has a negative impact on groundwater recharge. Depending on local conditions this negative impact may be neutralised by a decrease in water loss due to reduced evapotranspiration (NAIK et al., 2008). But also the uncontrolled input of contaminated water from urban runoff in surface and subsurface aquatic systems need to be considered. To pass surface runoff into the general waste water system and water treatment plants cannot be the answer although it is the classical route taken by most cities in the developed world. Eco-hydrological approaches using drainage into and via constructed wetlands (HABERL et al., 1995) – for example in recreation areas – could be an answer as documented by the City of Lodz in Poland (WAGNER; ZALEWSKI, 2009). Here new approaches are needed and should be discussed specifically for developmental programmes.

The management of water as a resource is inseparably connected to the management of waste water. A sustainable development requires the inclusion of environmental issues into resource management and urban planning, providing urban areas with resources while guaranteeing reliable resource provision for current and future generations (AGUDELO-VERA et al., 2011). Sustainable management following Otterpohl et al. (1997) and Terpstra (1999) is understood here as management that includes:

1) the preservation of water quality including re-use and recycling of waste waters;
2) the avoidance of accumulation of contaminants (in soil, surface water and ground water);
3) the reduction or degradation of water and soil resources; and
4) safeguarding water quality and quantity; and excludes
5) the transfer of problems in time or space (energy use, CO_2 production, etc.).

Bringing all these requirements together demands a strategy for an integrated resource management that focuses on the availability of resources while considering also the control of emissions and the prevention of pollution (TERPSTRA, 1999; AGUDELO-VERA et al., 2011). Here again more than metropolitan regions need to be considered. Sustainable management includes the maintenance of e.g. wetland ecosystem services in surrounding areas (e.g. wetlands). This is a challenging task in particular in the very fast growing cities of emerging countries, where growth rate often exceeds infrastructural development. Urban planning, resource, and waste management must also consider surrounding areas. Care has to be taken especially when waste, especially waste water, is brought back to the resource cycle. It is necessary to avoid urban waste water being used (e.g. for irrigation) before clarification as this may result in an enrichment of toxic substances (e.g. heavy metals) in the ecosystem ending finally up in the nutrient cycle.

Management approaches finally need to be realistic also in terms of financial investment and infrastructural feasibility. At present the traditional approach to deal with waste water are central treatment units (HABERL et al., 1995; JEPPSSON et al., 2002). Whereas in many urban areas, in particular in industrialised countries, this is an acceptable solution, in cities where urban sprawl dominates one should also consider decentralised systems where a combination of biological degradation of organic compounds in waste water (plus other organic wastes) are first fermented for methane and energy production and the residual fluid is filtered via membranes (FAO, 1992; PARKINSON; TAYLER, 2003). The filtration residue is then recyclable within the urban subunit or made available for agricultural activities. The DEUS system of the Fraunhofer Institute for Interfacial Engineering and Biotechnology (Systems analyses) in Stuttgart is an example (HIESSL; HILLENBRAND, 2010). The treatment of waste water also contains possibilities e.g. via a connection between waste water treatment and energy recovery/production. Such integrated solutions must be further explored and expanded in future.

One of the main challenges science faces in regards to water management is the development of strategies integrating resource management, urban planning, and sustainable development. Scientific approaches often focus on technological solutions based on engineering, the role of collaborative governance, however, increases. The development of effective management strategies requires also the involvement of stakeholders to increase the acceptance of controversial solutions (e.g. dam projects) (PAHL-WOSTL et al., 2007). As suitable strategies need to act on different scales it is necessary to include bottom-up as well as top-down approaches and to understand resource management as an element of urban planning that can be regulated via a number of ways. Water in urban areas is mostly used for washing, toilet, shower, etc. (TERPSTRA, 1999). The technical instruments and concepts to regulate the use of water and to cope with problems in sanitation are numerous (see examples above). There are however also important political instruments of regulation acting top-down, e.g. special taxes for sealed areas. On the other hand education is an important example for bottom-up approaches. For influence on various scales it is necessary to recognise that the government may not be the only decision making authority. Democratic legitimised decision makers act at different scales and involve a number of stakeholders that may contribute in the decision making process. Governance therefore also needs to act on multiple scales (PAHL-WOSTL et al., 2007). Science based solutions are available on all scales, varying from general approaches to regional or local solutions. Especially in regards to urbanisation related problems, a number of relevant fields need to be considered for the solution of emerging problems. Urban dynamics as well as problems in urban areas are complex and depend on regional circumstances. Solutions therefore need to include engineering sciences and natural sciences as well as social sciences and humanities. Finally any process that increases the efficiency of water usage and helps decreasing the growth rate of water need is a process of water management.

3 THE ROLE OF SCIENCE ACADEMIES

A large number of strategies have been developed to cope with problems of water resource management in urban areas, some of which may be applicable in general, while others are focused on regional problems. Such strategies include technological solutions but also mechanisms of regulation. To tackle problems that come along with urbanisation, scientific academies have been active in the dissemination of novel scientific approaches. Nevertheless, the dialogue between science, policy, and society needs to be strengthened and science academies need to be active as an interface between those parties.

Although science academies are structured differently among the globe they are first of all places of scientific excellence. Some academies are structured as research institutions whereas a large number, including the German National Academy of Sciences Leopoldina, are societies of scholars that build a network of excellence and interdisciplinarity. Where single academies are sometimes not able to display all fields of science and technology, academy networks fill those gaps. Given that academies are non-governmental organisations free of economic and political interests, science academies as well as academies of engineering and technology are suitable starting points and interfaces for the dialogue between science, society, and policy. As such neutral institutions academies can provide scientifically based information and recommendations that can be of great value for policy makers on the one hand but can on the other hand also strengthen the public acceptance of decisions made by those.

Recommendations need to fulfil a number of characteristics to achieve highest impact. They need to be 1) reliable, 2) realistic, 3) clear, 4) feasible, 5) tailor-made regarding the problem, and 6) tailor-made regarding the target group addressed. Furthermore, statements and recommendations need to be created following good scientific practice in a transparent process with peer-review. Academies with certain experience have formulated detailed guidelines to ensure a good practice in the dialogue of science and policy, one of which is the good practice guide of the European Academies Science Advisory Council EASAC (EASAC, 2012). Taking these points of good practice into account statements and recommendations can be useful tools that help decision makers to set priorities. It is however unlikely that decision makers will follow always recommendations made by science academies. Politicians are also influenced by a number of stakeholders and of course represent a certain opinion reflecting their voting bloc. Nevertheless, statements provided by science and engineering academies are the scientific state of the art formulated by a respected scientific authority and therefore have the potential to support the solution of huge societal problems. To comply with this, statements and in particular recommendations need to be written in an understandable language. Academies can thus also be places of translation of scientific knowledge, an important step on the way to the transfer of science into application. The fact that academies are interdisciplinary places can further strengthen the impact of statements made, in particular when recommendations are based on a broad scientific review that takes various fields into account. For example, in water management hydrology, geology, or engineering are not the only important fields. Economics and social sciences but also law, ethics, and political sciences can be relevant and ensure the formulation of balanced recommendations. This again can also be helpful for the public acceptance of decisions and acceptance by stakeholders.

However, just the production of a statement should not be enough. Recommendations need to be carried into politics. There are large numbers of institutions and lobby organisations that are active in policy advice. To policy makers this group often appears as a cacophony of different stakeholders, reflecting different opinions, and following different interests. The reputation of academies and their independence from economic and political interests can make the difference here. Usually a large number of scientists are not aware of how a dialogue between science and policy or science and society should work. This can jeopardise the efficiency of statements in the dialogue process. The work of scientists involved in the process of statement writing and the work of the academy staff does not end with the publication of a statement. In all, in particular, in cases, where the topic is of high relevance to the society or is controversial, communication via press and other media is of high relevance for the successful dissemination of results. As stated before, politicians reflect their own opinion and thus a certain part of the society and in most cases they are not experts in the topic they decide on. The more the society discusses an issue, including findings and recommendations of academies, the more politicians will perceive academies' work. Here it is important that qualified staff of the academy office supports the scientific authors of the statements. This includes the whole administration and coordination of subsequent work, the communication of findings on all relevant scales also via PR into the public, and also the collection of general feedback for later impact analysis and work flow improvement.

The decision on which scales statements are addressed should usually already be discussed during the process of finding a topic. Water management is a typical example. While water regimes are particular local or regional issues on the one hand, solutions for sewage treatment on the other hand can be an issue with a high potential of transfer to other geographic regions. It therefore needs to be decided early in the process whether a statement is communicated on local, regional, national, or international scale. While the local up to the national scale can be addressed by a single academy, it is advisable to include other national academies or international academy networks to ensure the impact on the international scale. International academy networks have proven their influence especially in international events. The G8 academies have for example published reports on the linkage of water and health (G-SCIENCE ACADEMIES, 2011) and also on the linkage between water and energy (G-SCIENCE ACADEMIES, 2012) and have fed these statements into the annual summits of the heads of state of the world's eight major economic powers. Here academies use the possibility to point out issues of particular importance at a very high level of decision making, probably the highest level in current politics. Also one of the European networks of Academies has published a statement on water issues in the Mediterranean region, pointing out a number of priorities for science and policy in this region (EASAC, 2010). The European Academies Science Advisory Council EASAC fills the gap of scientific policy advice on European level. These activities are of special importance as EASAC directly feeds its findings into the European Commission and the European Parliament. Today already more than 80% of national legislation of EU member states is influenced directly or indirectly by European guidelines and rules. Especially for European academies an activity on both scales, national and European can multiply the impact of findings and recommendations. The activities of the Inter Academy Panel-IAP have been an example of collaboration among various scales in particular in the Americas. Here, National Academies have worked together with the American network of Academies IANAS (Inter-American Network of Academies of Science) within the framework of the IAP water programme. This programme laid the founding for a more intense cooperation within these networks but showed also current lacks of collaboration.

4 OUTLOOK

The advice of society and policy has been a field of increasing activity of science and engineering academies around the globe. Where some academies like the Royal Society in the UK have a huge experience in this field and are well recognised by their national policy and society, other academies have just recently added such activities to their portfolio. In the 21st century the global community has to deal with a large number of huge challenges, related to climate change, population growth, or urbanisation that demand a shift from a policy driven by particular interests to global approaches based on scientific solutions. The field of science based policy advice therefore closes an important gap of dissemination from science to policy and to some extend also vice versa. There is however need to enhance Academies' activities in this field. Academies need to recognise their potential position in the science-policy-dialogue. The IAP water programme showed how a number of regional, national, and finally international workshops and symposia focused on water resource management can have impact on the development of local advisory structures also in countries without a science or engineering academy. It showed however also the partly unused potential of collaboration among continents. A stronger collaboration among African and Asian together with European and American Academies based on a mutual benefit would be desirable for the future.

The German National Academy of Sciences Leopoldina has set up a collaboration project with the Network of African Science Academies NASAC to strengthen the dialogue between science and policy in Africa and to create a network of excellent scientists between Germany and African states. The project partly focuses on capacity building, i.e. strengthening the African Academies network, but finally also aims to set up connections between academies and decision makers on all scales, from local to international. One of the first milestones within this on-going collaboration was a regional workshop, organised together with the Royal Dutch Academy of Sciences and addressing water management issues in Africa. This initiative has found large interest by African policy makers and thus shows that a stronger activity of academies in the field of policy advice is very much recognised and often valued by politicians. This example as well as the activities of the American academies within the IAP water programme shows the potential of academy networks to build an interface between science, stakeholders, decision makers, and the broader society.

Scientific and technological approaches of water management serve here as a suitable model topic and should thus explored further in this context. Urbanisation will remain one outstanding challenge for the future. Water management in these areas will remain an important issue in science as well as in politics. As such the dissemination and application of suitable scientific approaches will be of highest importance. Already today the application of frameworks for an integrated resource management together with technical approaches lacks efficiency. Science and engineering academies and their international networks thus need to enhance their cooperation to increase the interfaces of collaborative governance.

REFERENCES

Agudelo-Vera, CM, AR Mels, KJ Keesman & HHM Rijnaarts, 2011. Resource management as key factor for sustainable urban planning. – J Environ Manage 92: 2295-2303.

Bai, X, 2007. Industrial ecology and the global impacts of cities. – J Ind Ecol 11 (2): 1-6.

European Academies Science Advisory Council – EASAC, 2010. Groundwater in the Southern Member States of the European Union. – Available at: http://www.easac.eu/fileadmin/PDF_s/reports_statements/Easac_Groundwater_WebVersion.pdf Accessed: 29.09.2012.

European Academies Science Advisory Council – EASAC, 2012. EASAC Guidelines: Good practice in the dialogue between science academies and policy communities. – Available at: http://www.easac.eu/fileadmin/ppt/Science-Policy-Workshop/Short_EASAC_Guidelines_for_Workshop_PDF.pdf Accessed: 29.09.2012.

ESA-UN, 2007. World population prospects: The 2010 revision. – Available at: http://esa.un.org/wpp/ Accessed: 06.06.2012.

FAO – Food and Agriculture Organization of the United Nations, 1992. Wastewater treatment and use in agriculture. – FAO irrigation and drainage paper 47, FAO, Rome: 156 pp.

G-Science Academies Statements, 2011. Joint G8+ science academies' statement on water & health. – Available at: http://www.leopoldina.org/uploads/tx_leopublication/20011_G8_Statement_Water_ENGL_02.pdf Accessed: 06.08.2012.

G-Science Academies Statements, 2012. Energy and water linkage: Challenge to a sustainable future. – Available at: http://www.leopoldina.org/uploads/tx_leopublication/G-Science_Energy_Statement-FINAL_01.pdf Accessed: 06.08.2012.

Haberl, R., R. Perfler & H. Mayer, 1995. Constructed wetlands in Europe. – Water Sci Technol 32: 305-315.

Hiessl, H. & T. Hillenbrand, 2010. DEzentrales Urbanes InfrastrukturSystem DEUS 21 – Abschlussbericht. Fraunhofer-Institut für System- und Innovationsforschung, Karlsruhe: 415 pp.

Hua, B, J Yang & B Deng, 2009. Groundwater quality. – Water Environ Res 81 (10): 1975-1995.

Jeppsson, U., J. Alex, M.N. Pons, H. Spanjers & P.A. Vanrolleghem, 2002. Status and future trends of ICA in wastewater treatment – a European perspective. – Water Sci Technol 45: 485-494.

Nagy, RC, BG Lockaby, B Helms, L Kalin & D Stoeckel, 2011. Water resources and land use and cover in a humid region: The Southeastern United States. – J Environ Qual 40: 867-878.

Naik, PK, JA Tambe, BN Dehury & AN Tiwari, 2008. Impact of urbanization on the groundwater regime in a fast growing city in central India. – Environ Monit Assess 146: 339-373.

Otterpohl, R, M Grottker & J. Lange, 1997. Sustainable water and waste management in urban areas. – Wat Sci Tech 35 (9): 121-133.

Pahl-Wostl, C, M Craps, A Dewulf, E Mostert, D Tabara & T Taillieu (2007). Social learning and water resources management. – Ecol Soc 12 (2): 5 [online] URL: http://www.ecologyandsociety.org/vol12/iss2/art5

Parkinson, J. & K. Tayler, 2003. Decentralized wastewater management in peri-urban areas in low-income countries. – Environ Urban 15 (1): 75-89.

Terpstra, PMJ, 1999. Sustainable water usage systems: Models for the sustainable utilization of domestic water in urban areas. – Wat Sci Tech 39 (5): 65-72.

UNEP – United Nations Environment Programme, 2012. GEO-5 Global Environment Outlook. Environment for the future we want. – Progress Press, Valetta: 550 p.

Vázquez-Suñé, E, X Sánchez-Vila & J Carrera, 2005. Introductory review of specific factors influencing urban groundwater, an emerging branch of hydrogeology, with reference to Barcelona, Spain. – Hydrogeology Journal 13: 522-533.

Wagner, I. & M. Zalewski, 2009. Ecohydrology as a basis for the sustainable city strategic planning: focus on Lodz, Poland. – Rev Environ Sci Biotechnol 8: 209-217.

URBAN WATER MANAGEMENT IN MEXICO

Ricardo Sandoval[1]

[1] Consultant. E-mail: ricardo.sandoval@mav.mx.

ABSTRACT

In this paper, an overall assessment of the performance of urban water and sanitation systems is presented; public policies and programs which have been recently implemented to face urban water challenges are analyzed and some policy issues are proposed, in order to feed a necessary reflection on the scope and consequences of the present model for solving water problems in our Country's bigger cities; a call for setting up a new model is made, consistent with the need to guarantee equal access to water to urban and rural population while preserving the environment, as a part of a national urban water management policy.

1 INTRODUCTION

In Mexico, almost 8 of every 10 people live in urban localities (INEGI, 2010), while 73% of the total gross production[1] is generated in 56 metropolitan areas (ONU HABITAT, 2011). Despite an apparent high water and sanitation coverage, Mexican cities face growing problems for providing potable water with proper continuity and quality, replace aging infrastructure and support urban expansion. Besides, 53% of all groundwater extracted comes from overexploited aquifers (CONAGUA, 2012b), while surface water sources such as Chapala lake or Cutzamala dam system are threatened by pollution, competition with other users or climatic variability. The lack of sustainable high quality water and sanitation systems poses a huge challenge for the country's economic wealth and social welfare.

Federal, state and municipal authorities have set up different measures in order to reinforce the resource's preservation, build new infrastructure, improve technical and economic efficiencies, create public awareness and set up accountability and transparency frameworks. Still a lot remains to be done, especially in terms of integrating land development and use control with water management in the urban contexts, as well as setting up better institutional arrangements which could lead urban systems towards higher quality and performance instances.

In this paper, an overall assessment of the performance of urban water and sanitation systems is presented; public policies and programs which have been recently implemented to face urban water challenges are analyzed and some policy issues are proposed, in order to feed a necessary reflection on the scope and consequences of the present model for solving water problems in our Country's bigger cities; a call for setting up a new model is made, consistent with the need to guarantee equal access to water to urban and rural population while preserving the environment, as a part of a national urban water management policy.

[1] Total gross production means the value of all the goods and services commercialized by the economic units of a municipality. Gross domestic product is not reported for the municipal or city scale (ONU HABITAT, 2011, p. 39).

2 OVERALL ASSESSMENT. URBAN WATER AND SANITATION PROBLEMS AND CAPABILITIES IN MEXICO

2.1 STATE OF THE PROBLEM

Mexico is a Federal Republic, with an extension of 1964 million square kilometers; 76.8% of its population is considered "urban" (living in towns with more than 2500 inhabitants). Water and sanitation coverage in urban areas is relatively high: 95.4% of the urban households have access to water while 96.4% are connected to sewers or have decentralized wastewater disposal systems (CONAGUA, 2012, p. 22). A huge effort has been made to build 2289 wastewater treatment plants, with the capacity to process more than 130 m^3/s (2967 MGD)[2], as well as to support municipal utilities with financial and technical resources to develop new water sources, improve technical and commercial efficiencies and extend the services coverage. Some of the utilities serving bigger cities perform with acceptable indicators and based on best international practices. Nevertheless, there are big challenges still to be resolved:

- In 30 years, the pollutant load from point sources has increased in 42%, while groundwater, which accounts for 75% of water supply for public uses, is not being properly protected agaisnt salt intrusion, overexploitation, wastewater infiltration and other impacts (ABOITES, et al., 2008);
- Water availability per person has diminished because of the population growth, but in Mexico's case this is worsened by the concentration of most of the urban, industrial and agricultural zones of the country in the central and northern regions, where less water is available (SALTIEL, 2008);
- Water coverage is not only lower in rural localities (Figure 1), but also tends to be lower in poor districts within and around cities (SALTIEL, 2008);
- According to the 2010 General Census, only 73.04% of the households receive water supply every day, but most of them not on a 24 x 7 basis (INEGI, 2010)

[2] (CONAGUA, 2012, p. 47), to december 2011.

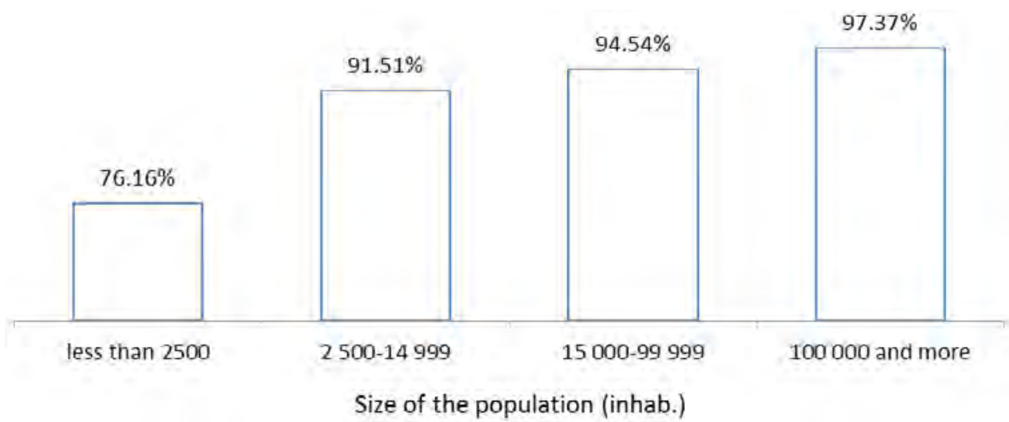


Figure 1 - distribution of water coverage[3] according to the size of the population
Source: (INEGI, 2010)

Urban population will keep growing, putting a growing pressure on urban development and the provision of services, usually in areas of the country where natural resources (especially water) are already scarce, under overexploitation patterns and threatened in their quality (Figure 2).

---

[3] Percentage of private occupied households which have access to water in their immediate surroundings.

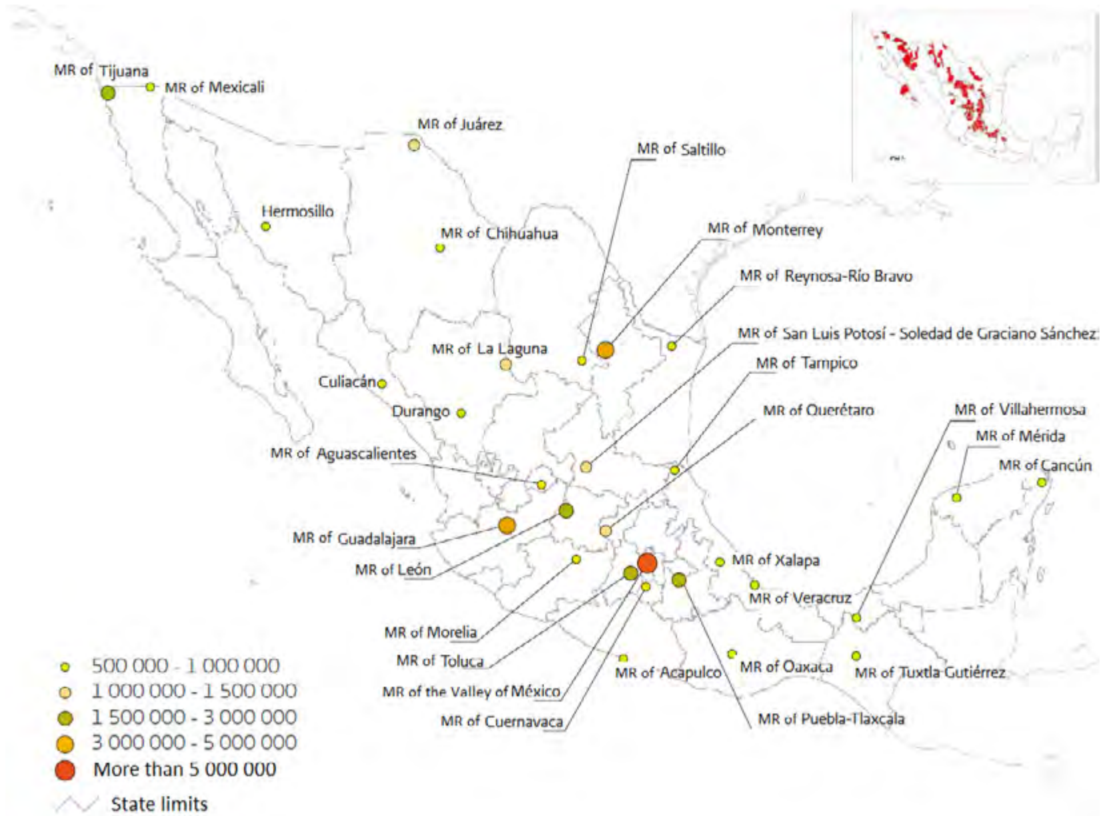


Figure 2 - metropolitan regions in Mexico by the size of their population and overdrafted aquifers
Source: CONAGUA (2012: 11) and CONAGUA (2012b: 34)

For analysis purposes, the system of cities or National Urban System is comprised of 56 metropolitan regions and 327 cities with more than 15 000 inhabitants; in the former live 56% of the people. Besides, in the last 30 years, territorial expansion of cities has grown 4 times faster than total population and 3 times than urban one, with our cities growing with a discontinuous, dispersed and low density spatial model; thus, the introduction of services becomes more expensive and difficult. Medium-sized cities (between 500 000 and 1 million inhabitants) are growing faster and there will be more than 20 big cities (with more than 1 million people) by 2030 (ONU HABITAT, 2011). The hardest problem will be posed by the "Megalopolis of Mexico City", which will be formed by 7 metropolitan regions: Valley of Mexico, Toluca, Cuernavaca, Cuautla, Puebla-Tlaxcala, Pachuca and Queretaro, all of them already facing water supply problems and being currently supplied under unsustainable conditions.

Clearly, the problem for achieving sustainable urban water services in Mexico is more complex than having water or sewage connections or importing water from other basins, since urban areas require to be served from farther sources and to collect and treat wastewater in more extended areas; aquifer recharge areas are being paved and riversides invaded, while climatic variability increases the risks of flooding with more intense precipitation events.

2.2 INSTITUTIONAL FRAMEWORK

In Mexico there are three governmental “orders” (with no hierarchical relationship between them): federal, state and municipal. While the country’s Constitution enacts federal government, through the National Water Commission (Conagua by its Spanish acronym), to take charge of the administration of the national waters within the Country, the National Waters Law also gives Conagua relevant capacities in at least two important issues: first, to support financially and technically the extension of services coverage through budgetary allocation and the definition of execution rules and norms; and second, to promote efficient practices, in physical and financial processes, among public water suppliers and productive users. Within this framework, Conagua can also build and operate water supply and sanitation infrastructure in coordination with states and municipalities. In the other hand, since 1982, the Constitution’s 115th article gives the municipality the responsibility for the provision of water and sanitation services, with the assistance of the state if needed. This has given place to a very varied set of institutional arrangements, with some states having a wider intervention (even a direct participation as water suppliers) and others setting aside of predominantly municipal utilities. Before 1982, bigger cities had been managed as federal organisms or had a more important federal participation, since they needed bigger infrastructure works which were normally financed and built by the national government since late 19th century. There is no formal mechanism for economic regulation of water services (formal and technically sound mechanisms to ensure a proper balance between price and quality of water and sanitation services), with the exception of private participation schemes. In most cases of public utilities, there is a board in charge of the system’s government and a group of directors in charge of the operation. The board presents a tariff proposal to the Ayuntamiento (city council), which then presents a revised proposal to the State Congress; the common practice is to set an upper limit according to general inflation rate, but without analyzing the utilities cost and technical structures, and disconnected from the investment programs. Without a formal supervision, it is common that utilities operate inefficiently and lack of resources for sustaining appropriate levels of operation and maintenance, transferring the costs of this inefficacy through resource overexploitation and capital improvement deferral. In most cases, political interference in staffing, administration, public works bidding processes and even in operational decisions, preclude even the most committed staff to get acceptable performances. It can be stated that, along with the lack of a planned and effective control of land use, institutional instability is a key root problem, leading to unsustainable provision of water and sanitation services.

3 THE PERFORMANCE OF URBAN WATER AND SANITATION SYSTEMS

There are different systems in place to collect and analyze performance data from water and sanitation utilities; none of them, though, is based on audited data, but on the information provided by the operators themselves. Here we review the results of one of the most complete, whether polemic exercise performed.

3.1 A SURVEY OF 50 URBAN WATER AND SANITATION UTILITIES

The Citizens Council for Water, an autonomous consultative organization set by the National Waters Law at the national level, organized in 2009 and 2010 a survey and classification effort, in order to try out a method of prioritization while promoting a benchmarking experience. Here we take some figures only for illustration purposes, taken from the 2010 survey, with no intention to discuss the methodology or results of the prioritization exercise. A set of 50 cities was analyzed and classified. Here we review some of the major findings (CCA, 2011) based on the revision of 4 of the 10 indicators included in the report.

Figure 3 shows the distribution of a continuity factor, that is, the percentage of connections receiving water on a 24x7 basis, according to the utilities themselves.

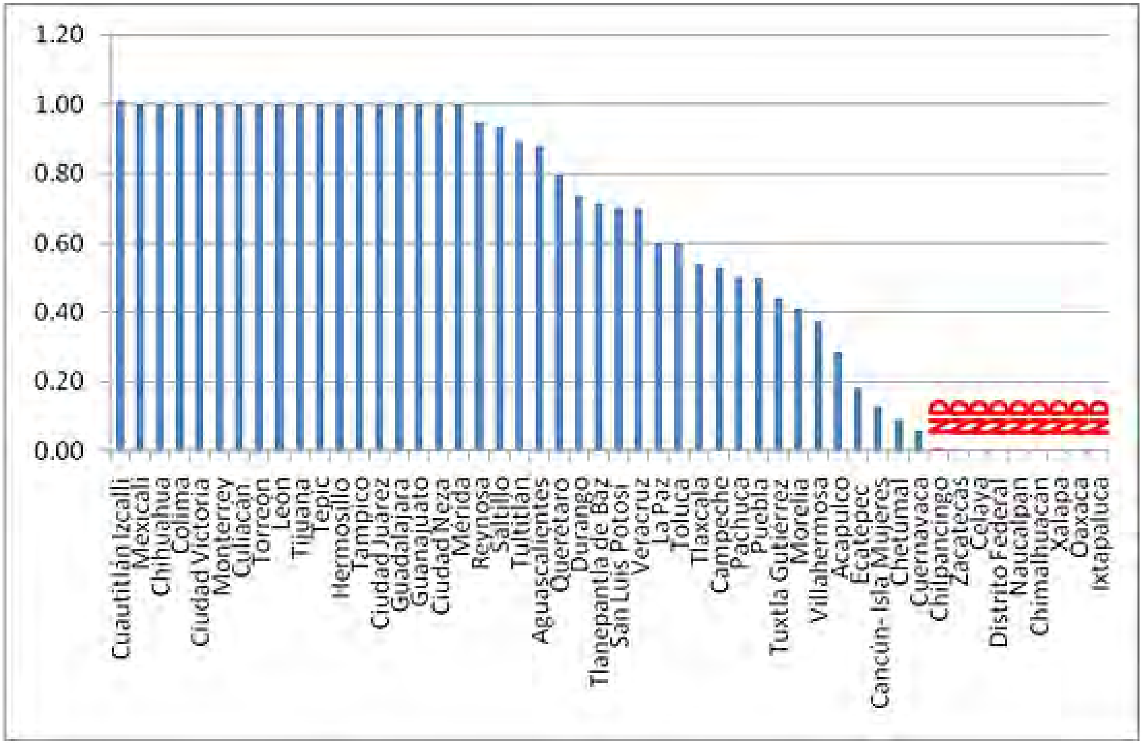


Figure 3 - distribution of the continuity factor among 50 Mexican cities
Source: CCA (2011) – ND: data not available

It is noticeable that less than a half of these utilities reported to have continuous service, even in the presence of a high potential level of error due to the lack of enough meters in many of these cities' households.

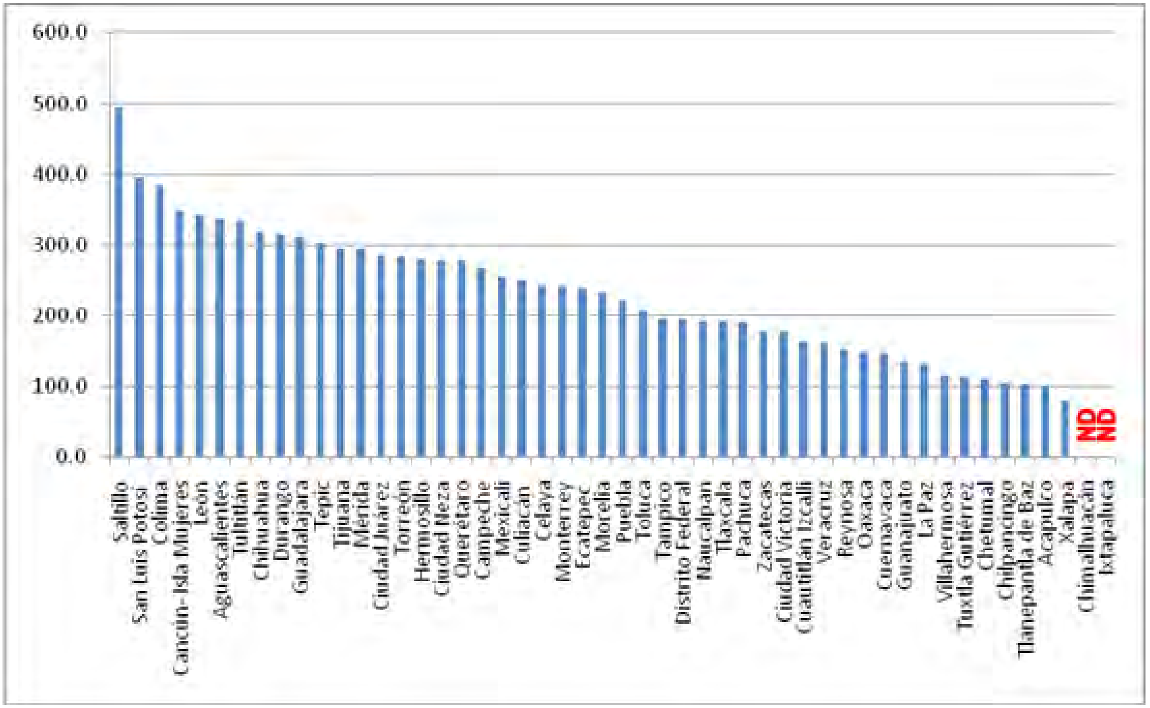


Figure 4 - distribution of the productivity factor among 50 Mexican cities
Source: CCA (2011) – ND: data not available

Figure 4 shows the distribution of a "productivity factor", as number of connections by employee (inverting the usual factor). Once again, nearly half of the sample remains below acceptable levels. In this case, each city's topographic context and the complexity of the networks can play a role, but this indicator is mainly related to the existence of stronger labor unions in some regions of the country which make workforce optimization difficult.

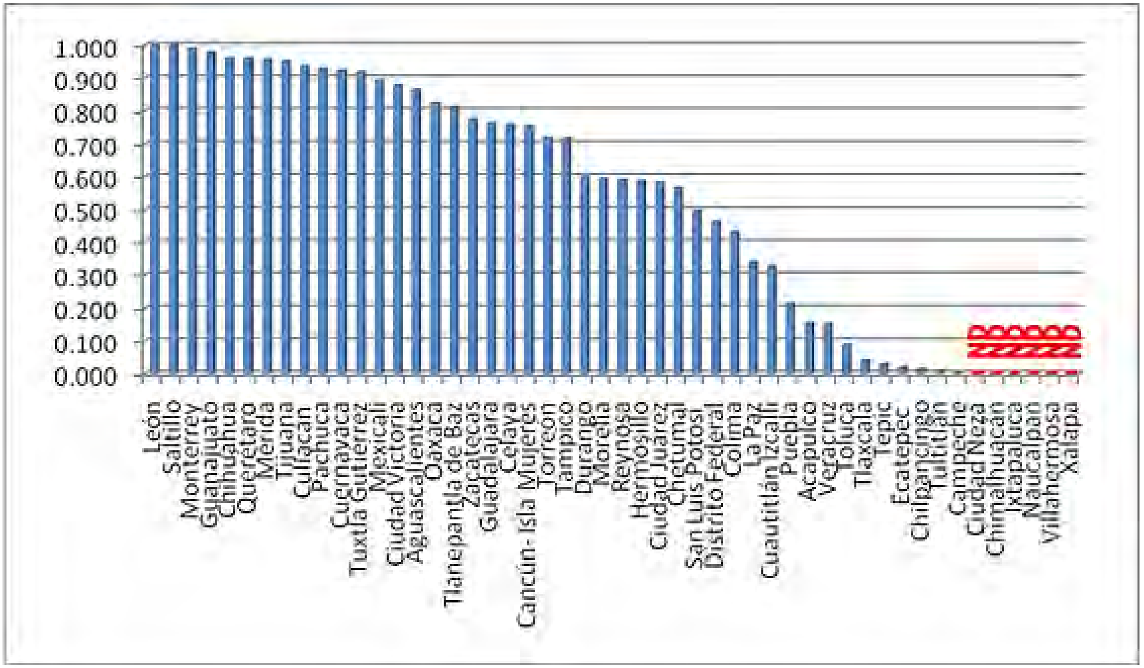


Figure 5 - distribution of the metering percentage at the household level for 50 Mexican cities
Source: CCA (2011) – ND: data not available

One very salient indicator is shown in Figure 5: the percentage of metered connections. Almost two thirds of the utilities fall below 80%, even without considering the percentage of meters actually functioning within acceptable ranks of precision. This means that one crucial element for, in the one hand, invoicing and collecting revenues to pay for the operating costs in an equitable way and, in the other, controlling the physical efficiency of the networks, is absent or deficient in some of the country's major cities. Not surprisingly, once more around 60% of the sample estimates to be collecting less than 80% of the volume sold

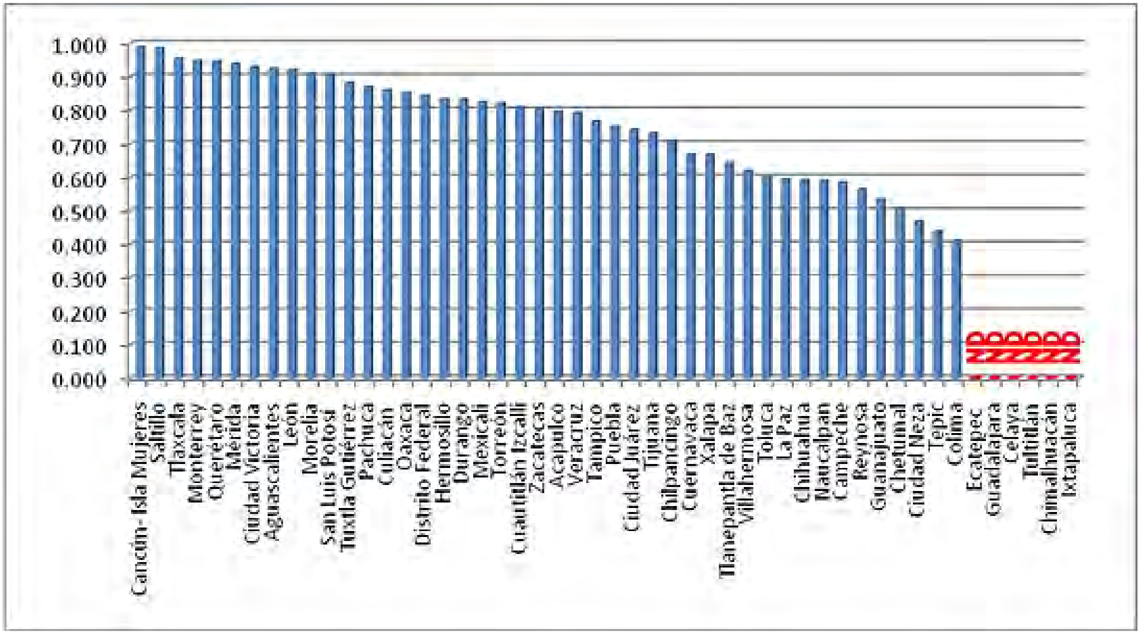


Figure 6 - volume collected as a percentage of the volume invoiced
Source: CCA (2011) – ND: data not available

3.2 MAJOR FINDINGS

The benchmarking exercise discussed in (CCA, 2011), in spite of some criticisms and possible improvements, has come to a set of useful findings:

- Services coverage, measured in terms of household connections which make possible the supply of potable water and the discharge of wastewater, appears to be high, as reflected in national statistics; nevertheless, when it comes to continuity, numbers vary a lot, with less than 40% of the utilities reporting 100% of connections with continuous service. Sewage coverage doesn't match either the capacity of waste water treatment;
- There are noticeable differences in terms of labor productivity and commercial efficiencies. It seems to be a geographical discrimination, where cities located in the northern part of the country show better indicators, with the exception of metered connections, where more dispersion is present;

- Although some utilities declare to have relatively high technical efficiencies, that is, low leakage ratios, it must be noticed that with a limited metering capacity, this figure should be questioned. The lack of appropriate measurement and invoicing of flows also hits the utilities' financial health, or causes a translation to the users' prejudice, since many of the cities not having adequate metering ratios usually charge fixed charges per household, which precludes efficient use at the home level and can cause a decrease in families' available income without relationship to the utility's cost structure and quality of service;
- One salient analysis performed by the CCA was to include a set of questions related to the existence of seven good governance practices: long term planning, governing board, users' participation in the board, audited annual reports, management autonomy, independent tariff setting and customer service systems. Once more, the best performing utilities seem to have also the best practices and they are mainly located in the central and northern parts of the country;

The report concluded, from the weighted addition of all the indicators (a method partly contested by the utilities themselves), that the cities of Leon, Saltillo, Monterrey, Aguascalientes and Cancun ranked the best 5 utilities in Mexico. The authors try to point out how those utilities with private sector participation seem to show consistently better indicators, but a caveat should be stated in this direction: first, most of them already had good indicators and a local tradition inclined towards efficiency and second, the availability of a long-term arrangement including relevant federal subsidies along with agreed tariff formulae, have provided these utilities with an income stability not usual in the sector. Nevertheless, it does seem to be a relationship between good governance arrangements and good performance, though further research is desirable.

Beyond these findings, it seems worrying that even among the best urban utilities in the country, there are important challenges in terms of their internal efficiency and functioning, worsened by the growing need of funding to bring water from new sources, protect existing ones and collect, treat and dispose of wastewater, with limited management and financial autonomy. Many factors which worsen the scene haven't been considered in CCA's assessment, such as the existence of impoverished neighborhoods and sections within and around some of the best performing cities, in which nearly 80% of the users wouldn't afford much higher tariffs. The stakes for the country's future development are huge, considering the relevance of urban economies for national wealth.

4 PUBLIC POLICY RESPONSES

As it was stated before, Mexican Constitution gives the state order the capacity to intervene in the regulation, operation and control of municipal water supply and sanitation services where municipalities lack the capacity to assure adequate levels of service. Historically, though, the states have only taken part of public works planning and construction programs and only recently there have been some states whose water commissions or similar organizations set up capacity building programs. There is still no formal economic regulation, although some state organisms have a role in analyzing and supporting the approval of water tariffs; states set up investment programs along with federal ones, in one hand to support the extension of services coverage and in the other to promote the improvement of water and energy use efficiencies, as well as managerial development and training. The lack of continuity in the utilities' managerial staff due to political interference, along with a wider lack of accountability (where a municipal government can receive a well working utility and leave a broken one to the next administration, and no one is called to respond), have systematically blocked any long-term development program in most of the cities. State programs usually mirror federal ones, which has given Conagua's criteria a central role in defining actual policy orientations, because of its budgetary and political strength, accentuated by the state level's frequent negligence in taking a wider role in water and sanitation regulation and capacity building, beyond public works execution. This distance between the operator and the government's sphere where policies are defined has important consequences, as it is discussed later in this document.

4.1 BUDGETARY SUPPORT AND FINANCE

Conagua, whose central role is *resource regulation*, should therefore concentrate on guarding national waters' integrity in terms of quality and availability, by means of the effective administration of a set of mechanisms for measuring, registering and controlling water extraction and discharge permits and rights. Nevertheless, it is also entitled to promote water and sanitation services' expansion and efficient operation, as it was mentioned before. While results in terms of resource regulation are far from being effective (with growing problems of water pollution and overexploitation), substantial resources are being dedicated to the development of very big infrastructure projects.

In Mexico, water infrastructure can be financed by the usual sources:

- Tariffs, with a limited capacity to generate capital investment resources, due to the common practice of setting up tariffs upon operating costs plus an increase capped by the general inflation rate;
- Taxes, which come to the municipal expenditure chapters as federal or state transfers, since local taxes as property taxes are rarely applied to capital investments for water in cities, partly because of the existence of the mentioned transfers;
- Transfers, in a direct fashion as specific chapters where federal taxes are assigned on a regular basis, as well as in the form of state and federal programs, usually associated with a set of operating rules stating technical, administrative and financial commitments expected from the part of the utility or municipality;
- Credit, which is only in the direct reach of the very few utilities operating with healthy financial structures and a reasonable stability, but recently very important to support some private participation schemes, along with risk capital and subsidies, where federal or state government usually bear with financial commitments, rather than the municipality or the utility. The existence of subsidies and transfers also precludes a wider recourse to credit by utilities. Bigger ones sometimes get short-term loans for supporting working capital issues;
- Direct private investment, even more rare, with the exception of “Aguas de Saltillo”, where a private firm owns 49% of the assets;
- Emission of debt instruments, not common in Mexico.

Even when there are no consolidated figures available, it can be stated that federal transfers constitute the main source of capital investment financing for utilities and municipalities; at the beginning, some programs included credits, but presently the majority of the resources are allocated as pure subsidies. In the following lines, a brief review of main federal budgetary supporting programs is presented.

4.1.1 federal budgetary support programs to municipal services

Federal policy investment on water and sanitation infrastructure pretends to act as a catalyst of state and local or private funding, achieving a wider reach by raising more funds in face of the lack of public funds available (CONAGUA, 2012:2). Conagua assigns federal funds by means of a set of investment programs, each one with particular operating rules that usually vary slightly from one year to the other and have to adjust to the rules defined also by state authorities. In the recent years, the main programs in place have been:

a) APAZU, for its Spanish acronym, "Potable water, sewage and sanitation program for urban areas", created in 1990 to support state and municipal projects for the expansion and improvement of water services. At its beginning part of the finance was implemented in the form of mid-term credits; presently resources are allocated as subsidies;

b) PROSSAPYS, "program for the construction and rehabilitation of potable water and sanitation in rural areas, implemented in 1996, with a stronger focus on expanding services coverage in localities with less than 2500 inhabitants;

c) PAL, "clean water program", since 1991, to support the preservation and expansion of disinfection capacities;

d) PROMAGUA, "program for the modernization of water utilities", implemented in 2001 to support utilities in cities with more than 50 000 inhabitants, where private participation schemes were promoted. Differential conditions were proposed for those utilities showing better performance;

e) PRODDER, "program for the devolution of water rights", set up in 2002 to induce water utilities to pay the water rights demanded by Conagua as part of the resource administration scheme; since municipalities were consistently omitting that payment before that date, a Presidential decree was issued to allow Conagua to reinvest collected water rights in water and sanitation infrastructure, where local authorities accepted to invest a similar sum under federal guidelines;

f) Program for supporting the Valley of Mexico's water supply and sanitation projects, recently called "Program for water sustainability for the Valley of Mexico", supported by federal funds plus resources collected from the utilities which receive wholesale water supply from Conagua's infrastructure (Cutzamala, Lerma and wells operated by the federal organization), funds that are managed through a Trust originally set up for the execution of an international credit;

g) PROTAR, "program for wastewater treatment", created to support the utilities' investment programs on wastewater treatment plant construction, improvement and expansion;

h) PROSANEAR, "federal program for wastewater sanitation", in which a fiscal incentive is created, by cancelling or exempting municipal authorities from the payment of water discharge rights. Some funds have been allocated to support wastewater treatment operating costs to utilities showing full compliance of discharge norms;

i) PROME, "program for the improvement of water utilities efficiencies", under a program for technical assistance signed with the World Bank (called "PATME"), with the aim of strengthening the technical development and financial self-sufficiency of a selected set of utilities. It has a component for improving Conagua's capacity for collecting information and assessing the sector's evolution, and another to "modernize" services in the utilities, by bringing technical assistance and assessments, as well as a "classical" investment program based on the assessments and diagnosis, with some actions implemented under an output-based disbursement scheme.

Most of the funds are allocated by transferring the resource to state or local authorities, under a coordination agreement where executors commit to follow federal rules; in some States, local programs are set up to support specific goals and targets. The majority of the municipalities take part only with 25% or less of the funds requested, with the exception of PRODDER, where the rule sets the counterpart in 50%.

Figure 7 shows the evolution in federal, state and municipal investments[4]. It can be seen that funding has grown steadily, even when a big part of federal funds has been assigned to the construction of big "strategic" infrastructure works, as it will be shown later.

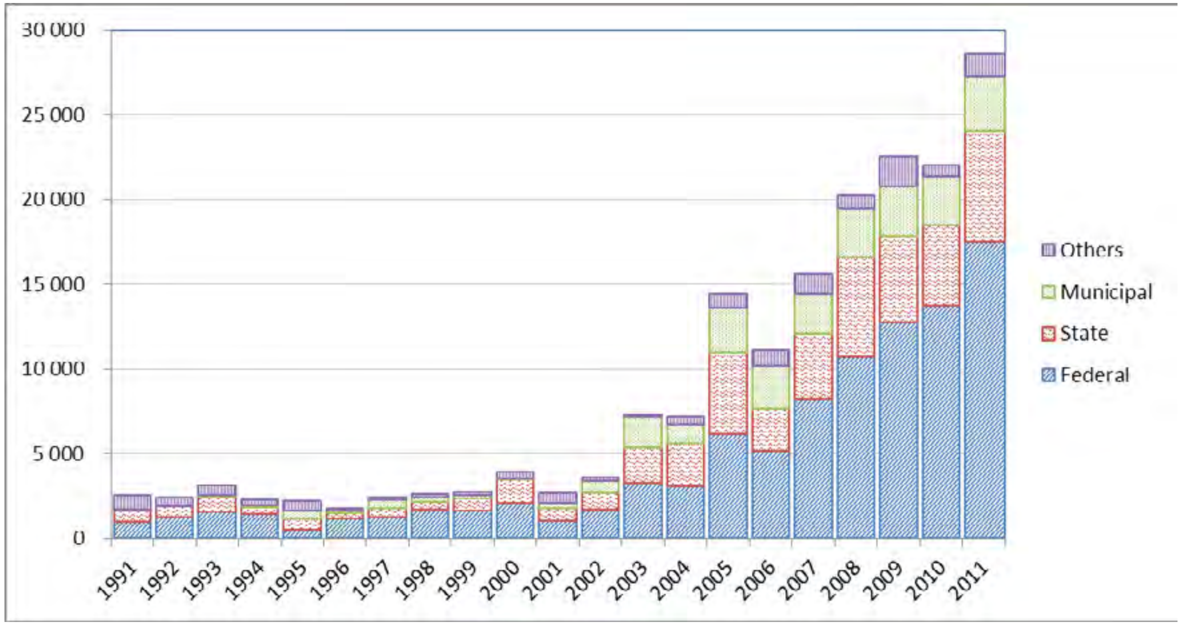


Figure 7 - total spending by source in projects through Conagua programs (million mx$)
Source: CONAGUA (2012: 3) – "Others" accounts for state investments and credits

[4] Original source omits to state if investments are presented deflated or in current prices.

4.1.2 The "strategic" projects – short description and rationale

Among the myriad of projects that are supported by Conagua by means of the federal budget it administers, the so called "strategic" projects deserve a special mention. As it can be seen in Figure 2, major metropolitan areas are located in regions where aquifers have been overexploited; most of them are in water scarce regions. And, as it has been shown in section 3, not all of them have salient practices of good water metering and pricing. By means of the application of resources through the programs described before, an improvement in their managerial and technical practices was expected to be achieved, but since demand kept growing faster, an ambitious program for developing new water sources has been carried out, based on a general rationale: since demand would not be controlled fast enough and efficiencies would not reach acceptable levels in the short term, it became urgent to develop and build new water transfer projects to increase supply; in the regions facing aquifer overexploitation, part of the volumes transferred would serve to substitute local groundwater sources, to cancel extractions and reach the equilibrium in the aquifers. Thus, these projects were called "hydric sustainability projects", even when they often imply large transfers by permanent pumping of water volumes usually three or four times more expensive than local sources. In a way, this has been seen as the cost of accepting that it has become impossible to control groundwater overexploitation; despite the discourse, this rationale falls neatly in the supply management category.

It must be mentioned that back in 1974, the same rationale was proposed to justify the first large scale water transfer in the Country: Cutzamala system. Then, the costs associated to land subsidence, because of the damages it caused to sewage and buildings, were presented as a justification for importing water, because that cost was considered to be "considerably higher than bringing water from other basins to stop overexploitation of the local aquifer" (FIGUEROA VEGA, 1984). While this system was being built, a supply crisis emerged and a set of "temporary" deep well fields was developed, called "Immediate Action Plan" (PAI); almost 40 years later, this temporary supply system is still working, extracting water from overexploited aquifers. Needless to say, overexploitation of the local aquifer wasn't stopped with the water transfer. Now, the fourth stage of Cutzamala system and other water import projects are being promoted as "sustainable solutions", since deep wells will be cancelled once the new water comes to the Valley of Mexico. The need of new sources is real, but a more careful consideration should be given to the assumptions dealing with the reduction of groundwater extractions, in order to set up realistic goals derived from effective groundwater management programs.

Water demand growth in metropolitan areas is posing a huge challenge to local and federal authorities. A set of "strategic" projects has been developed, with a "conception that comes from rational water use, incorporating new water supply sources through surface water extraction, protecting overexploited aquifers, as well as recovering the ecology of rivers and basins by means of wastewater treatment" (CONAGUA, 2012: 75). Table 1 below shows the most important projects considered in this program.

The amount of the investment, over 9 billion US dollars[5], and the extent of the financial and administrative effort are remarkable and will be the most salient outcome of Conagua's recent program. Most of the projects have been implemented along with capacity building programs, to improve the utilities performance so as to make the projects financially viable. In some cases, financial or operating weaknesses make the challenge bigger.

Table 1 - strategic water, sewage and sanitation urban infrastructure projects

(continue)

Category	Project	Metropolitan area or city	Investment (million MX$)	Status nov. 2012
Valley of Mexico	New sources	Mexico	4543	Studies
	Cutzamala system	Mexico	7039	Under construction
	WWTP Atotonilco	Mexico	10219	Under construction
	WWTP El Caracol	Mexico	787	Under construction
	West sewer tunnel (TEO)	Mexico	20262	Under construction
	Sewage works	Mexico	3176	Under construction
	Compania River Tunnel	Mexico	1938	Finished
	Remedios River Tunnel	Mexico	800	Finished
	Main Canal Piping	Mexico	500	Finished
Dams and aqueducts	El Zapotillo dam	Leon - Guadalajara	4505	Under construction
	El Zapotillo aqueduct	Leon	8584	Under construction

[5] Calculated with an exchange rate of 13 MX$/USdll, as in November 2012.

(continue)

Category	Project	Metropolitan area or city	Investment (million MX$)	Status nov. 2012
Dams and aqueducts	El Purgatorio	Guadalajara	5790	At bidding process
	El Realito dam	San Luis Potosí - Celaya	1064	Finished
	El Realito aqueduct	San Luis Potosí	2463	Under construction
	Integral water management improvement	San Luis Potosí	924	Under construction
	Paso Ancho Dam	Oaxaca	941	Under preparation
	Paso Ancho aqueduct	Oaxaca	1700	Under preparation
Aqueducts	Monterrey VI	Monterrey	14317	Under preparation
	Independencia	Hermosillo	3997	Under construction
	Acueducto II	Queretaro	2854	Finished
	Agua Futura	Durango	1652	Under preparation
	Rio Colorado - Tijuana	Tijuana	1490	Finished
	Conejos-Medanos	Cd. Juarez	1327	Finished
	Chicbul-Cd. del Carmen	Cd. del Carmen	1063	Under construction
	Actopan - Pachuca	Pachuca	800	Under preparation
	Picachos - Mazatlan	Mazatlan	429	Under preparation
	Paso de Vaqueros	San Luis de la Paz	127	Under construction
Wastewater treatment	Sewage works	Guadalajara	3691	Under construction
	WWTP Agua Prieta	Guadalajara	2605.3	Under construction
	WWTP El Ahogado	Guadalajara	858.9	Finished
	Atoyac River Sanitation	Puebla and Tlaxcala	845.7	Under construction

(continuation)

Category	Project	Metropolitan area or city	Investment (million MX$)	Status nov. 2012
Wastewater treatment	Apatlaco River Sanitation	Morelos (Cuernavaca)	1680	Under construction
	Acapulco integral sanitation	Acapulco	731	Under construction
Desalting projects	Ensenada	Ensenada	517	Under construction
	Other projects	7 cities	3232	Under preparation
	TOTAL		**117451.9**	

Source: CONAGUA (2012c) – Millions MX$ November 2012

In the coming years, federal administration will have to be very attentive to the development of these projects, since financial commitments are firm, while institutional and financial performance of the utilities remain unstable in most of the cases. For instance, the repayment funds for some of the wastewater treatment plants by the final benefitiaries is not firmly assured with formal agreements with the municipalities; in other cases, the projects viability is highly sensitive to the achievement of overall improvements in financial and technical performances. The final impact of these projects will show up in the coming years, but a close surveillance has to be implemented in order to avoid the multiplication of the Valley of Mexico's model, in which most of the operating costs are, in one way or the other, supported by subsidies coming from the federal general budget.

In the other hand, achieving an effective reduction of groundwater extraction will require an institutional, financial and political effort well beyond the good intention of signing agreements to obtain a voluntary closure of existing wells in exchange of the imported water. In many cases, supplementary investments will be needed in order to make physically feasible the substitution of dispersed supply systems with the new one-source systems; in Queretaro and Monterrey this was achieved through the construction of peripheral conveyance systems, but these are two of the strongest systems in the Country. Other cities will need additional subsidies and strong technical support to make the new projects work.

4.1.3 An assessment of the current model

Undoubtedly, important goals in terms of coverage extension and efficiency improvements have been and will be achieved by means of the implementation of the federal programs for the expansion of infrastructure and the improvement of efficiency in the water and sanitation sector.

Nevertheless, there are some aspects that deserve to be revised:

- Most funds are allocated disregarding the outputs, performance and evolution of water utilities; those utilities having stronger administrative and financial capacities are better placed to get funding from federal programs, leading to a somehow "regressive" scheme, where weaker utilities receive less support than those already stronger. For instance, in the PRODDER program, some utilities pay for the water rights but don't have the additional counterpart needed to obtain the devolution of these funds. There is no information available regarding the number of utilities actually paying water rights;
- In some cases, the origin and destination of the funds are not consistent, which leads to a lack of accountability and economic rationality. For instance, in the Valley of Mexico, the rights paid for the wholesale water supply are derived into a trust fund, where they are used to build infrastructure, while operating funds for assuring proper maintenance of the system come from general budget and have to compete against many other projects throughout the country. Another example comes from the PRODDER, since water extraction rights have been designed as a pigovian tax to promote efficiency, but now they are seen as a means for financing infrastructure expansion. Something similar is happening with the funds allocated through PROSANEAR program;
- Funding through existing programs is subject to yearly modifications in the operating rules and to delays in the actual transfer of the resources. It is especially difficult for the utilities to implement mid-term financial planning when they don't know how much money they will get, when and under which conditions. This has been particularly difficult in the case of the PRODDER program, since for the last two years the funds are reallocated to the utility very lately in the fiscal year, leading to hasty bidding processes;
- A better framework for the allocation of existing funds is needed, in a way that balances giving bigger support to the weaker utilities with acknowledging actual improvement with financial incentives to those achieving the goals. State authorities participation must be effectively encouraged with concrete incentives and penalties, not only as a part of the funding sources but must importantly as the catalysts for achieving better institutional arrangements in the municipal settings.

In a way, current model for the development of the water and sanitation sector considers that, since most of the urban water utilities show low economic and technical performances, it is necessary for the federal government to support infrastructure financing and performance improvement. Taking into account the current institutional situation of water and sanitation services in the municipal level, this approach seems to be correct or at least unavoidable, but in the long term it appears to be perpetuating a vicious cycle, where municipal authorities rely on federal and state funds to periodically "rescuing" their systems, but refuse to give them the institutional stability and accountability needed for a sustainable operation.

5 OVERALL ASSESSMENT AND POLICY QUESTIONS

5.1 THE CHALLENGES FOR A SUSTAINABLE OPERATION OF URBAN WATER AND SANITATION SYSTEMS

As it has been shown, sustainability of services is being threatened because of the lack of an adequate supply and management of the different assets or resources involved. According to the ECLAC (ECLAC, 1991) sustainability requires for the balanced use of six kinds of assets or forms of capital: natural, physical, financial, human, institutional and social, taking into account their relationships of complementarity and substitution. Within this framework, bigger cities face also bigger challenges, not only because of the lack of regular and enough access to the different forms of capital (in some cases, big cities have clear advantages to get resources due to their greater economic and political influence), but because of their very diverse capabilities to administer and use those assets. In general:

- Natural capital is being compromised because of the deterioration of water sources, watersheds and aquifers, worsened now by climatic variability and growing competition among sectors;
- Physical capital, that is, infrastructure, equipment and systems, are also subject to two ways of pressure: the need to extend their coverage due to the cities ongoing growth, while replacing the assets which have largely surpassed their lifespan;
- Financial capital should be analyzed in two parts. First, investment capital depends heavily in Mexico of the capacity of cities and state governments to get federal subsidies; several programs exist and it becomes a matter of

negotiation. Second, operating capital relates to each system's capacity to measure, invoice, collect and administer operating revenues, but it also depends on each utility's tariff setting and approval framework, where only a few big cities have been able to reach a virtuous cycle off good services with adequate tariffs. In recent years, it has been more frequent that State governments and even water operators themselves are asked to commit to repay part of the capital financing, as well as setting up efficiency improvement programs, which is shifting the rules towards a more incentive-based framework. Nevertheless, in Mexico a lot remains to be done to effectively link water operator's performance to their creditworthiness;

- Human capital is usually easier to access by bigger utilities, because they operate in cities where a richer and wider job market exists and they have larger revenues to pay for better salaries; in this direction, the most important threat is the lack of stability and professionalization, due to the excessive intervention of political instances and the lack of effective accountability mechanisms;
- Institutional assets would comprise the set of rules determining whether the relationship between the quality of services in a broad sense, and their price, is adequate for each city's characteristics, establishing clear boundaries between the tasks, capacities, rights and obligations of the political authority (which beholds the system's property in the name of the general population), the operator and the public, with a proper balance between goals and means. In Mexico there are several institutional settings but in general there is a lack of a well-structured regulation framework, with the exception (to some extent) of the very few private participation schemes; political authorities are in charge of the process of revision, approval and implementation of tariff structures and investment programs, but tariffs tend to be kept below inflation rates without further considerations, while it is usual that utilities provide bad quality services trying to "finance" their operation by delaying maintenance and distributing water intermittently to cope with growing demands with the same (or less) water and financial resources;
- Last but not least, social capital would be the capacity of every system to obtain from their users or customers a level of commitment beyond their formal or contractual responsibilities towards the service, by means of a proper communication and influence on the people's knowledge, behavior and habits. While most of the utilities have implemented communication programs, only a few have effective mechanisms for getting feedback and being transparent to their users. Citizens outside the utilities' governing bodies usually find it difficult to access its information and to get answered their demands and expectations in a structured manner. A set of citizen observatories which have been set up

in a set of Mexican cities –Xalapa, Tuxtla Gutierrez, Saltillo, Ecatepec and San Miguel de Allende—have not achieved to set up a more horizontal relationship with the utilities to have incidence on their practices and results, in part because of the lack of resources which impedes the utilities to adopt commitments when they are not getting enough resources or lack operating independence.

Clearly, many of our urban water and sanitation systems are operating under vulnerable circumstances, and it's hard to identify the key elements which would bring them to a sustainable path. Even if the federal authorities achieved to balance water budgets and to assure every water system, as a national waters user, a reliable access to good quality water in their sources, other challenges would preclude our systems to be sustainable. The most difficult one seems to be the institutional instability, along with the pressure coming from the lack of a planned and effectively enforced land use development. Since these three issues seem to be beyond the utilities' scope –assuring an effective resource regulation and preservation, getting a more balanced institutional arrangement and controlling land use development–, a double effort needs to be done: first, promoting a sectorial reform to change the external rules which define the way water and sanitation systems access natural and financial resources and are forced to show results; second, keep on working on the internal strengthening of water utilities.

5.2 SOME GUIDELINES TO IMPROVE THE SUSTAINABILITY OF URBAN WATER AND SANITATION SYSTEMS

In the same terms presented in the former section, some guidelines that can be proposed to improve our urban water and sanitation systems' sustainability could be:

- Mexico needs an authority fully committed and devoted to the custody, restoration and preservation of its national waters and related public goods. Water rights should serve primarily to set up a strong capacity to measure, register and administer water usage and discharges, to enforce law and to supervise the state of the nation's watersheds and water bodies. It's true that public and productive systems often need financial and technical support to be efficient and thus to reduce extraction, but having this task assigned to the same authority could be leading to a conflict of interest. The recourse to coordination mechanisms such as basin or aquifer councils has been thought as a means to promote consensual solutions to specific issues, such as temporary limitations to water extractions during droughts, or water uses prioritization for administrative purposes; but users' participation doesn't exempt federal authority of the fundamental responsibility for preserving and maintaining national waters' quality and availability;

- Water supply and sanitation are capital intensive activities. So, infrastructure and equipment are instrumental to have sustainable and reliable services. Water utilities and municipalities should be forced to have an updated registry of all the water and sanitation assets they operate, so they can get accountable for their conservation, improvement and expansion. Specific responsibilities over the state of the assets should be assigned to municipal authorities and utilities. Setting up proper registry, accounting and asset management procedures would be urgently needed in order to be capable to design a national strategy for infrastructure renewal and expansion;
- Financial system for water and sanitation development needs to be revised and restructured. Mexico needs to leave the current subsidy-based system, where federal and state programs operate as "relief funds" for rescuing eternally developing utilities, with a financial support that is often variable, unpredictable and insufficient. Concrete steps must be taken to set up a financial system that incentives performance improvement, creates real responsibility in the side of the municipality and operates under clear, equitable rules. Those utilities with better institutional arrangements and managerial practices should get incentives; those showing clear trends of performance improvement should also get advantages. Funding should act as a catalyst for financial self-sufficiency, and not as a life saver. This restructuring of the financial system goes along with a deep institutional reform;
- Human capital is perhaps a key element in this puzzle. In spite of the existence of several regulations trying to set up a civil service system in the sector, there is a lot to be done to achieve this goal. Funding programs could also set more stringent conditions to the utilities and municipalities in terms of the profiles and certification credentials of their staff, as a condition to get the funds. In the other hand, federal, state and municipal authorities need to commit to give water and sanitation services the professional level that is already given to health or security services. It's true that unions sometimes block any effort to set up more efficient staffing practices, but this is also a matter of negotiation and, in the long term, of designing a financial and political solution. Water and sanitation utilities are fundamentally operating enterprises which rely on their ability to manage capable, well trained and committed personnel. Capacity building programs are necessary, but not sufficient, to strengthen this sector's human capital. An effective accountability framework should drive the sector towards its professionalization, where political interference would find it hard to support improvised or incompetent managers;

- Institutional reform could be the key to develop every other improvement. The National Association of Water Utilities (ANEAS) has proposed to enact a national reference law in order to set up the minimal conditions to have, at the state and municipal levels, a well-structured arrangement, where goals match the resources available, the quality of service corresponds with its price, and the relationships between political authorities, utilities and the public reach an adequate balance. That is, to set up proper economic regulation structures. For some bigger and well-performing systems, new financing mechanisms should be explored, such as the emission of debt instruments and the implementation of better corporate governance mechanisms. Urban water utilities should operate within a proper regulatory framework, with a clear contractual agreement with political authorities and users, under an appropriate law enforcement environment and, most importantly, responding and promoting a more informed and active citizen participation. Information must be the key to restore the system's capacity to acknowledge its current problems and to design the path towards a more sustainable operation. The enactment of a constitutional reform, recognizing the constitutional right to water, should spur all the actors on to find effective ways to ensure an equitable supply for all;
- Finally, sustainable urban water and sanitation services call for a more informed and participative user. It's true that people cannot devote to take part of the decisions regarding every aspect of their lives as citizens, since they have already delegated the responsibilities of taking charge of public services on their municipal authorities, through their political representatives. But there is a general rule in management science: authority can be delegated, but responsibility remains. Citizenship implies sharing responsibility with authorities, which means to be informed, understand and have incidence in the decisions. Utility managers must also understand that transparency and openness to dialogue can act in favor of the system's stability towards political and influence group intervention. Citizen observatories should be supported and encouraged, as well as public communications that go beyond the messages for promoting water savings; civic culture is a fundamental asset for every modern utility.

In the other hand, utilities can do a lot to promote improvements in the three areas mentioned before, as framing conditions normally out of their scope:

- They can help federal authority to better measure, supervise and control extractions of other users within the same watershed or aquifer. They can set up agreements with other users to help them use the water more efficiently, if possible to promote exchange agreements of water for treated wastewater, but mainly as a stewardship function for which they are especially well positioned. Water is every utility's main input: anything they can do to support its conservation works in favor of their sustainable operation;

- Water utilities should strive for having proper regulation mechanisms and social participation schemes, whether it could seem contradictory. A better set of rules would favor the utility's foundations to work with more stability, gain creditworthiness and create a space for professional development for its members. Water utilities need to have a leading role in the discussion of the mechanisms that need to be put in place to ensure human right to water, instead of regarding these efforts as a threat;
- Finally, water utilities should also participate in every initiative in order to set up better rules for a better control of land use and development. In the context of climate change, the presence of more frequent droughts and intense precipitation events poses additional challenges to our utilities. New urban design patterns and the use of sustainable drainage structures should be a part of our land use regulations.
- These proposals call for the effective adoption of the integrated urban water cycle management model, where every part of the cycle is designed taking into account the full cycle and land use and design becomes part of the water and sanitation management system within cities.

6 CONCLUSION

Cities represent a fundamental link in the economic chain of a country. In Mexico, their importance will grow in terms of their economic contribution to national wealth, but also as development centers where an equitable access to water and sanitation can help fulfilling every citizen's right to health and work.

Huge financial and administrative efforts have been implemented by the federal, state and local authorities to support the systems' expansion and performance improvement. Infrastructure has grown at an unprecedented pace and many programs have been put in place to give water utilities several ways of getting financial and technical support. But the challenge is also huge, which calls for a profound reform in the way water resources and services are being managed in Mexico.

First, there is an urgent need to set up an effective resource regulation system which leads to the restoration and preservation of water balances in many of our watersheds and aquifers. No infrastructure or money will suffice if we run out of clean water sources.

Second, a deep institutional reform must take place to set up the proper incentive framework to ensure an appropriate relationship between political authorities, utility operators and citizens. Utilities must be empowered and provided with enough resources to achieve their goals, but also must be obliged to be accountable and transparent. Water users must be encouraged to be informed, understand and participate in the decisions affecting them. Good corporate practices must be implemented in the boards, so they effectively defend the people's interest. Local political authorities should be fully accountable for the state of the assets and processes associated to water and sanitation services. A more mature and informed dialogue should take place between authorities, operators and citizens.

Third, financial system should be revised and restructured to become a catalyst for efficiency and accountability. Performance improvement should be rewarded and funds should be equitably and transparently allocated. Funding should become more predictable, stable, sufficient, equitable and productive for water utilities. Budgetary support programs should promote self-sufficiency and responsibility. Better management models and capacities are needed in order to achieve a more efficient use of financial funds within the utilities and their regulatory counterparts.

And finally, water utilities must take part of the political efforts seeking for a more effective land use planning and development. New urban design practices must be implemented into the utilities' processes for the approval of new developments, taking into account the need to better manage precipitation events, to favor rainwater infiltration and detention and to contribute with the proper management of urban rivers and water bodies.

Integrated urban water management needs to become the model for urban water management in Mexico. Demand management needs to be taken seriously, since public policies in this sector remain clearly in the supply management side. A lot of well-intended negotiation and communication between federal, state and municipal authorities must occur in order to achieve a new institutional framework. The size of the threat calls for an unprecedented coordination effort.

REFERENCES

Aboites, L., Cifuentes, E., Jiménez, B., & Torregrosa, M. (2008). Agenda del Agua. México, D.F.: Academia Mexicana de Ciencias - Red del Agua.

CCA. (2011). Gestión del Agua en las Ciudades de México. México: Consejo Consultivo del Agua.

CONAGUA. (2012). Situación del Subsector Agua Potable, Alcantarillado y Saneamiento Edición 2012. México, D.F.: SEMARNAT-CONAGUA.

CONAGUA. (2012b). Estadísticas del Agua en México 2011. México, D.F.: SEMARNAT-CONAGUA.

CONAGUA. (2012c). Proyectos estratégicos de agua potable, drenaje y saneamiento. Conagua, Gerencia de Estudios y Proyectos. México: Conagua.

ECLAC. (1991). El desarrollo sustentable: transformación productiva, equidad y medio ambiente. Satiago de Chile: UNO-ECLAC.

Figueroa Vega, G. (1984). Case History No. 9.8. Mexico., D. F. En J. Poland, Guidebook to studies of land subsidence due to groundwater withdrawal (págs. 217-232). Paris: UNESCO.

INEGI. (2010). Censo de Población y Vivienda 2010. Aguascalientes, Ags.: INEGI.

ONU HABITAT. (2011). Estado de las Ciudades de México 2011. México, D.F.: SEDESOL.

Saltiel, G. (2008). Problemática del sector agua potable mexicano - análisis, ejemplos y propuestas. En R. Sandoval, & R. Olivares, El agua potable en México - historia reciente, actores, procesos y propuestas (págs. 229-237). México: ANEAS.

SESSION 7

MANAGING WATER IN URBAN AREAS AND METROPOLITAN REGIONS: AN EVER-GROWING CHALLENGE

SUMMARY

CLIMATE CHANGE IMPACT AND ADAPTIVE WATER MANAGEMENT IN NORTH CHINA

Xia Jun[1]
Qiu Bing[2]

[1] Chinese Academy of Sciences
[2] Chinese Academy of Sciences

ABSTRACT

Huang-huai-hai River basins that is also called as North China are one of the core areas in food production and agricultural development of China. Water shortage has already brought about serious water crisis in agriculture in this region and will possibly continue to intensify the contradiction as climate changes and socio-economic develops rapidly, thus affecting the country food security. Assessment of water resource vulnerability for identifying where water resources are potentially more vulnerable to adverse effects is a pre-requisite to take adaptation strategies. This study proposed a method for water vulnerability evaluation as a function of sensitivity to climate change, people per flow unit of one million cubic meters per year, water use to availability ratio, and per capital water use. The levels of water vulnerability for the ten major river basins in China and for the Huang-huai-hai River basins on base of second-order basin are assessed. Further, predictions of vulnerability for these three basins in 2030 under 3 scenarios are proposed: (1)climate changes while no socio-economic change; (2) no climate change while socio-economic changes; (3) climate and socio-economy change simultaneously. Results show that the situation of water vulnerability in Huang-huai-hai River basins is very serious at present and no improvement will be anticipated under climate change and socio-economy development to 2030, especially in Hai river basin. Thus, appropriate strategies, such as, adjustment of the industrial structure, promoting the Water-Saving irrigation and changing cultivating structure, are required to mitigate the increasing water vulnerability brought about by rising water demands in Huang-huai-hai River basins in the future.

1 INTRODUCTION

About a decade and a half ago, Lester Brown's question "Who will feed China?" (1995) raised a new wave of China threat theory. He posited that China cannot produce enough food for a huge, continuously growing population, thus resulting in the consequent ballooning in China's grain imports in the future, which would finally affect global food security by driving up food prices. In their later elaborations, they suggested water shortage, which is one of the greatest challenges facing China, as the possible ultimate driver of this global impact (BROWN; HALWEIL, 1998; BROWN, 2004; JIA et al., 2010).

China is one of the thirteen water-poor countries all around the world, with the second lowest per capita water resources, which are less than one third of the world average (WORLD RESOURCES INSTITUTE, 1998). Particularly, in north China, the most water-starved area in the country, a more serious imbalance of water resources between supply and demand has been witnessed (CHEN, 2003). As the major grain-growing area, north China has entered a long arid cycle since the 1980s and been suffering severe water shortage. With only 24% of total national water, this region is one of the areas with the highest population density in the world. And 65% of the country's agricultural lands are found here, growing nearly all of China's maize and wheat, and from where half of all grain production comes (ENCYCLOPEDIA, 2003). Water shortage in north China, which would get worse as climate change and water demand increase in the future, may critically restrict the sustainable development of China.

The hydrological system is an integrated part of the geophysical system, which combines numerous processes of land surface and controls the water yield. It is determined by both natural environment factors and anthropogenic factors. Changes in temperature and precipitation can affect evapotranspiration rates, soil moisture, snowmelt, streamflow regime (including the timing and magnitude of streamflow) and finally the water availability. On the other hand, population increase, fast-growing urbanization and industrialization and economy development can enhance the water demand, finally increasing the pressure of water resources in already vulnerable regions.

According to the China's National Assessment Report on Climate Change (DING et al., 2007) , the annual rainfall and observed discharges of rivers in north China have generally decreased over the last 50 years, and total amount of water resources have changed from 18% to 16% of national total during 1950~2000. Predictions based on the outputs of GCMs indicate that climate warming will possibly reinforce the drought trend in northern China, thus intensifying water scarcity and contradiction between water supply and demand in this region as socio-economy develop rapidly and population continues to grow. Assessing the vulnerability of water resources and identifying regions which are potentially more vulnerable to adverse effects is a pre-requisite to anticipate where impacts may be greatest, and to set priorities for careful regional assessment of climate change impacts and taking corresponding adaptation strategies in these regions (SULLIVAN; MEIGH, 2005, 2007).

Since the 1980s, studies on vulnerability assessment have been completed in various parts of the world. (BROUWER; FALKENMARK, 1989; GLEICK, 1990; KULSHRESHTHA, 1993; FALKENMARK, 1994; UNDP-GEF, 2000; VOGEL, 2001; IPCC, 2001; ADGER et al., 2004; BROOKS et al., 2005; MOHAMED A et al., 2009; CAROLINE A. SULLIVAN, 2011; LIU L., 2002; ZOU J. et al., 2007; TANG G et al., 2000; WANG G et al., 2005; DENG S. et al., 2010). At first, water vulnerability of a region was expressed in one of the following four ways: water dependency, water resource constraints, water deficit, and demand-supply balance (KULSHRESHTHA, 1993).

Water dependency criterion was suggested by Brouwer and Falkenmark (1989). They utilized the number of inhabitants per unit (quantity) of water to measure the vulnerability of water resources and determined the threshold values, which divided various regions into four categories:

- Water surplus: less than 100 persons per million m^3 of water;
- Water management problems: 101 to 500 persons per million m^3 of water;
- Water stress: 501 to 1,000 persons per milion m^3 of water;
- Water scarcity: more than 1,000 persons per million m^3 of water.

Additionally, Brouwer and Falkenmark (1989) also utilized the demand-supply balance criterion to assess the vulnerability levels by comparing water supply (availability) and use on a per capita basis. In water resource constraints criterion, Shaw et al. (1991) compared different water use conditions in the linear relationship between the population and per capita use of water, both of which were measured in logarithmic terms. Shuval (1987) used the quantity of water deficit as the criterion, with a certain level of water supply assumed to remain unchanged, while the water use increases, as a direct result of economic activities in the region.

After climate change becoming the hot topic in many areas, some researchers introduced climate scenarios into the assessment of water resources vulnerability to predict the possible changes. Choosing the ratio of water use, i.e. the combination of domestic, industrial and irrigated agriculture water use, to discharge to provide a local index of water stress which is same to water vulnerability, Charles et al. (2000) analyzed the vulnerability of water resource to climate change, population growth and migration, and industrial development between 1985 and 2025 on global scale, utilizing a high-resolution (30' grid, latitude by longitude) geography of water use and availability, and presented a complete picture of global water vulnerabilities.

On the other hand, Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report, defined vulnerability as 'the extent to which climate change may damage or harm a system; it depends not only on a system's sensitivity but also on its ability to adapt to new climatic conditions' (WATSON et al., 1996: 23). This framework provides a reference for the latter multi-index evaluation methods. Caroline A. Sullivan (2011) provided an outline of an index based methodology on which an assessment of water vulnerability can be made. Water Vulnerability Index (WVI) in this study was composed of a measure of Water system vulnerability and Water user vulnerability. The supply-driven vulnerability (from water systems) and the demand-driven vulnerability (from water users) were evaluated at the municipal scale in various dimensions and combined together to generate the Water Vulnerability Index.

In China, studies of water resource vulnerability are originally derived from groundwater vulnerability assessment and most of them still focus on the definition of vulnerability or qualitative description of the assessment framework. Only limited researches try to adopt one or a series of indexes to quantify the vulnerability of water resources. Liu (2002) redefined the vulnerability of water resources as the description of the ability of the system to recover its original structure and function when it is damaged, and built an integrative index system as well as a quantitative assessment method, however without practice. Deng et al. (2010) adopted the DPSIR conceptual model as a reference to construct an assessment index system for water resources system vulnerability and built an assessment model based on projection pursuit interpolation with particle swarm optimization, using a large amount of sample data and an interpolation curve. Finally, they took the water-receiving region of the South-to-North Water Diversion Project (SNWDP) in Hebei Province as an example to analyze the system vulnerability in terms of driving forces, pressures, states, impacts, and responses.

These researches either choose to define a single index, such as ratio of water use, which is obviously not enough for water system vulnerability estimation, or utilize weighted values of integrative index system collected from water resource system, socio and economic system and ecology system, which is greatly influenced by subjective factors and difficult for widely practical. Thus, it is necessary to propose a concise but applicable indexes system and an integrated estimation model to estimate water resources vulnerability.

In this paper, we proposed a method for water vulnerability evaluation as a function of sensitivity to climate change, people per flow unit of one million cubic meters per year, water use to availability ratio, and per capital water use. The levels of water vulnerability for the ten major river basins in China are assessed. Furthermore, we concentrate on the water resource vulnerability of Huang-huai-hai River basins on base of second-order basin in the current situation and three assumed scenarios for 2030.

2 METHOD AND DATA

2.1 STUDY AREA

The Huang-huai-hai River basins, which located in the north-central of China (Fig. 1), cover an area of 1.44 million kilometers and have a population of 438 million, accounting for 35% of national total. It is an important economic region and one of the core areas in food production and agricultural development of China, with GDP and irrigated area occupying 32% and 42% of national total, respectively. Food production in this area occupies 34% of the country. However, based on the assessment carried out by MWR, the multi-annual average precipitation in Huang-huai-hai River basins is around 450mm and total water resource is only 7.8% of national total. The current water supply deficit is at the least 23.0 km^3, including agricultural water supply deficit of 11.3 km^3 and ecological water supply deficit of 11.7 km^3. Huang-huai-hai River basins have already become one of the most water scarce areas in the world.

The climate in these regions is dominated by the East Asia monsoon in the summer and by continental air currents in winter.

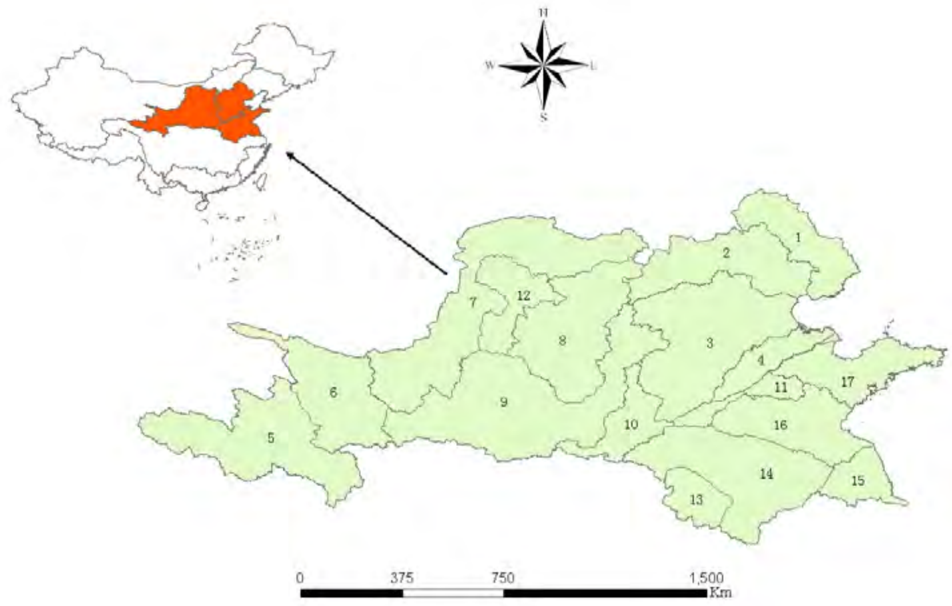


Figure 1 - Study area location and divisions of second-order basins

The Hai river basin belongs to temperature, semi-humid semi-arid continental monsoon climate, with the north and northwest wind prevailing in winter and southeast wind in summer. The mean annual temperature is 1.5~14. Temporal-spatial distribution of precipitation in this region has remarkable zonality, seasonality and inter-annual variability. Mean annual precipitation is 535 mm in this basin, most of which concentrate in summer while little in winter and spring, characterized by drought in spring, flood in autumn and drought in late autumn. In Yellow (Huang) river basin, the mean annual temperature decreases from downstream to upstream, from south to north, from east to west, with a basin average of 7.7 ºC. Influenced by the monsoon climate and topography, mean annual precipitation in Yellow river basin has large regional disparities and varies greatly for each year. The total amount of the basin is 446.5mm, which in general, increases from northwest to southeast and decreases as time increases. The Huai river basin is located in warm temperature to subtropical transition zone. Frequent cold warm air mass activity in this region brings about uneven distribution of precipitation in time and space, with 50%~80% concentrating in June to September. The mean annual precipitation in this basin is 883mm, which has a decreasing trend from the southern mountain area to the northern plains area. Mean annual temperature is 11~16ºC, with extreme maximum temperature above 40ºC and extreme minimum temperature below 0ºC.

2.2 QUANTIFYING WATER RESOURCES VULNERABILITY

Vulnerability is defined as the degree, to which a system is susceptible to, or unable to cope with, adverse effects of climate change. It can be determined by the character, magnitude, and rate of the climate change on the one side and the system's sensitivity and its adaptive capacity on the other (IPCC 2001; NERI, 2002).

As a result, we describe the water resource vulnerability as follow:

$$V(t) = \frac{S(t)}{C(t)} \qquad \textbf{(1)}$$

Where, *t* is time; *V(t)* is water resources vulnerability; *S(t)* and *C(t)* is sensitivity and adaptability of water resources systems. *S(t)* is related to the natural features of water system, while *C(t)* concerned with adaptation strategies as well as the integrated socio-economic capacity and science technical and management levels to tackle water stress caused by various factors. Thus, water resource vulnerability can be regarded as a function:

$$V = \frac{S_1}{C_1} \cdot \frac{S_2}{C_2} \cdot \frac{S_3}{C_3} \cdots \frac{S_n}{C_n} \qquad \textbf{(2)}$$

Where, $\frac{S_i}{C_i}, \quad i = 1,2 \ldots n$ represents the vulnerability of water resources system affected by one of the following factors: hydrological spatial and temporal variations, flood and drought disasters, exploitation and utilization of water resources and so on.

In this study, our focus is the sensitivity of runoff to climate change and the relationship of water supply and demand in Huang-huai-hai River basins. Thus function (2) can be simplified as:

$$V(t) = \frac{S(t)}{C(t)} \quad \textbf{(3)}$$

According to the report of IPCC (2007), sensitivity to climate change can be quantified by the following function:

$$S(t) = \delta(\Delta P, \Delta T) = \frac{f(P+\Delta P, T+\Delta T) - f(P,T)}{f(P,T)} \times 100\% \quad \textbf{(4)}$$

Where, *P*, *T*, ΔP and ΔT are precipitation, temperature and changes of them; $f(P+\Delta P, T+\Delta T)$ is runoff; $f(P+\Delta P, T+\Delta T)$ is simulated runoff with precipitation and temperature changing by ΔP and ΔT, and $\delta(\Delta P, \Delta T)$ is sensitivity of runoff to changes of precipitation and temperature. In this study, values of *S(t)* are cited from the results of Wang et al (2011) and showed in ***table1***.

Table 1 - Sensitivity of water resource to climate change for the ten major basins (%)

Songhua River basin	Liao River basin	Hai River basin	Yellow River basin	Huai River basin
20.3	23.7	23.6	21.5	20.6
Yangtze River basin	SE Rivers basin	Pearl River basin	SW River basin	NW River basin
13.0	18.4	14.0	12.1	13.5

Source: SW: southwest; NW: northwest rivers basin

In view of their relationship, the water adaptability can be expressed as the reciprocal of water stress, which is concerned with the integrated socio-economic capacity and science-technical and management levels of water resources.

Falkenmark and Molden (2008) proposed a framework for assessment of water resources pressure through a rather concise index system. According to the framework, water scarcity demonstrates two dimensions, i.e., Demand-driven (*WD*) water stress (high usage compared to the availability of water) and Population-driven (*P*) water shortage (many people dependent on the availability of water), quantified by population-driven water shortage (water crowding, people per flow unit of one million cubic meters per year, *P/Q*), water-use driven mobilization level (use-to-availability, percent of water availability, r), and per capita water use (withdrawals in cubic meters per capita a year, *WD/P*).

This study refers to the above framework and chooses the two dimension variables to determine the adaptability of water resource, *C(t)*:

$$C(t) = C\{r \cdot \frac{Q}{W_D}\} = f_1(r) f_2(\frac{Q}{W_D}) \quad \textbf{(5)}$$

Where, f1 and f2 are functions to be determined.

The relationship between water supply and water demand *Q /WD* can be described as

$$\frac{W_D}{Q} = \frac{P}{Q} \cdot \frac{W_D}{P} \quad \textbf{(6)}$$

Where, *P* is the population. Substitution of equation (4) in equation (3) gives

$$C(t) = f_1(r) \cdot f_2(1/(\frac{P}{Q} \cdot \frac{W_D}{P})) \quad \textbf{(7)}$$

The boundary conditions are determined as follow:

$$\begin{aligned} & f_1(r) \to 0, \quad i.e., \quad C(t) \to 0, when \quad r \to \infty \\ & f_1(r) \to 1, \quad when \quad r \to 0 \\ & f_2(P/Q) \to 0, \quad i.e., \quad C(t) \to 0, when \quad P/Q \to \infty \\ & f_2(W_D/P) \to 0, \quad i.e., \quad C(t) \to 0, when \quad W_D/P \to \infty \end{aligned} \quad \textbf{(8)}$$

Linkage of the three indexes and the above boundary conditions help to select the functional forms of f1 and f2 and finally determine equation (5) as

$$C(t) = C\{r \cdot \frac{Q}{W_D}\} = \exp_1(-r \cdot k)\exp(-\frac{P}{Q} \cdot \frac{W_D}{P}) \qquad \textbf{(9)}$$

Where, *k* is the coefficient larger than zero. Utilizing the critical value of 40%water use ratio and 0.4 adaptability, 2.3 is obtained for *k*.

Substitution of equation (8) in equation (3) generates the final expression of water resource vulnerability. Then, standardized by the critical value with *r*=1 and $\frac{P}{Q} \cdot \frac{W_D}{P} = 1$, water vulnerability are divided into 5 categories with the critical value of 0.05, 0.1, 0.2, 0.4, reflecting its different levels (Table2).

Table 2 - Classification of water resource vulnerability

no vulnerability	low vulnerability	Moderate vulnerability	high vulnerability	Serious vulnerability
<0.05	0.05-0.1	0.1-0.2	0.2-0.4	>0.4

3 WATER RESOURCE VULNERABILITY

This study applies water resources vulnerability framework in section 2.2 to estimate the water vulnerability of the ten major river basins of China under climate change and human activities. Results in Figure 2 indicate that high water stress exists in most parts of north China, i.e. use to availability larger than 40%, especially for Hai River basin where water withdrawal exceeds 100% of the availability, resulting in over extraction of groundwater and other water problems. The Yellow river basin also faces ‘physical water scarcity’ according to the threshold defined by the

Comprehensive Assessment of Water Management in Agriculture (MOLDEN et al., 2007a), when the use to availability ratio exceeds 70% , over-appropriating environment flows. Although with use-to-availability only 1.2%, the Southwest rivers basin suffers from serious engineering water shortage which is intensified by the severe drought in recent years.

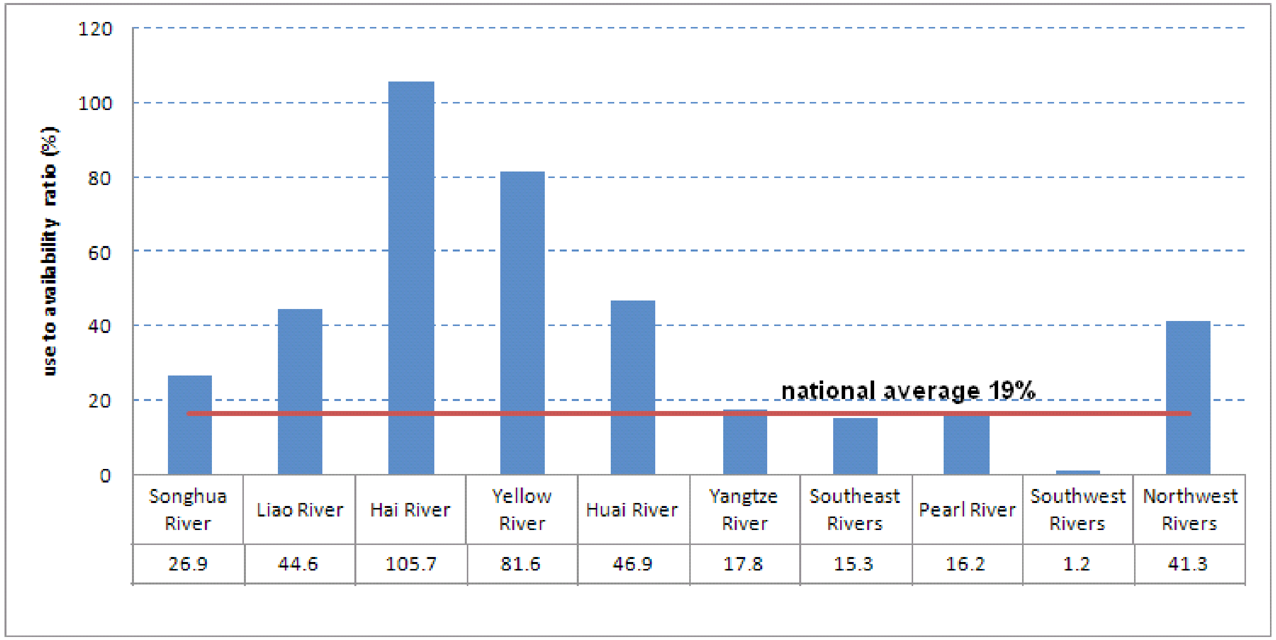


Figure - Use to availability ratio in China

Vulnerability evaluation results in Figure 3 show that the Hai and Yellow river basins belong to serious vulnerability, while Huai river basin, Liao river basin, Southwest rivers basin, Songhua river basin and Southeast rivers basin, with 0.35, 0.39, 0.27, 0.22 and 0.20 respectively, belong to high water vulnerability. The Northwest rivers, Yangtze river and Pearl river basins are moderate vulnerability level. The inconsistencies between water withdrawal ratio and water resource vulnerability level in the Southeast Rivers basin and Northwest rivers basin can be explained by the different sensitivity of water resource to climate change, demonstrating the advantages of our method by combined consideration of climate change and human activity impacts for scientific evaluation of water system vulnerability.

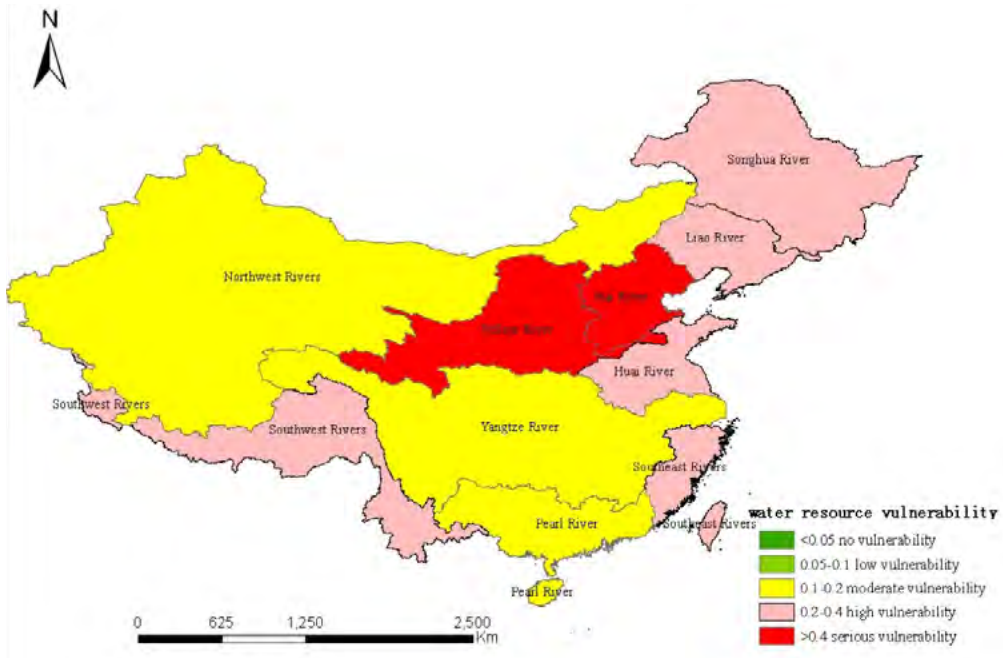


Figure 3 - Water resource vulnerability of ten major river basins in China

Moreover, the levels of water stress, water crowding of Huang-huai-hai River basins on base of second-order basins are shown in Figure 4, 5. In general, 8/17 of the second-order basins in this region suffer from physical water scarcity and 7/8 of them belong to extreme water scarcity basins, with more than 2000 people depending on per million cubic water resources. Among the left 9 sub-basins, those with high or medium water stress meanwhile belong to extreme or severe water scarcity, except number 12 basin, where use-to-availability equal to 30% while only 495 people depending on per million cubic water resources, belonging to medium water stress but mild water shortage. Number 5 basin located in the upper reaches of Yellow river is the only belonging to low water stress and no water shortage, indicating the low exploitation and water crowding in this region. Figure 6 illustrates the level of water vulnerability for the 17 second-order basins. In Hai and Huai river basins, except number 13 basin with high vulnerability, all of the other sub-basins face serious vulnerability. In Yellow river basin, 4/8 of the sub-basins belong to high vulnerability, leaving 2 with serious vulnerability and 2 with moderate vulnerability. In summary, water resources in 10/17 of the second-order basins face serious vulnerability to climate change and human activities, in line with the study results gained by a national key scientific research project of the 10th Five-Year Plan (ZHANG J.; WANG G., 2007).

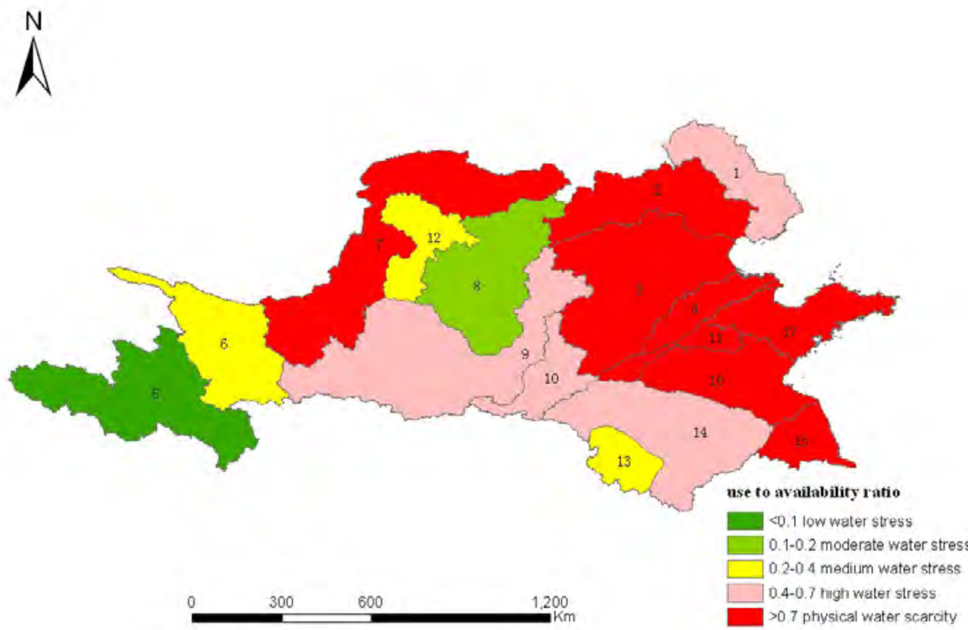


Figure 3 - Water stress of Huang-huai-hai River basins

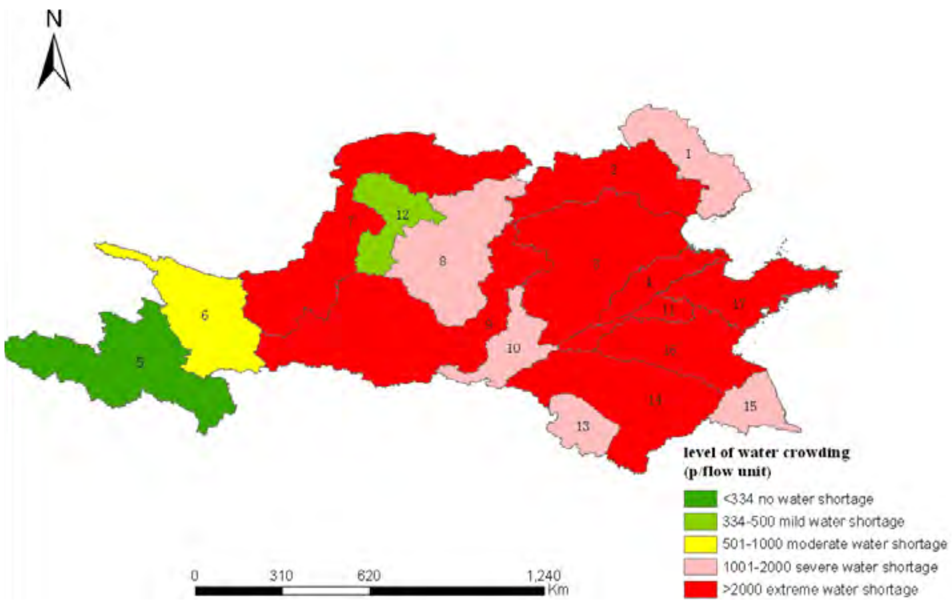


Figure 4 - Water crowding level of Huang-huai-hai River basins

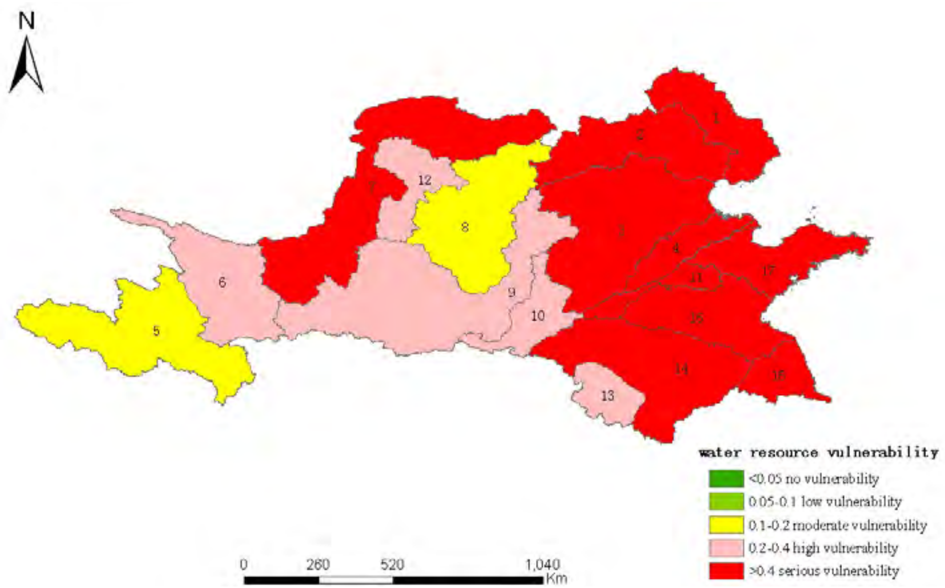


Figure 6 - Water resource vulnerability of ten major river basins in China

To predict the possible changes of water vulnerability levels under climate change and socio-economy developments in the future, three scenarios for Huang-huai-hai River basins in 2030 were formulated: in Sc1, climate varied, i.e. water availability changed, but human population, economic development and water withdrawals were fixed at 2006 levels; Sc2 utilized projected water demands for 2030 but availability were based on contemporary climate; in Sc3, both of the climate and water demands changed (CHARLES et al., 2000).

Study of the sensitivity to climate change indicated that mean runoff varied in response to precipitation and temperature change in different basins (WANG et al, 2011). For Hai river basin, a 1Cº increase results in 8% streamflow decrease and decrease of 10% precipitation results in 26% decrease in streamflow, however, both 1Cº decrease and 10% decrease in precipitation results in 30%-35% decrease in streamflow (LIU et al., 2004). In the up-reach of Yellow (Huang) river basin, increase of 10%, 20% precipitation results in 20%, 42% streamflow increase and 1Cº, 2Cº increase results in 4%, 8% decrease in streamflow, while both 2Cº decrease and 20% increase in precipitation results in 55% increase of precipitation (XIA J et al., 2011). In the middle reach of Yellow river, streamflow also increase as precipitation increase and temperature decrease, and vice versa. Response of runoff to climate change in Huai river basin has the same trend as the above two basins.

According to the outputs of the GCMs under SRES A2 and B2 scenarios, it is estimated that the temperature will increase by 0.96~1.4Cº, 0.95~1.15Cº, 1.3~1.5Cº and about 2%, 3%, 5% increase of precipitation in 2030 for Hai river, Yellow river and Huai river basins respectively (DING et al., 2010; XIA J et al., 2011). Taking the South-North Water Transfer Project into consideration, in this study, we take the -12%, -25%, -10% increase of streamflow as the scenarios of water resource in 2030 for Hai river, Yellow river and Huai river basins. Water demand values, determined by the population growth and economic development, are projected according to socio-economic driving factors prediction under climate change (SHEN et al., 2008). The results are shown in Table 3.

Table 3 - Water vulnerability changes under climate change and human activities to 2030 of Huang-huai-hai River basins (%)

	Hai river basin			Yellow river basin			Huai river basin		
	ΔQ	ΔWd	ΔV	ΔQ	ΔWd	ΔV	ΔQ	ΔWd	ΔV
Sc1	-12	0	57.6	-25	0	145.4	-10	0	18.8
Sc2	0	11.5	49.4	0	12.6	40.4	0	8.0	13.2
Sc3	-12	11.5	148.1	-25	12.6	285.7	-10	8.0	36.3

Compared with the benchmark year, for Hai river, Yellow river and Huai river basins in 2030, climate change alone (Sc1) may produce increases of *V(t)* by 0.58, 1.45, 0.19, while rising water demand under Sc2 may increase *V(t)* by 0.49, 0.40, 0.13, and Sc3 combining both climate and economic development effects producing relative increases by 1.48, 2.86, 0.36. *V(t)* surpassing 1 is due to use-to-available ratio over 1. Despite the existence of large uncertainties in the projections of future anthropogenic climate change, in particular in the projections of change in precipitation by GCMs, there is likely to be a sustained and severe pressure on water resources in Hai river and Yellow river basins, where water resources are already seriously vulnerable, aggravating the water shortage problem in the future.

4 ADAPTIVE WATER MANAGEMENT & NEW STRATEGY IN NORTH CHINA

Climate change impact is a big issue to water sustainable use in China due to existing or planning water projects and programming do not fully consider potential impact on climate change , particular on possibility of increasing variability of water overtime and space and extremely events such as floods & droughts . Adaptive management, particular on improving water governance to changing environment will be a priority issue. A good water governance is the process in which government and society get organized to use water resources sustainably to meet needs within a legal and ethical framework in accordance to the water availability at any given time with equity and dignity.

To adapt to the adverse effects of climate change and to mitigate the water resource vulnerability in Huang-huai-hai River basins, appropriate strategies must be taken for water resources planning and management.

Agriculture consumes the largest part of water resources in China, with the ratio to the national water above 75% and mainly using for irrigation, for which waste is very severe. As one of the core areas in food production and agricultural development, this problem is outstanding in Huang-huai-hai River basins. Thus adjusting the industrial structure to improve the efficiency of water use and save water resources is of vital importance.

As for agriculture water saving, firstly, investments in Low-flow irrigation (also called Water-Saving irrigation) should be increased. After being used in experimental plots across China, ecological and economic benefits of this type of irrigation has been proven. As a result, it can be put into practice and expanded to large scale. Moreover, changing cultivating structure and choosing the more water-efficient crops can also be effective measures for Huang-huai-hai River basins to reduce irrigation water consumption.

Ministry of Water Resources in China is now processing a strategies of water adaptive management based on three red lines controls, i.e.: The red line I is the water resources development controlled by Total Water Resources Quantity; the red line II is the water use efficiency improved by Water Demand Management, and the red line III: water resources protection by Water Quality Management i.e., control of waster water. Adaptive water management will face to new opportunity & challenges on implementing these strategies.

5 CONCLUSION

1) An integrated estimation model was proposed in this paper for assessment of water resource vulnerability on basin-scale by combing the natural features of water system and adaptation strategies as well as the integrated socio-economic capacity and science technical and management levels to tackle water stress caused by various factors. Specifically, this study focused on sensitivity of runoff to climate change and the relationship of water supply and demand and referred to Falkenmark's index system for assessment of water resources pressure;

2) Evaluation of the water resources vulnerability of the ten major river basins in China was carried by the proposed framework. Results indicate that Hai river basin and Yellow river basin suffer from the most serious vulnerability with 'physical water scarcity'. Huai river basin, Liao river basin, Southwest rivers basin, Songhua river basin and Southeast rivers basin belong to high water vulnerability, while Yangtze river basin and Pearl river basin with moderate level of vulnerability;

3) Especially, for Huang-huai-hai River basins, vulnerability of water resources on second-order river basins as well as predictions of future conditions under three scenarios in 2030 was assessed. 8/17 of the second-order basins in this

region suffer from physical water scarcity, almost all of which belong to extreme water scarcity basins, with more than 2000 people depending on per million cubic water resources. In summary, water resources in 10/17 of the second-order basins face serious vulnerability under current situation. Predictions of 2030 show that climate change and increasing water demand will bring about increasing vulnerability for this region, especially for Hai river and Yellow river basins, aggravating the water shortage problem in the future;

4) Water policy, in China will had to shift from *Water Quantity Management* into *Water Quality Management*, from *Water Supply Management* into *the Water Demand Management*. Appropriate adaptive strategies to mitigate the water vulnerability may include adjustment of the industrial structure to improve the efficiency of water use, increase of investments in Low-flow irrigation (also called Water-Saving irrigation) and changing cultivating structure and choosing the more water-efficient crops.

6 ACKNOWLEDGEMENT

This study were supported by the Natural Science Foundation of China (No. **51279140**) & Supported by CAS-CSIRO Cooperative Research Program, Grant No. GJHZ1223

REFERENCES

Adger WN, Brooks N, Bentham G et al. 2004. New indicators of vulnerability and adaptive capacity. Technical report 7, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich

Brooks N, Adger WN, Kelly PM. 2005. The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Glob Environ Change 15(2): 151-163

Brouwer, F., and M. Falkenmark (1989) "Climate-Induced Water Availability Changes in Europe." Environmental Monitoring and Assessment 13:75-98.

Brown, L.R., 1995. *Who Will Feed China?* New York: W.W. Norton.

Brown, L.R., 2004. Outgrowing the earth: the food security challenge in an age of falling water tables and rising temperatures. New York: W.W. Norton.

Charles J. V, Pamela G, Joseph S. 2000. Global water resources: vulnerability from climate change and population growth. Science 289:284-288.

Chen Zhikai 2003 The issues of sustainable utilization of water resource in China. Hydrology, 23(1): 1-5

Deng S, Deng Z, Chen K. 2010. Analysis of water resources system vulnerability based on DPSIR conceptual model. Water Resources Projection 26(4): 1-25 (in Chinese)

Ding X, Jia Y, Wang H, et al. 2010. Impacts of Climate Change on Water Resources in the Haihe River Basin and Corresponding Countermeasures. Journal of Natural Resources 25(4): 604-613

Ding Yihui, et al., 2007. China's National Assessment Report on Climate Change (I): Climate change in China and the future trend. Advances in climate change research 3(1)1-5

Encyclopedia, November 2003. North China Plain. http://www. nationmaster .com/ encyclopedia/north-china-plain

Falkenmark, M., 1994. Water Availability as Carrying Capacity Determinant - a New Factor in Third World Demography, in Environment and Population Change. Eds. Zaba, B. and Clarke, J. IUSSP Ordina Editions: Liege.

Falkenmark M, Molden D (2008) Wake Up to Realities of River Basin Closure. International Journal of Water Resources Development 24(2): 201-215.

Gleick, P.H. 1990. Vulnerability of water systems. In: Waggoner PE (eds). Climate change and U.S. water resources. Wiley, New Yark

Halweil, B., 2007. Grain harvest sets record, but supplies still tight. Available from: http:// www.worldwatch.org/ node/5539 [Accessed 31 December 2009].

IPCC. 2001. Climate Change 2001: impacts, adaptation, vulnerability. Contribution of working group to the third assessment report of the intergovernmental panel on climate change. UNEP/WMO. Geneva

IPCC, 2007: Climate change 2007: Synthesis report M . Cambridge: Cambridge University Press.

Jia S., Lin S., and Lv A., 2010. Will China's water shortage shake the world's food security? Water international, 35(1), 6-17

Kulshreshtha, S.N. 1993. World water resources and regional vulnerability: impact of future changes. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Liu C, Liu Z, Xie Z. 2004. Study of trends in runoff for the Haihe River Basin in recent 50 years Jorunal of Applied Meteorological Science 15(4): 385-393. (in Chinese)

Liu L. 2007. Concept and Quantitive Assessment of Vulnerability of Water Resource. Bulletin of Soil and Water Conservation 22(2): 41-44 (in Chinese)

Mohamed A. Hamouda, et al., 2009. Vulnerability Assessment of Water Resources Systems in the Eastern Nile Basin. Water Resources Management, 23(13): 2697-2725

Molden, D., Frenken, K., Barker, R., de Fraiture, C., Mati, B., Svendsen, M., Sadoff, C. & Finlayson, M. 2007a. Trends in water and agricultural development, in: D. Molden (Ed.) Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture, pp. 57–89 (London: Earthscan; Colombo: IWMI).

NERI "National Environmental Research Institute, Demark". 2002. Burden sharing in the context of global climate change, a North-South perspective. NERI Technical Report, No. 424

World Resources Institute, 1998. China's Health and Environment: Water scarcity, Water Pollution, and Health. Environmental Change and Human Health. http://pubs.wri.org/pubs_content_text.cfm?ContentID=1429

Shaw, R, Gallopin, G, Weaver, P and Oberg, S. 1991. Sustainable Development: A Systems Approach. International Institute for Applied Systems Analysis, Laxenberg, Austria.

Shen Y, Oki T, Utsumi N, et al. 2008. Projection of future world water resources under SRES scenarios: water withdrawal. Hydrological Sciences Journal 53(1): 11-33.

Shuval, H.I. 1987. "The Development of Water Reuse in Israel." Ambio 16:186 - 192.

Sullivan CA. 2011. Quantifying water vulnerability: a multi-dimensional approach. Stoch Environ Res Risk Assess 25:627–640

Sullivan CA, Meigh JR. 2005. Targeting attention on local vulnerabilities using an integrated indicator approach: the example of the climate vulnerability index. Water Sci Technol (Spec Issue Clim Change) 51(5):69–78

Sullivan CA, Meigh JR. 2007. Integration of the biophysical and social sciences using an indicator approach: addressing water problems at different scales. J Water Resour Manag 2(1):111–128

Tang G, Li X, Liu Y. 2000. Assessment Method of Vulnerability of Water Resources Under Global Climate Change. Advance in Earth Sciences 15(3): 313-317 (in Chinese)

UNDP-GEF “Global Environment Facility”. 2000. Vulnerability and adaptation assessment. National Communications Support Programme, Workshop Report, Amman, Jordan

Vogel CH. 2001. Vulnerability and global environmental change. Human Dimensions of Global Change Meeting, Rio

Watson, R.T., Zinyoera, M.C., and Moss, R.H. 1996. Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Wang G, Zhang J, Zhang S. 2005. Impacts of climate change on water resources and its vulnerability in China. Journal of Water Resources &Water Engineering 16(2): 7-15 (in Chinese)

Wang G, Zhang J, Liu J, et al. 2011. The sensitivity of runoff to climate change in different climatic regions in China. Advances in Water Science 22(3): 307-314

Xia J, Liu C, Ding Y, et al. 2011. Water Issues Vision in China: Impacts of climate change to water resources of typical regions in North China and adaptation strategies. Science Press (in Chinese), Beijing, (in Chinese).

Zhang J, Wang G .2007. The impact of climate change on water resources. Science Press (in Chinese), Beijing, pp 138-181(in Chinese).

Zou J, Liu L, et al. 2007. Concept and Quantitative Assessment of Vulnerability of Surface Water Resource. Resource Science 29(1): 92-98

THE ROLE OF GROUNDWATER IN ADAPTING TO THE IMPACTS OF CLIMATE CHANGE ON FRESHWATER RESOURCES

Richard Graham Taylor[1]

[1] Department of Geography, University College London, United Kingdom. Email: r.taylor@geog.ucl.ac.uk.

EXTENDED ABSTRACT

Projections of climate change derived from General Circulation Models (GCMs), reviewed under the 4^{th} Assessment of the Intergovernmental Panel on Climate Change (IPCC) in 2007, indicate an approximate global pattern wherein wet regions will become wetter and dry regions will become drier[1,2]. At regional scales, substantial uncertainty exists in projections of precipitation that is primarily associated with the choice of GCM[3-5]. The translation of these precipitation projections into water resource projections amplifies imprecision through a cascade of uncertainty[6] associated with (i) downscaling GCM projections to the basin scale[7,8], (ii) the estimation of evapotranspiration[9,10], and (iii) the choice of the applied hydrological model[11]. For example, a recent collaborative Brazilian-UK study in the Rio Grande Basin, a tributary of the River Parana in Brazil, reveals that under a 2°C rise in global mean air temperature uncertainty in projections of mean river discharge is such that there is consensus in neither the magnitude nor even the direction of projected change[12]. This result is similar to large basins examined in southern Africa and southeast Asia[2]. Uncertainty in hydrological projections need not, however, excuse inaction on climate change adaptation.

A robust, global climate change signal is the intensification of precipitation[13,14]. Extreme rainfall events (*i.e.* those in the uppermost quantiles of the rainfall distribution) are projected to increase with the rise in the water-holding capacity of the atmosphere defined by the Clausius–Clapeyron relation (6.5% per 1°C rise in air temperature). This assertion is based on the observation that the heaviest rainfall events tend to deplete air of all of its available moisture. As total increases in global precipitation as a result of warming have been estimated at 1% per 1°C rise in air temperature[15,16], the projected rise in extreme rainfall events is necessarily accompanied by a reduction in the number of low and medium intensity rainfall events or an overall decrease in the frequency of rainfall events. The intensification of precipitation is expected to be especially pronounced in the tropics where warmer air temperatures will lead to larger absolute rises in the moisture content of the atmosphere[15-17]. More frequent extreme rainfall and longer droughts give rise to greater but more variable river discharge ("blue water") but also lower soil moisture ("green water"). The former will exacerbate inter- and intra-annual freshwater shortages and the risk of flooding whereas the latter threatens food security through reduced crop yields[18]. A consistent projection of more variable river discharge involving higher peak (5^{th} percentile[1]) river discharges as well as lower and longer low (95^{th} percentile[a]) flows has recently been demonstrated from basin-scale

[1] Exceedance in % of months over a simulated 30-year period.

analyses on five continents[2]. These hydrological projections highlight the importance of storage in enabling adaptation to climate change. The magnitude of constructed storage (*e.g.* reservoir capacity) has previously been argued[19,20] to be central to the resilience of communities to climate variability and change. More feasible and less costly is the use of natural groundwater storage due to its widespread distribution, reliability and generally high quality. Existing groundwater-based strategies for adapting to inter- and intra-annual freshwater shortages include 'Managed Aquifer Recharge'[2] and 'Aquifer Storage and Recovery'[3]. In the Bengal Basin for example, substantial increases in groundwater recharge over the last few decades have been induced by groundwater-fed irrigation that not only sustains food security but also captures a greater proportion of the annual monsoonal inundation[21]. Indeed, increased groundwater abstraction for dry-season irrigation is expected to be sustainable in areas where potential recharge currently exceeds actual recharge[20]. Recent evidence from East Africa suggests that the shift to more intensive rainfall reducing soil moisture serves under favourable conditions (*i.e.* transmissive soil cover) to increase groundwater recharge[22,23]. Consequently, use of groundwater to supplement soil moisture through irrigation is a hydrologically sensible adaptation.

Increased use of groundwater is not a universal strategy to adapting to the impacts of climate change on freshwater supplies. Groundwater depletion observed in northwest India[24], southwest United States of America[25-27], North China Plain[28], and Bengal Basin[29], not only threatens global food security but is also estimated to contribute to sea-level rise[28,30,31]. It should be noted, however, that groundwater depletion often results either from the use of non-renewable, 'fossil' groundwater (where depletion is inevitable) or from a lack of groundwater management. Globally, evidence from recent global modelling, supported by satellite observations under NASA's Gravity Recovery and Climate Experiment (GRACE), reveals groundwater storage is increasing in response to return flows from surface-water fed irrigation[32]. In light of the critical role that natural storage can play in adapting to the impacts of climate change on freshwater resources, there is an urgent need to improve our knowledge of groundwater. A recent assessment of groundwater storage in Africa[33] suggests that its total volume is more than 20 times greater than Africa's renewable freshwater resources estimated from river discharge. Nevertheless, such estimates of groundwater storage remain poorly resolved by a lack of ground-based observations with which to characterise the saturated thickness of aquifers and their respective storage co-efficients[34]. On-going efforts to collate ground-based observations of groundwater globally (*e.g.* UNESCO-IHP IGRAC) are constrained

[2] http://www.iah.org/recharge/.

[3] http://www.asrforum.com/.

by a lack of long-term investment. At present, freshwater storage, be it natural or constructed, is excluded from current metrics used to characterise the global water crisis[35]. We remain, therefore, with flawed descriptions of the scale and dimensions of global water crisis that are based on these metrics (*e.g.* water stress index, relative water demand[37]). For example, the water stress index grossly overestimates freshwater demand in many environments (*e.g.* sub-Saharan Africa) thereby leading overly pessimistic estimations of future water scarcity[35]. In addition, neither metric effectively informs management responses to hydrological variability and change as renewable freshwater resources are defined in terms of "mean annual river runoff". The importance of natural groundwater storage, though currently underappreciated by the water management community, is gaining considerable interest from the financial community that targets investments in land ("Land Grabs") where they are underlain by transmissive aquifers and associated water rights[38].

More effective translation of climate change science into policies supporting adaptation is required. Although new innovations in climate change science such as fully coupled Earth System Models mark important scientific steps forward, accurate projections of climate change impacts on precipitation, let alone freshwater resources are a long way off. Historically, improving the resilience of communities to climate variability has commonly involved either increasing freshwater storage (*e.g.* construction of large-scale reservoirs or household cisterns) or increasing access to freshwater storage through the drilling of boreholes. Globally, groundwater currently supplies 50% of the freshwater used for drinking and domestic purposes[39] and 42% of that used in irrigation[40]. Increasing dependence upon groundwater through well-proven strategies for adapting to climate variability (*e.g*. aquifer storage and recovery, managed aquifer recharge) could, in many environments, prove invaluable in enabling adaptation to the impacts of climate change on freshwater resources. Indeed, strategies that exploit opportunities for adaptation in natural, rather than constructed, landscape are likely to be less expensive and more sustainable but, as is the case of groundwater, will require greater investment in monitoring and research to resolve the dimensions, characteristics, and capacity of this natural freshwater store around the world.

REFERENCES

Allan, R.P. & Soden, B.J. Atmospheric warming and the amplification of precipitation extremes. *Science* 321, 1481-1484 (2008).

Todd, M.C., Taylor, R.G., Osborn, T., Kingston, D., Arnell, N.W. and Gosling, S. Quantifying the impact of climate change on water resources at the basin scale on five continents – a unified approach. *Hydrology and Earth System Sciences* 15, 1035-1046 (2011).

Bates, B.C., Kundzewicz, Z.W., Wu, S., Palutikof, J.P. (eds.) Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, pp. 210 (2008).

Prudhomme, C. and Davies, H. Assessing uncertainties in climate change impact analyses on the river flow regimes in the UK. Part 2: future climate. *Climatic Change* 93, 197-222 (2009).

Maslin, M. and Austin, P. Climate models at their limit? *Nature* 486, 183-184.

Taylor, R.G., Koussis, A. and Tindimugaya, C. Groundwater and climate in Africa: a review. *Hydrological Sciences Journal* 54(4), 655-664 (2009).

Holman I.P., Tascone D. and Hess T.M. A comparison of stochastic and deterministic downscaling methods for modelling potential groundwater recharge under climate change in East Anglia UK: implications for groundwater resource management. *Hydrogeology Journal* 17, 1629–1641 (2009).

Stoll, S., H. J. Hendricks Franssen, M. Butts and Kinzelbach, W. Analysis of the impact of climate change on groundwater related hydrological fluxes: a multi-model approach including different downscaling methods. *Hydrology and Earth System Sciences* 15, 21–38 (2011).

Kingston, D., Todd, M., Taylor, R.G., Thompson, J.R. and Arnell, N. Uncertainty in PET estimation under climate change. *Geophysical Research Letters* 36, L20403 (2009)

Sorooshian, S., J. L. Li, K. L. Hsu, and Gao, X.G. How significant is the impact of irrigation on the local hydroclimate in California's Central Valley? Comparison of model results with ground and remote-sensing data. *Journal of Geophysical Research-Atmospheres* 117, D06107 (2012).

Crosbie, R.S., S.P. Charles, F.S. Mpelasoka, S. Arval, O. Barron and Summerell, G.K. Differences in future recharge estimates due to GCMs, downscaling methods and hydrological models. *Geophysical Research Letters* 38, L11406 (2011).

Nóbrega, M.T., W. Collischonn, C.E.M. Tucci and A. R. Paz, A.R. Uncertainty in climate change impacts on water resources in the Rio Grande Basin, Brazil. *Hydrology and Earth System Sciences* 15, 585-595 (2011).

Allan, R.P. and Soden, B.J. Atmospheric warming and the amplification of precipitation extremes. *Science* 321, 1481-1484 (2008).

IPCC Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, p. 582 (2012).

Allen, M.R. and Ingram, W.J. Constraints on future changes in climate and the hydrologic cycle. *Nature* 419, 224–32 (2002).

Trenberth, K,E, Dai, A., Rasmussen, R.M. and Parsons, D.B. The changing character of precipitation. *Bulletin of the American Meteorological Society* 84, 1205–17 (2003).

Pall, P., Allen, M.R. and Stone, D.A. Testing the Clausius–Clapeyron constraint on changes in extreme precipitation under CO2 warming. *Climate Dynamics* 28, 351–63 (2007).

Challinor, A., T. Wheeler, C. Garforth, P. Craufurd and Kassam, A. Assessing the vulnerability of food crop systems in Africa to climate change. *Climatic Change* 83, 381–99 (2007).

Brown, C. and Lall, U. Water and Economic Development: The Role of Variability and a Framework for Resilience. *Natural Resources Forum* 30, 306 – 317 (2006).

Grey, D. and Sadoff, C. Sink or swim? Water security for growth and development. *Water Policy* 9, 545-571 (2007).

Shamsudduha, M., Taylor, R.G., Ahmed, K.M. and Zahid, A. The impact of intensive groundwater abstraction on recharge to a shallow regional aquifer system: evidence from Bangladesh. *Hydrogeology Journal* 19, 901-916 (2011).

Owor, M., Taylor, R.G., Tindimugaya, C. and Mwesigwa, D. Rainfall intensity and groundwater recharge: evidence from the Upper Nile Basin. *Environmental Research Letters* 4, 035009 (2009).

Taylor, R.G., Todd, M., Kongola, L., Nahozya, E., Maurice, L., Sanga, H. and MacDonald, A. Dependence of groundwater resources on extreme rainfall: evidence from East Africa. *Nature Climate Change* (in review).

Rodell, M., I. Velicogna and Famiglietti, J.S. Satellite-based estimates of groundwater depletion in India. *Nature* 460, 999-1002 (2009).

Longuevergne, L., B. R. Scanlon and Wilson, C.R. GRACE Hydrological estimates for small basins: Evaluating processing approaches on the High Plains Aquifer, USA. *Water Resources Research* 46, W11517 (2010).

Famiglietti, J. S., M. Lo, S. L. Ho, J. Bethune, K. J. Anderson, T. H. Syed, S. C. Swenson, C. R. de Linage, and Rodell, M. Satellites measure recent rates of groundwater depletion in California's Central Valley. *Geophysical Research Letters*, 38, L03403 (2011).

Scanlon, B. R., L. Longuevergne, and Long, D. Ground referencing GRACE satellite estimates of groundwater storage changes in the California Central Valley, US. *Water Resources Research* doi:10.1029/2011WR011312 (2012).

Konikow, L. F. Contribution of global groundwater depletion since 1900 to sea-level rise. *Geophysical Research Letters* 38, L17401 (2011).

Shamsudduha, M., Taylor, R.G. and Longuevergne, L. Monitoring groundwater storage changes in the Bengal Basin: validation of GRACE measurements. *Water Resources Research* 48, W02508 (2012).

Wada, Y. van Beek, L.P.H., Sperna Weiland, F.C., Chao, B.F., Wu, Y.-H. and Bierkens, M.F.P. Past and future contribution of global groundwater depletion to sea-level rise. *Geophysical Research Letters* 39, L09402 (2012).

Pokhrel, Y.N., N. Hanasaki, P.J-F. Yeh, T.J. Yamada, S. Kanae and Oki, T. Model estimates of sea-level change due to anthropogenic impacts on terrestrial water storage. *Nature Geoscience*, DOI:10.1038/NGEO1476 (2012).

Döll, P., Hoffmann-Dobrev, H., Portmann, F.T., Siebert, S., Eicker, A., Rodell, M., Strassberg, G. and Scanlon, B.R. Impact of water withdrawals from groundwater and surface water on continental water storage variations. *Journal of Geodynamics*, doi:10.1016/j.jog.2011.05.001 (2012).

MacDonald, A., Bonsor, H.C., O Dochartaigh, B.E. and Taylor, R.G. Quantitative maps of groundwater resources in Africa. *Environmental Research Letters* 7, 024009 (2012).

Taylor, R.G., Tindimugaya, C., Barker, J.A., Macdonald, D. and Kulabako, R. Convergent radial tracing of viral and solute transport in gneiss saprolite. *Ground Water* 48, 284-294 (2010).

Taylor, R.G. Rethinking water scarcity: role of storage. *EOS - Transactions of the American Geophysical Union* 90, 237-238 (2009).

Falkenmark, M., J. Lundqvist and Widstrand, C. Macro- scale water scarcity requires micro- scale approaches: Aspects of vulnerability in semi- arid development. *Natural Resources Forum* 13, 258–267 (1989).

Vörösmarty, C. J., E. M. Douglas, P. A. Green and Revenga, C. Geospatial indicators of emerging water stress: An application to Africa. *Ambio* 34, 230–236 (2005).

Anseeuw, W., Alden Wily, L., Cotula, L. and Taylor, M. Land Rights and the Rush for Land: Findings of the Global Commercial Pressures on Land Research Project. ILC (Rome), p. 72 (2012).

Coughanowr, C. (1994) Ground Water. In: Water-related Issues of the Humid Tropics and Other Warm Humid Regions. IHP Humid Tropics Programme Series 8. UNESCO, Paris, France.

Siebert S, Burke J, Faures J M, Frenken K, Hoogeveen J, Döll P and Portmann F T 2010 Groundwater use for irrigation—a global inventory Hydrol. Earth Syst. Sci. 14 1863–80.

SUMMARY

CLIMATE CHANGE AND INTEGRATED WATER MANAGEMENT

Walter Rast[1]
Masahisa Nakamura[2]

[1] Vice-Chair, Scientific Committee, International Lake Environment Committee (ILEC), and Director, International Center for Watershed Studies, Texas State University, San Marcos, Texas USA.

[2] Chair, Scientific Committee, International Lake Environment Committee, and Research Center for Sustainability and Environment, Shiga University, Japan.

ABSTRACT

A number of important international conferences were previously convened to discuss the interacting topics of environmental protection and sustainability, including the natural resource needs of economic development. Major gatherings include the 1972 United Nations Conference on the Environment (Stockholm), 1987 United Nations Commission on Environment and Development, 1992 United Nations Conference on Environment and Development (UNCED; Rio de Janeiro), 2002 World Summit on Sustainable Development, and the RIO+20 United Nations Conference on Sustainable Development, most recently convened here in Rio de Janeiro. All these international gatherings generally focused on facilitating the ability of nations to continue their economic development, while also recognizing the capacity or limits of nature to provide the necessary resources to fuel and sustain this development. These various international fora also provided many recommended actions and programs to be considered and implemented on the regional and national level and, in doing so, to provide global-scale benefits.

The topic of climate change as a global-scale issue also was a focus of important international activities. The initial impetus was the United Nations Framework Convention on Climate Change (UNFCCC), which put the issue of potential global impacts of climate change squarely on the global environmental agenda. Open for signature at the 1992 UNCED, it established the Intergovernmental Panel on Climate Change (IPCC), and laid the foundation for the subsequent Kyoto Protocol. The IPCC, a United Nations scientific body, continually reviews and assesses globally-derived scientific and socio-economic information and data relevant to increasing our understanding of climate change, its causes and its impacts. In doing so, however, it does not conduct any research or engage in any monitoring activities relevant to climate change.

1 INTRODUCTION

The topic of climate change is on the minds of many individuals, organizations and governments around the world, and has been for a number of years. It has implications at the global, regional, national, and local levels. Depending on one's perspective and concerns, it evokes a variety of differing, and sometimes conflicting, reactions. To many, it represents an environmental issue, to others an economic issue, a social issue to others yet, and an emotional issue to many. The collective opinion of many scientists and politicians is that climate change is a potentially devastating threat to human societies, ecosystems, and our planet in general. To most individuals, the term 'climate change' equates to global warming. There is, however, some persisting differing opinion regarding its ultimate cause. Most attribute climate change/global warming to human activities, particularly the increasing use of fossil fuels on a global scale, which is producing increasing quantities of carbon dioxide and other so-called 'greenhouse gases.' Others have suggested it to be a manifestation of a longer-term continuing cycle our planet has experienced through the centuries, noting the Earth has been coming off the last ice age since approximately the 16th Century. Nevertheless, the general consensus is that human activities, particularly the increasing use of fossil fuels, are at the core of the global warming phenomenon. An inescapable reality, however, is that although global warming is a significant scientific issue, it has become 'politicized' over the past decades, resulting in differing and often conflicting agendas at global, national and local levels. It continues to be a topic of global debate, one with significant environmental and economic consequences.

A number of important international conferences were previously convened to discuss the interacting topics of environmental protection and sustainability, including the natural resource needs of economic development. Major gatherings include the 1972 United Nations Conference on the Environment (Stockholm), 1987 United Nations Commission on Environment and Development, 1992 United Nations Conference on Environment and Development (UNCED; Rio de Janeiro), 2002 World Summit on Sustainable Development, and the RIO+20 United Nations Conference on Sustainable Development, most recently convened here in Rio de Janeiro. All these international gatherings generally focused on facilitating the ability of nations to continue their economic development, while also recognizing the capacity or limits of nature to provide the necessary resources to fuel and sustain this development. These various international fora also provided many recommended actions and programs to be considered and implemented on the regional and national level and, in doing so, to provide global-scale benefits.

2 CLIMATE CHANGE AS A GLOBAL ISSUE

The topic of climate change as a global-scale issue also was a focus of important international activities. The initial impetus was the United Nations Framework Convention on Climate Change (UNFCC), which put the issue of potential global impacts of climate change squarely on the global environmental agenda. Open for signature at the 1992 UNCED, it established the Intergovernmental Panel on Climate Change (IPCC), and laid the foundation for the subsequent Kyoto Protocol. The IPCC, a United Nations scientific body, continually reviews and assesses globally-derived scientific and socio-economic information and data relevant to increasing our understanding of climate change, its causes and its impacts. In doing so, however, it does not conduct any research or engage in any monitoring activities relevant to climate change.

The Convention initially sought commitments from participating nations to reduce overall emissions of six greenhouse gases by at least 5% below 1990 levels between 2008 and 2012. Specifically, Article 3(1) of the Convention calls on developed countries to take the lead in addressing climate change, including precautionary measures to anticipate, prevent or minimize the causes of climate change, and to mitigate its adverse impacts on human livelihoods and sustainable ecosystem services. Article 4 seeks commitments to address climate change through various mitigation activities and/or adapting to climate change impacts. The subsequent Kyoto Protocol established under the Convention, the UNFCC's largest body of work, set emission targets for developed countries that were binding to the Parties to the Convention under international law.

These Articles and targets have nevertheless been difficult for some countries to accept, a major factor being that they were not binding on all nations. Rather, developing countries, who now include the largest emitters of carbon dioxide (the major greenhouse gas targeted under the Convention), were initially exempt from the Kyoto Protocol requirements. These countries include India and China, the world's two most populous countries. The latter has since become the largest emitter of carbon dioxide on our planet. The United States, which did not ratify the Convention, suggested climate change was not a conventional environmental issue. Rather, because it touched on virtually every aspect of a country's economy, it was not only an environmental issue, but also an economic issue. Subsequent lack of progress by various nations in meeting their emission targets also has discouraged others from diligently working to achieve them. Japan, Canada and New Zealand, for example, considered withdrawing from the Kyoto Protocol requirements, although some also are considering internal implementation of voluntary emission reductions outside the Kyoto Protocol. Most recently, climate change talks at the 2012 Doha Conference (the 18th meeting of the Parties since the Convention came into effect) included agreement to a timetable by 2015 for a global agreement to include all countries, with its implementation by 2020.

3 PREDICTED IMPACTS AND IMPLICATIONS OF GLOBAL WARMING

The IPCC has made a number of observations over the years regarding the status and potential impacts of global warming on the environment and human well-being. As noted earlier, although the fundamental cause is still debated by some, based on recent observations of increased average atmospheric and ocean temperatures, rising sea levels, and increased glacial and ice melting, the overwhelming consensus is that the Earth is warming. The IPCC (2007) previously reported the average global temperature during the 20th Century has increased by what many might consider an insignificant 0.74 °C. It also suggested a temperature increase of 1.8 to 4.0 °C could occur over the coming century if present conditions continue. More recently, based on multiple, independently-produced datasets, the IPCC (2014) reported the globally-averaged combined land and ocean surface temperature data, based on a linear trend, "indicated a warming of 0.85 (0.65 to 1.06) °C during 1880 to 2012." Many predicted ramifications of this predicted temperature increase are sobering, including that the major impacts of climate change will be manifested by significant changes in the hydrologic cycle. Particularly noteworthy are predicted changes in precipitation patterns, which would translate into changes in water availability, hydropower production, navigation, recreational possibilities and other water-requiring activities. One prediction is that many low- and mid-latitude areas will receive less precipitation than in the past, affecting water availability and degradation, posing challenges to all activities dependent on a sustainable water supply, particularly irrigated agriculture. In contrast, predicted precipitation in high latitude areas will generally increase, with increasing floods, ecosystem degradation, economic losses and human deaths. Even more problematic is that precipitation will still be variable on the regional scale, making longer-term predictions difficult. This translates into uncertainties and risks that must be considered by governments, particularly for countries and populations most vulnerable to climate change impacts. Such possibilities will lead to increased malnutrition and waterborne disease, threatening human health and destroying human livelihoods Further, noting the unprecedented recent increase in the average global temperature, one cannot necessarily count on past weather patterns as a basis for future predictions (Table 1).

Although the negative impacts of future climate change on freshwater systems, particularly surface waters (lakes, rivers), are expected to outweigh the benefits (IPCC, 2014), there are some predicted beneficial aspects of a warmer atmosphere. These include less severe winters in some locations, more precipitation in some dry areas and less precipitation in some wet areas, increased food production in some areas, and an expanded range for some plant and animal species adapted to higher temperatures (ENGER, SMITH, 2013). More sobering predictions, however, are an increased frequency of extreme weather events, including a larger number and greater intensity of heat waves and storms (UNEP, 2012a). Global warming has been suggested, for example, as the underlying cause of the severe winds, increased precipitation, floods and tornadoes that have recently plagued the Midwest, Central and Northeastern United States. On a more global scale, such events can significantly affect other countries, with particularly severe impacts on poor people in developing countries and small island developing states that lack the financial and manpower resources to address them with effective mitigation and/or adaptation activities. In fact, people in poor and mountainous countries contribute least to global warming, yet are the most vulnerable to climate change and its associated erratic weather patterns because they have inadequate capabilities to address these impacts (WCES, 2011). Indeed, the impacts of climate change will likely engender new kinds of challenges and opportunities, in addition to magnifying the challenges that people in developing countries are already facing (NUORTEVA et al., 2010).

Table 1 - Climate Change Impacts on Key Hydrologic Variables

(continue)

Variable	Present/Projected Impacts
Precipitation	Increase (~2%/ºC) in total precipitation; high latitude areas generally to increase; many low- to mid-latitude areas to decrease; but variable at regional scale
Droughts	Increasing in many areas, particularly lower latitudes; decreasing in many high latitude areas; complex patterns
Tropical cyclones	Increase in intensity (North Pacific, Indian, Southwest Pacific Oceans); frequency and track changes uncertain
Glaciers and snow cover	Continued decrease in glacial mass and snow cover (but not all regions); earlier peak runoff from glacier and snowmelt
Sea level	~0.2 m increase over 20th Century; rise equivalent to 0.3 m/century since early-1990s; IPCC: 0.2-0.6 m by 2100 (upper end may be much higher)

(continuation)

Ocean acidification	Mean surface pH projected to decrease from ~8.2 (present) to ~7.8 by 2100
Sea surface temperature	Increase by 0.5° C since 1980; continuing to increase

Source: adapted from UNEP (2012a)

The very recent RIO+20 discussions reaffirmed climate change as one of the greatest challenges of our time, identifying adaptation to climate change as an immediate and urgent global priority. Climate change was characterized as a persistent, cross-cutting crisis, noting the Timing and magnitude of its potential negative impacts will affect all countries, undermining their ability to achieve sustainable development and the Millennium Development Goals, thereby also threatening the viability of some nations, particularly the developing countries. UN-Water, for example, the United Nations mechanism for strengthening coordination and coherence among UN agencies working on all aspects of freshwater and sanitation, identified water as the primary medium through which climate change will influence our planet, including environmental stability and the livelihoods and well-being of its inhabitants. It also identified climate change as a key driver of changing water availability and use, interacting dynamically with demographic, economic, social and technological forces to influence human well-being, as well as environmental sustainability. The hydrologic cycle, particularly any significant changes in its patterns and magnitude, will ultimately affect human socio-economic conditions as well. The United Nations Environment Programme (UNEP), which devoted a special session at the recent RIO+20 conference devoted to important environmental issues facing our planet in the 21st Century, also made important observations regarding climate change. UNEP pointed out, for example, that a major new global challenge facing humanity was management of the unintended consequences of some climate change adaptation and mitigation measures. Cited examples include the impacts on migratory bird behaviors of wind farms developed to reduce our dependency on fossil fuels, and the impacts on the ecology of natural wetlands of constructing sea walls to address sea level rise. UNEP also highlighted the need for humans to adapt to the changing frequency, strength, distribution and duration of extreme weather events attributed to global warming. In addition, UNEP pointed out that many glaciers in the Himalayas, Central Asia and the Andes were in retreat, threatening people and ecosystems, including increased flood risks from bursting of natural dams, and an eventual decrease in dry season runoff in some regions, all factors that require us to develop a better understanding of the overall hydrological, economic and social consequences of the climate change presumed to be the underlying cause of such phenomena.

4 CLIMATE CHANGE MITIGATION AND ADAPTATION ACTIVITIES

The immediate responses to climate change impacts have focused primarily on mitigation activities for treating or ameliorating the symptoms of climate change. They include a range of mitigation measures involving human water demands and uses. The issue of water quantity as related to climate change, for example, typically focuses on attempting to address predicted water shortages. There has been less concern, at least to date, on issues involving the impacts of excessive quantities of water, even though floods represent one of the most devastating natural disasters facing both humans and ecosystems, with both socio-economic and ecological consequences. Lakes, reservoirs and other lentic water systems have a special role to play in regard to such issues, noting that they contain at any given instant more than 90% of the liquid freshwater on the surface of our planet. The characteristics and management challenges of lentic (pooled, standing) water systems, in contrast to lotic (flowing) water systems, and their relation to sustainable use of freshwater systems, were previously discussed in the paper by Nakamura and Rast (2015) elsewhere in this volume. In regard to lake and reservoir management, for example, water quantity measures generally focus on controlling lake-river interactions, including both water scarcity (drought) and water excess (floods) situations. Such mitigation measures often are addressed by the development and implementation of appropriate drought and flood mitigation policies, even though such measures are not necessarily within the capabilities of developing countries. Discussions at the 5th World Water Forum included a keynote speaker suggestion that construction of new dams was inevitable as a means of storing water, whether to address periods of water scarcity, or to provide a pooling mechanism for controlling water excesses associated with flood events. In regard to the ubiquitous problem of eutrophication, a major global concern for lakes and reservoirs, mitigation has focused on nutrient control measures. Developed countries often approach this problem by constructing municipal wastewater treatment plants capable of removing nutrients associated with human wastes from domestic sewage prior to its discharge into receiving waters. Removal of phosphates from detergents also is a popular and easily-implemented measure. On the other hand, although such point sources of nutrients are being brought under control in many countries, the issue of nonpoint nutrient sources, particularly in the form of urban and agricultural runoff, remains a major challenge in both developed and developing countries throughout the world. This latter problem is particularly difficult to address, requiring innovative monitoring programs to be implemented, appropriate technology and behavioral changes to be developed and implemented, and appropriate education and public awareness activities to be undertaken. Ecosystem degradation also is a major climate change concern, particularly in regard to habitat alteration or destruction, with its wider implications for the protection of biodiversity.

Nevertheless, the IPCC has emphasized that, despite the scale of such mitigation measures to address the symptoms of climate change, another essential need is adaptation measures to proactively address these impacts, including land and water management at the local level. Rather than mitigation actions alone, the emphasis must shift to developing a more integrated approach that embraces both mitigation and adaptation. Consistent with this conclusion, the IUCN has equated climate adaptation with water adaptation, suggesting that investments in water security translate into investments in adaptations. There is little doubt that adapting to climate change will require reexamination of current approaches in water management, including the design of many components of urban settlements, and economic and social infrastructure generally. In discussing the links between climate change and water, a recommendation from the 2008 World Water Week in Stockholm was that governments must work out a strategic framework for adaptation strategies to counter climate change, including early warning or insurance systems, as well as building resilience through financial measures, policies and institutions focusing on adaptation. The potential role of Integrated Lake Basin Management (ILBM) in addressing this challenge is discussed in more detail in a following section.

A myriad of issues must be considered in planning adaptation measures to address water resources and climate change. In fact, the “Art of Adaptation” in water management is essentially a challenge in finding the right mix of information, institutions and infrastructure. This challenge is easy to envision and discuss, but difficult to address in reality. This is due partly to the fact that many challenges to effective adaptation to climate change are directly linked to water resources, while others are consequences of less directly-related issues. Even the adaptation measures themselves can sometimes result in unanticipated consequences. Water storage in all forms, for example, will play a key role in climate change adaptation, as well as achieving the broader goal of sustainable development. As previously noted, this will encompass developing new water storage capacity in various forms, as a buffer against both water shortages (decreasing precipitation) and floods (increasing precipitation), including dams (reservoirs), aquifer storage and recovery systems, wetlands, ponds and tanks. Such measures will work to decrease the vulnerability of humans and aquatic ecosystems to climate change impacts. At the same time, however, water storage can also enhance negative climate change impacts by increasing water evaporation, changing runoff volumes and patterns, and similar hydrologic modifications with associated human and ecosystem implications.

The need for water-related information will be critical for effective water adaptation. Indeed the need for increasing hydrological monitoring has been repeatedly highlighted in the international water arena since the 1977 Mar del Plata Conference. Unfortunately, the reality is the opposite. Notwithstanding some significant UN-based monitoring efforts, there has been a worldwide decline in monitoring of freshwater resources over the past three decades, resulting in inadequate and/or increasingly outdated water-related data bases. Much of the GRDC stream flow data, for example, is more than 30 years old. The Global Environmental Monitoring System for water (GEMS/Water) initially jointly undertaken by UNEP and WHO, and the only global-scale freshwater monitoring program, is in a precarious position because of lack of sustained funding and other necessary resources (although recent actions have been undertaken by UNEP to facilitate its continued existence). Further, the countries participating in the GEMS/Water program do not represent a broad global coverage in regard to needed water data. In addition, the participation of such countries in GEMS/Water monitoring efforts is voluntary in nature. Partially as a result, the hydrologic monitoring networks in many developing countries are seriously deteriorated. And even when water-related data and information are collected, some countries and organizations often are reluctant to share them with others.

Water policies and practices to facilitate adaptation to climate change should focus on establishing institutions, providing information and enhancing capacity to predict, plan for, and cope with climate change variability, and the associated uncertainties and risks regarding sustainable freshwater resources. This will involve a broad range of institutions that provide water for people, industries, energy generation, agricultural production, and ecosystem protection. The needed infrastructure for such activities also must be sufficiently resilient to address disaster risk management, with hard solutions that also must realistically consider the above-noted construction of dams, aquifer storage and retrieval systems, wetlands and ponds as water storage facilities. So-called “soft solutions” also are feasible in many instances, including water demand management, water allocations and conservation, increasing water use efficiency, and related land use planning.

Drinking water scarcity will always be a critical human concern, often being the basis for international cooperation directed to the goal of sustainable water supplies. This issue must consider both water supply and water demand strategies. Water demand strategies must take into account such factors as water allocations between sectors, reducing water consumption (e.g., improved irrigation techniques), increasing public awareness of the consequences of water scarcity, and progressive water tariffs. The other side of the equation; namely, water supply strategies, must focus on increasing water availability in specific locations and/or times by such methods as water storage, rainwater harvesting, wastewater reuse, desalination, and even interbasin water transfers and virtual water sources.

Effectively adapting to extreme climate events must encompass considerations of such measures as developing effective early warning systems, constructing improved physical defenses for existing water facilities, and careful sighting of new facilities, even those not directly related to water resources. Although outside the direct scope of lake-related issues, the recent nuclear disaster in Japan associated with the impacts of the tsunami event on nuclear power facilities provide a dramatic example of the latter. Adaptation measures to sea level rise and flooding will include building and strengthening of dikes and embankments, reforestation and coastal vegetation (i.e., erosion buffers). The so-called water-energy-climate nexus also represents a significant challenge facing humanity, noting traditional energy production sources emit increased quantities of greenhouse gases, with their attendant climate change impacts. Even so-called 'lower carbon fingerprint' energy is not without its water-related challenges. Hydropower production, for example, although not emitting greenhouse gases, causes river system fragmentation and has displaced many thousands of people and their livelihoods in some situations (e.g., Three Gorges Dam in China; Lake Kariba in Zimbabwe). Further, although a prominent renewable energy source, some forms of solar energy require much water, but are often located in arid regions already experiencing water scarcity. Desalination, although allowing us to tap the vast water resources of our oceans, requires large quantities of energy. Major potential future oil sources such as oil shale, tar sands, and hydraulic fracturing (fracking), being practiced in the United States and Canada, also require large quantities of water, but often exist in water-scarce areas (UNEP, 2012a).

5 CLIMATE CHANGE, IWRM AND ILBM

Experiences around the world clearly demonstrate that managing water resources, even ignoring the need to consider the potential impacts of climate change, is a complex, intensive and continuing task, in terms of both finances and manpower. The issue of climate change adds another dimension of difficulty to be considered. There has been much discussion and use of Integrated Water Resources Management (IWRM) in the international water arena as a basis for addressing water resources. To this end, a major recommendation arising from the 2002 International Summit on Sustainable Development in Johannesburg was the development of water use efficiency and integrated water management plans, produced under the auspices of IWRM. There is no doubt IWRM has provided an important impetus for demonstrating that management of water resources is more than just managing a commodity. Nevertheless, as discussed by Nakamura and Rast (2013), IWRM experiences to date (HOOPER; LLOYD, 2011; UNEP, 2012b) suggest it does not adequately address the long-term sustainability of lentic water resources and the life-supporting ecosystems they provide, nor does it consider that water systems in a given region comprise a dynamic, interacting linkage of nested flowing (lotic) and still (lentic) water systems, each with its own particular characteristics related to their sustainable use.

It is for such reasons that the concept of Integrated Lake Basin Management (ILBM) was developed, and continues to be applied to lakes and reservoirs throughout the world. ILBM is continuing to be refined on the basis of these experiences (NAKAMURA; RAST, 2011; NAKAMURA et al., 2012). Noting the utility of the ILBM Platform Process, as described elsewhere

in this volume (NAKAMURA; RAST, 2015), it is useful to briefly consider the six governance 'pillars' (policies, institutions, participation, information, technology and finances) that form the core of this comprehensive approach, and to describe their relevance in regard to sustainable water resources and climate change linkages (Figure 1). It is the experience of the International Lake Environment Committee (ILEC) and others, for example, that consideration of scientific issues alone is not sufficient to address sustainable water resources and their associated ecosystem goods and services, even without considering the added dimension of climate change. Rather, such topics must be addressed in a comprehensive and interdisciplinary manner, noting that nature acts in this same manner within the context of the interacting biotic and abiotic components that comprise aquatic ecosystems.

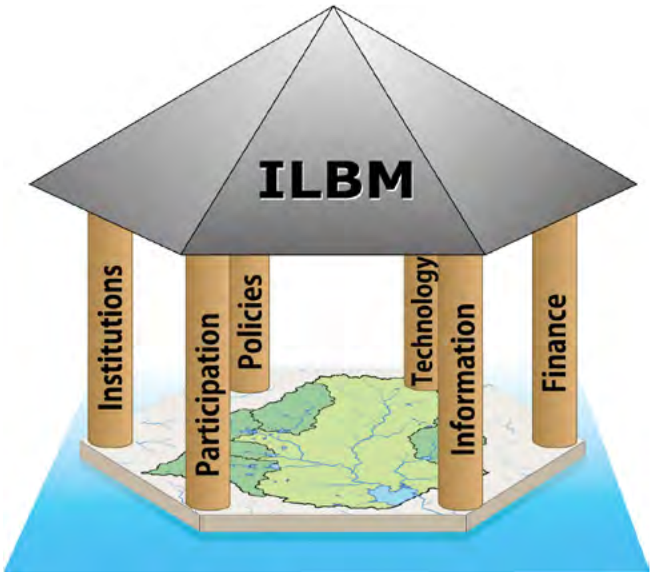


Figure 1 - ILBM Governance Framework for Sustainable Management of Lakes and Other Lentic Water Systems
Source: Taken from Nakamura and Rast (2011)

As a basis for developing effective water resources policymaking and planning, including the climate change linkages and considerations, the participatory integrated management approach encompassed in ILBM provides an extremely useful platform. It is beyond the scope of this report to discuss in detail the comprehensive framework encompassed within the ILBM Platform Process, and its associated 'Lake Brief' (designed to obtain needed information, data and insights regarding a given water basin; NAKAMURA; RAST, 2011; NAKAMURA et al., 2010). It is noted, however, that they are sufficiently broad to consider the major governance challenges hindering the sustainable use of freshwater sources, including those associated with the uncertainties and risks attributed to climate change. This includes consideration of appropriate policies ("rules of the game") ideally directed to the sustainable use of water systems, while also being sensitive to the need to maintain the life-supporting ecosystem services they provide to humanity. Such rules must now be developed so as to consider the predicted consequences of climate change. The institutions that carry out these rules of the game also must be comprehensive, representative and collaborative to be most effective. The sustainable use of the international Rio Grande, the transboundary river-lake system shared and used by Mexico and the United States, provides an example of the complexity of this goal. Water resources, including water allocations, is a state responsibility in the United States, but a federal responsibility in Mexico, complicating the responsibilities, lines of authority and sustainable funding needs. There also appears to be a lack of interagency and inter-sectoral cooperation regarding the sustainable use of its waters (MOORE et al., 2002). These differing levels of responsibility are among the factors that have seriously hindered achievement of the goal of sustainable use of this important transboundary water system, even to the present time. The Rio Grande, which is located in a generally arid region of both countries, was previously identified among the ten more imperiled rivers in the world, and provides an excellent example of the need to address its sustainable use against a background of the uncertainties and risks associated with predicted climate change impacts.

Inadequate stakeholder participation in water resources policymaking and implementation also is an important issue in many places. Important stakeholders usually comprise relevant water resource users and suppliers. Yet, even though their input may be sought, appropriate avenues of communication to obtain public viewpoints may not exist, or may be difficult to access. Public awareness, an important means of spreading (and obtaining) knowledge, also is often inadequate. This situation is usually counterproductive, since active public awareness can both educate water users about how their actions impact the supply and condition of water resources, as well as providing guidance on how they might change their particular water use habits to help address potential water shortages and/or degradation. It also facilitates the wider community ownership of management activities and their costs. This goal is admittedly easier said than done, being particularly difficult in an urbanizing world, in which the majority of the global population often do not appreciate, or even directly notice, how their actions may affect the sustainability or degradation of existing water resources. The incremental nature of environmental degradation, particularly for lentic water systems, adds to this difficulty.

The use of technological solutions, in contrast to facilitating human behavioral changes, represents another challenge. Developed countries typically utilize “high tech” solutions to address many water-related problems. Such solutions, however, are usually too expensive and difficult for developing countries. On the other hand, greater use of both public awareness and education activities to facilitate behavioral changes in the form of reducing water demands, more conscientious utilization of existing resources, more efficient agricultural irrigation practices, etc., would assist both developed and developing countries to better manage and utilize their existing water resources. An adequate knowledge and information base also is an essential requirement for effective water resources management. It can include both 'modern' scientific knowledge, as well as indigenous knowledge gained over many years of experience with water resource issues. An information network of experiences and lessons learned in climate change adaptation can also enlighten the global water community. Finally, it appears to be virtually impossible for any government or organization to ensure adequate and sustainable financial resources to implement and carry out water resources management activities and programs. Rather, many activities turn into one-time, stand-alone projects, rather than the continuing efforts that they are in reality.

The specter of uncertainty and increased risks, as well as their implications for effective water management and aquatic ecosystem maintenance, also are overriding concerns associated with climate change. Whether or not it is ultimately found that humans are unequivocally the primary cause of climate change and associated global warming, it is clear the impacts of climate change will likely result in new types of assessment and management challenges, both spatially and temporally. This will be especially significant for individuals and communities in lake, reservoir and lentic water basins in developing countries, which exhibit the highest levels of vulnerability to such impacts. Further, as noted by Bates et al. (2008), climate change can affect precipitation patterns and river runoff. This also will impact lake and reservoir basins, as they lie within the former. The associated risks are manifested in the prospects of changing precipitation patterns that can result in reduced water availability or, alternatively, floods associated with excessive precipitation. As previously noted, an added dimension of difficulty rests is the fact that attempting to model or manage water systems, including lakes and other lentic water systems, on the basis of past hydrologic (and associated assessment and management) experiences will be especially risky, since we are only now beginning to appreciate the magnitude and timing of climate change impacts (IPCC 2007, 2014; MILLY et al. 2008).

Increasing water scarcity or excesses can adversely impact many sectors important to human well-being, including agriculture, water supply and sanitation, energy production, water quality and physical infrastructure (IPCC, 2007). Increased political tensions between riparian countries in international lake basins also are potential consequences. As noted by De Stefano et al. (2012), and consistent with past and ongoing ILEC experiences in lake basin governance, transboundary lake basins not governed by treaties or other international agreements may not be able to meet their water-related treaty obligations (with attendant environmental and economic impacts) in the face of predicted climate change impacts. They identified 24 transboundary river basins exhibiting high potential risk for hydropolitical tensions associated with water variability, concentrated mainly in northern and sub-Saharan Africa. This finding suggests that international water agreements and river basin organizations represent important means for addressing climate-based changes in transboundary water basins, including the lake and reservoir basins lying within them. Governments also must strive to develop better water resources and climate change plans, including improved integration of effective water resources management into climate and other national and international policies, including poverty reduction considerations where appropriate. To this end, the previously-noted Integrated Lake Basin Management (ILBM), perhaps more appropriately called Integrated Lentic-Lotic Basin in Management (ILLBM), provides a comprehensive platform for attempting to manage lakes and other lentic water systems and their basins for sustainable ecosystem services within the context of the hydrologic variability and associated risks characterized by climate change. It would also facilitate framing of climate change impacts more precisely within the broader challenges of better water resource management, as well as promote better linkages between water-related climate adaptation and mitigation measures.

In conclusion, water resources are very sensitive to climate change, and particularly global warming and its predicted consequences, which can significantly impact precipitation, floods and water supply in rivers, lakes, wetlands and aquifers. These factors, in turn, can directly or indirectly affect such natural and human-related phenomenon as biodiversity, food production, human health and ecosystem viability. Thus, identifying and assessing the effects of these impacts is essential for the effective planning for sustainable water resources. With the inherent variability associated with climate change, and particularly the predicted changes in the hydrologic cycle, water planners and managers must be able to take the impacts of climate change into account. The lack of long-term data sets, as well as inadequate financial and technical experts, adds to the difficulty of water resources management. Current research regarding adaptation measures also suggests a long-term perspective is essential, particularly at the regional-transboundary scale, since some have predicted that some climate change impacts may be irreversible for a long time period (XU et al., 2009).

It is freely admitted that improving the adaptive capabilities of humans and their economic livelihoods is a difficult task, particularly when the differing capabilities of developed and developing countries is considered. It is suggested, however, that promising starting points may exist at the local level, building on past experiences to strengthen and diversity existing livelihood strategies within the local context. At the same time, however, such local adaptation strategies must be accompanied by more comprehensive, long-term policy responses (NUORTEVA et al., 2010). The latter can clearly be facilitated with the use of ILBM, as discussed in detail elsewhere in this document (NAKAMURA; RAST, 2015).

REFERENCES

Bates, B., Zbigniew, K., Wu, S. and J. Palutikof (eds). 2008. Climate Change and Water. Technical Paper 6, IPCC Secretariat, Geneva. 210 p.

Enger, E. and B. Smith. 2013. Environmental Science: A Study of Interrelations. McGraw Hill, pp. 378-385.

Hooper, B.P. and G.J. Lloyd. 2011. Report on IWRM in Transboundary Basins. UNEP-DHI Centre for Water and Environment, Horsholm, Denmark. 40 p.

IPCC. 2007. Fourth Assessment Report, Climate Change Synthesis Report, Summary for Policymakers. IPCC Secretariat, Geneva.

IPCC. 2014. Fifth Assessment Report, Climate Change Synthesis Report, Summary for Policymakers. IPCC Secretariat, Geneva. 31 p.

Milly, P., Betancourt, J., Falkenmark, M., Hirsch, R.M., Kundzewicz, Z.W., Lettermaier, D.P. and R.J. Stouffer. 2008. *Stationarity is Dead: Whither Water Management*. Science, 319(5863):573-574.

Moore, J.G., W. Rast and W.M. Pulich. 2002. *Proposal for an integrated management plan for the Rio Grande/Rio Bravo*. In: Aldama, A., F.J. AParicio and E. Equihua (eds.), 1st International Symposium on Transboundary Water Management, Avances en Hidraulica 10, XVII Mexican Hydraulics Congress, Monterrey, Mexico, Nov. 18-22, 2002, pp. 189-204.

Nakamura, M. and W. Rast. 2011. Development of ILBM Platform Process. Evolving Guidelines Through Participatory Improvement. Research Center for Environment and Sustainability, Shiga University, and ILEC, Kusatsu, Japan. 76 p.

Nakamura, M. and W. Rast. 2015. Promoting Integrated Lake Basin Management (ILBM): The Initial Global Experience, 2008-2012. This volume.

Nakamura, M., W. Rast and A. Hinatsu. 2010. Guidelines for Lake Brief Preparation. Research Center for Environment and Sustainability, Shiga University, Japan. 17 p.

Nakamura, M., Rast, W., Kagatsume, T. and T. Sato. 2012. Primer: Development of ILBM Platform Process. Evolving Guidelines Through Participatory Improvement. Research Center for Environment and Sustainability, Shiga University, and ILEC, Kusatsu, Japan. 76 p.

Nuorteva, P., Keskinen, M. and V. Olli. 2010. *Water, Livelihoods and Climate Change Adaptation in the Tonle Sap Lake area, Cambodia: Learning From the Past to Understand the Future*. Jour. Water and Climate Change, 1(1):87-101.

De Stefano, L., Duncan, J., Dinar, S., Stahl, K. Strzepek, K.M. and A.T. Wolf. 2012. *Climate Change and the Institutional Resilience of International River Basins*. Jour. Peace Research, 49(1):193-209.

UNEP. 2012a. Global Environment Outlook 5: Environment for the Future We Want. United Nations Environment Programme, Nairobi, Kenya. 528 p.

UNEP. 2012b. Status Report on the Application of Integrated Approaches to Water Resources Management. United Nations Environment Programme, Nairobi, Kenya. 106 p.

WECS. 2011. Water Resources of Nepal in the Context of Climate Change. Water and Energy Commission Secretariat, Government of Nepal, Singha Durbar, Kathmandu. 67 p.

Xu, J., Grumbine, R.E., Shreshtha, A., Mats, E., Yang, X., Wang, Y. and A. Wilkes. 2009. The Melting Himalayas: Cascading Effects of Climate Change on Water. Conservation Biology, 23(3):520-530.

SESSION 8

MANAGING WATER IN URBAN AREAS AND METROPOLITAN REGIONS: AN EVER-GROWING CHALLENGE

SUMMARY

WATER CHALLENGES IN THE MINING INDUSTRY: EXAMPLES FROM AFRICA

Daniel O. Olago[1]

[1] Dr. Department of Geology/Kenya National Academy of Sciences - University of Nairobi. PO Box 30197. Nairobi, Kenya.

ABSTRACT

Water links Africa's economic fortunes and climate change challenges, and contributes enormously to economic productivity and social well being of the human populace as both social and economic activities rely heavily on the quantity and quality of water. With the increasing growth in population and the subsequent socio-economic pursuits (including urbanization, industrial production, tourism and agricultural activities) demand for water has increased rapidly. Africa is well endowed with mineral resources and mining plays a crucial role in many African economies. Africa is experiencing some robust economic growth, and consequently, the continent's demand for water will increase to support water-intensive industrial and agricultural development. Mining by nature is inherently unsustainable in that the life of the mine is limited and will eventually come to a close; however, its sustainability can be ensured by the linkages (downstream, upstream and side stream) it forms with other sectors of the economy, including the water sector, and social and environmental aspects. Climate variability and increasing demand for water as a result of development and population pressure are factors that have increased water demand. The growing population increases the demand for water for domestic use, food security and industrial development. However, water storage and delivery infrastructure has remained in a poor state, being inadequate and in some cases being on a declining trend for many years. The mining and industrial sectors produce high concentrations of wastes and effluents that act as point and non-point sources of water quality degradation and acid mine drainage, and as such water treatment technologies are required. In some areas, due to variable and unreliable resources, conflicts have arisen over the resource. Inter- or intra-basin water transfers can also be potential sources of conflict if not well managed. Increase in the negative environmental impacts caused by mining activities, coupled with disruption of local social values, traditional norms and livelihoods have resulted in environmental and social requirements becoming major features of national mining legislation. Effective water management systems that embrace transparency and accountability need to be put in place, as well as development of human capital, the knowledge base, and participation by all stakeholders is important if Africa is to cope with the challenges and impacts of water in the mining sector.

1 INTRODUCTION

Water links Africa's economic fortunes and climate change challenges (BEERS, 2011). Water resources contribute enormously to economic productivity and social well being of the human populace as both social and economic activities rely heavily on the quantity and quality of water (WWAP, 2006). With the increasing growth in population and the subsequent socio-economic pursuits (including urbanization, industrial production, tourism and agricultural activities) demand for water has increased rapidly (WWAP, 2006).

Africa is well endowed with mineral resources: it harbours the world's largest mineral reserves of platinum, gold, diamonds, chromite, manganese, and vanadium (Table 1; ECA, 2009). Thus, mining plays a crucial role in many African economies, accounting for more than half of export earnings in seven - from 50% in Sierra Leone to 85% in Guinea (WORLD BANK, 2002). In some countries, such as Botswana, mining accounts for a third of GDP, and it also accounts for a significant percentage of GDP in South Africa and Namibia (ECA, 2004). Africa produces 77% of the world's platinum; 62% of aluminum silicate; more than 50% of vanadium and vermiculite; more than 40% of diamonds, palladium, and chromite; and more than 20% of gold, cobalt, uranium, manganese, and phosphate rock (BEERS, 2011) as well as about 17 per cent of the world's uranium (ECA, 2009). Africa is experiencing some robust economic growth, and consequently, the continent's demand for water will increase to support water-intensive industrial and agricultural development (BEERS, 2011).

Table 1 - Some leading African mineral resources, 2005

(continue)

MINERAL	AFRICAN Percent OF WORLD PRODUCTION	RANK	AFRICAN Percent OF WORLD RESERVES	RANK
Platinum Group Metals	54 Percent	1	60+ Percent	1
Phosphate	27 Percent	1	66 Percent	1
Gold	20 Percent	1	42 Percent	1
Chromium	40 Percent	1	44 Percent	1
Manganese	28 Percent	2	82 Percent	1

(continuation)

MINERAL	AFRICAN Percent OF WORLD PRODUCTION	RANK	AFRICAN Percent OF WORLD RESERVES	RANK
Vanadium	51 Percent	1	95 Percent	1
Cobalt	18 Percent	1	55+ Percent	1
Diamonds	78 Percent	1	88 Percent	1
Aluminium	1 Percent	7	15 Percent	1

Source: ECA (2009)

Water in the mining industry is used as follows:

- Mining **(**blasting, waste removal and ore extraction) - water is used in the pit to dampen dust created by mining activities to extract ores. It aids visibility and reduces risks to health;
- Processing (crushing) - water is not used here, but ore optimization – crushing the ore to the best size for extracting minerals, reduces the amount of water needed later;
- Scrubbing/washing - scrubbers 'wash' the crushed ore in preparation for filtering. Saltwater, or water recovered from the pit sump or other sources may be used;
- Screening - Crushed ore is washed and screened. Small pieces pass straight through, while larger pieces go through another round of crushing, scrubbing and filtering;
- Separation - the screened and washed material is separated out and water recovered from this process is either recycled or treated according to environmental standards and discharged back into natural water sources.

2 AFRICA'S FRESHWATER RESOURCES

Freshwater is a necessary input for industry and mining, hydropower generation, tourism, subsistence and commercial agriculture, fisheries and livestock production, and tourism. These activities are central to livelihoods and human well-being; they provide employment and contribute to national economies through, among other things, export earnings (PIETERSEN et al., 2006). Arid lands cover about 60% of Africa which, with 15% of the global population, has only 9% of global renewable water resources; in 2010, approximately 330 million people in sub-Saharan Africa lacked access to safe drinking water, and the impacts of climate change will compound this further (Table 2) (BEERS, 2011). Economic security and human well-being are dependent on the protection of this resource (PIETERSEN et al., 2006). Some river basin organizations harness water for irrigation, energy production, and water supplies for communities and mining operations. Some cooperate with other stakeholders to manage ports and improve navigation by incorporating such needs in dam designs (ECA 2004). This demands that water be managed as part of a healthy functional ecosystem, in order to ensure it continues to deliver essential environmental goods and services (PIETERSEN, et al., 2006), particularly since many of the countries that are water stressed or water scarce (Figure 1) such as Kenya and Tanzania, are also rapidly ramping up their mineral prospecting and production as well as having recently discovered potentially or commercial oil and gas prospects.

Table 2 - Renewable water resources in Africa

Sub-region	Population (million)	Area (1000 km²)	Average precipitation		Internal renewable resources	
			(mm/yr)	(km³/yr)	(km³/yr)	Percentage
Northern Africa	174	8259	195	1611	79	>1
Western Africa	224	6138	629	3860	1058	27
Central Africa	82	5366	1257	6746	1743	44
Eastern Africa	144	2758	696	1919	187	5
Southern Africa	150	6930	778	5395	537	14
Western Indian Ocean islands	19	594	1518	2821	345	9
Total	793	30045	744	22352	3949	

Source: AQUASTAT (2003)

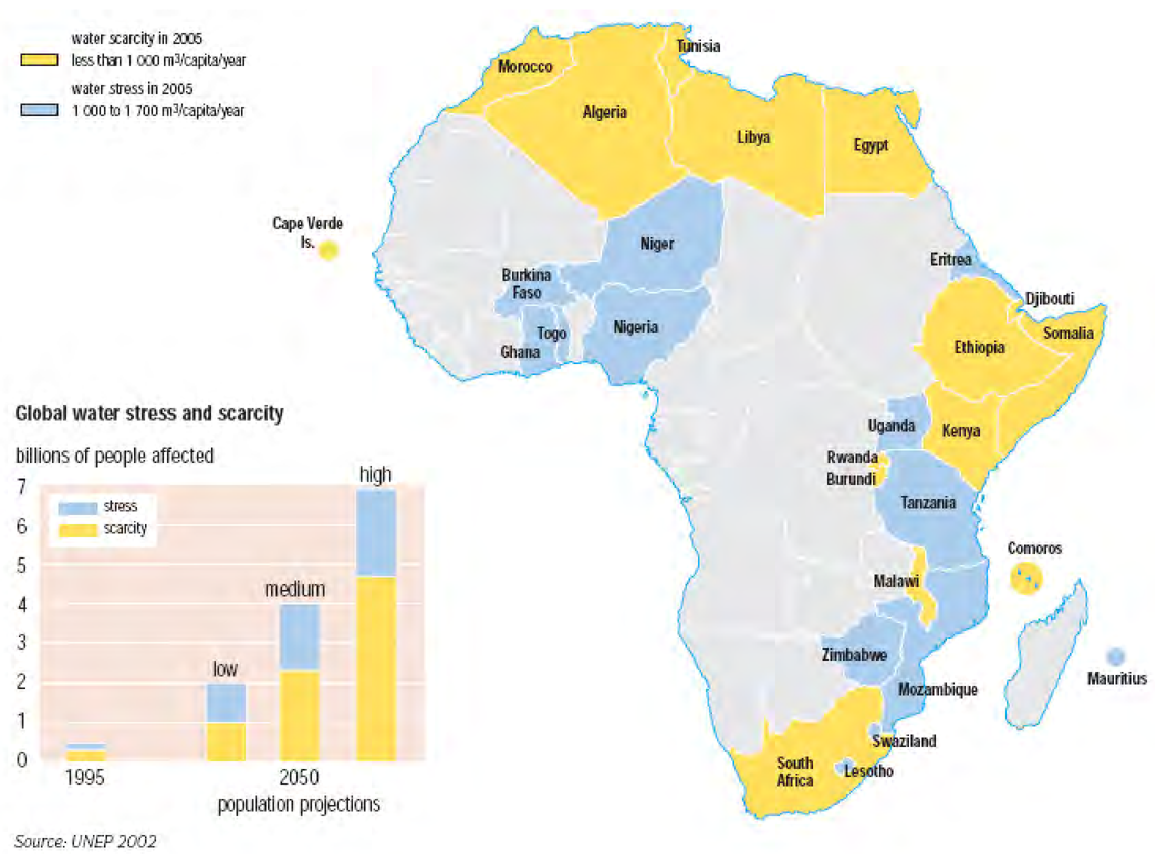


Figure 1 - Freshwater stress and scarcity by 2025 in Africa
Source: Pietersen et al. (2006)

3 THE FOUNDATION FOR SUSTAINABLE DEVELOPMENT AND MINING

Mining by nature is inherently unsustainable in that the life of the mine is limited and will eventually come to a close; however, its sustainability can be ensured by the linkages (downstream, upstream and side stream) it forms with other sectors of the economy (ECA, 2009), including the water sector, and social and environmental aspects (Figure 2).

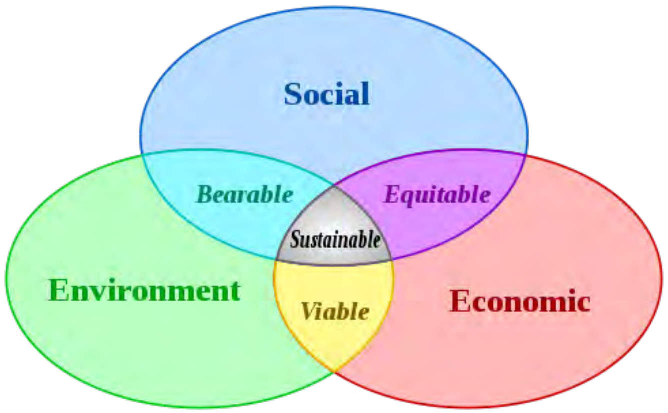


Figure 2 - Scheme of sustainable development at the confluence of three constituent parts
Source: Johann Dréo (2006 - Wikipedia)

The Johannesburg Declaration created "a collective responsibility to advance and strengthen the interdependent and mutually reinforcing pillars of sustainable development at local, national, regional and global levels" (WSSD, 2002). It also asserts that we should "Enhance the contribution of the industrial sector, in particular mining, minerals and metals, to the sustainable development of Africa by supporting the development of effective and transparent regulatory and management frameworks and value addition, broad-based participation, social and environmental responsibility and increased market access in order to create an attractive and conducive environment for investment" (WSSD, 2002).

There has been improved stability in the political and economic environment and this has led to increased investment in the African minerals sector, but very limited or no investment in the minerals linkage sectors (ECA, 2009). There is also an emergent realization that mining could be a key instrument in establishing infrastructure (transport, energy and water) for the development of other sectors, such as agriculture and forestry: this is embodied in the NEPAD Sustainable Development Programme (SDP) initiative and also in the Africa Mining Vision (AMV) (ECA, 2009). The vision advocates for "transparent, equitable and optimal exploitation of mineral resources to underpin broad-based sustainable growth and socio-economic development". The vision is therefore consistent with the principles of sustainable development, wealth creation and the integration of the mining sector into Africa's social and economic development process (ECA, 2009).

4 WATER DEMAND

Climate variability and increasing demand for water as a result of development and population pressure are factors that have increased water demand (WWAP, 2006). The growing population increases the demand for water for domestic use, food security and industrial development. In Kenya, for example, the population growth trend has resulted in reduction of per capita water availability (Figure 3).

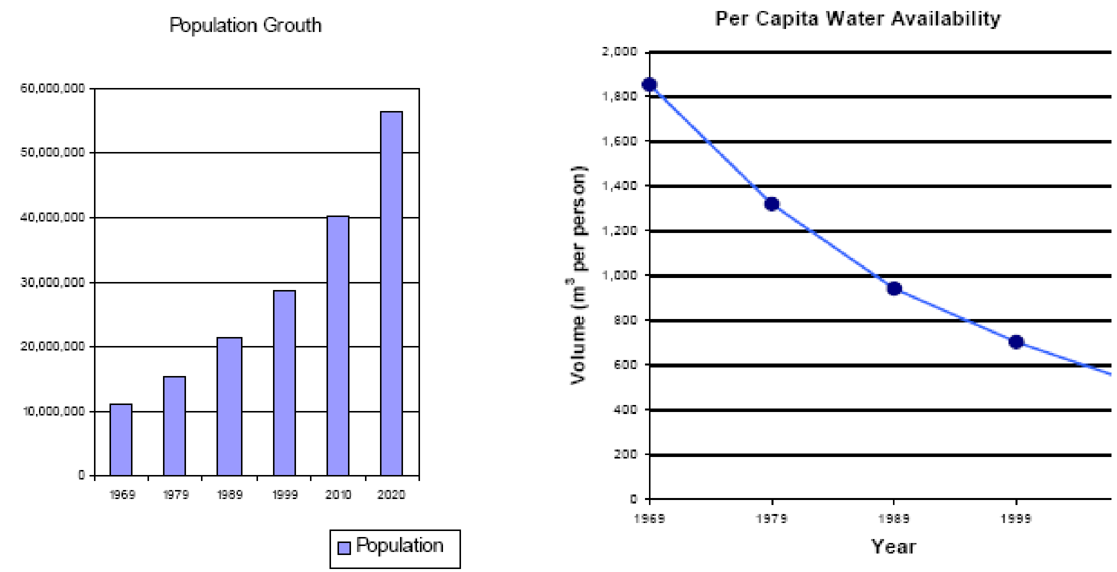


Figure 3 - Population growth and per capita water availability in Kenya
Source: WWAP 2006: sourced from: 1992 Water Master Plan Projections, and 1998 Aftercare Study, Ministry of Water and Irrigation, Kenya

Table 3 - Estimated water demand in Kenya

Category	Demand (1,000 m^3/day)	
	1995	2010
Residential urban	747.8	1,642.8
Residential rural	468.2	932.6
Sub-total	1,216.0	2,575.4
Non-residential, health facilities, schools, industry and commerce	593.9	986.3
Total	1,809.9	3,561.7
Livestock water	376.6	621.4
Irrigation	3.9M	8.1M
Grand Total	2,186.6	4,183.2

Source: WWAP (2006)

In Kenya, the estimated water demand shows that industry is lumped with other low users of water, as compared with water for irrigation and livestock (Table 3). The specific industries mentioned are: agro-based industries in rural areas including: coffee pulping and fermenting, sugar cane milling, sisal fibre processing, pulp and paper milling, tanneries, textile mills, canneries, vegetable oil extraction, food processing, and tea processing, and; urban-based industries which have significant reliance on water, such as tanneries, textile mills, breweries, creameries, paper recycling mills, chemical processing factories (paints, pharmaceuticals, plastics, soaps, detergents, glass, etc.), slaughterhouses, soft drink industries, engineering and metal fabrication, and various other small-scale industries. It also includes the agriculture and energy sector as significant water users, but does not directly mention the mining industry. This study, which was conducted in the 1990s, did not foresee the current rapid growth in the mining sector and hence its rapidly increasing demand for water (both Kenya and Mozambique have found rich deposits of titanium-containing sands in beach and inshore dunes), as well as the possibility then (and now fact) of having potentially viable commercial deposits of oil and gas which would require a higher use of water from industry than was projected.

5 WATER STORAGE AND DELIVERY INFRASTRUCTURE

In Kenya, there are presently 26 large dams and about 3,000 small dams and water pans with a storage capacity of approximately 124 million cubic meters (Figure 4) (WWAP, 2006). The storage capacity has been low due to the fact that investment levels in water management infrastructure have been inadequate and have been on a declining trend for many years.

In South Africa, since access to modern water delivery infrastructure is divided among racial lines, the failure of the government to provide quality water to all could further contribute to the high-level of violent crime and continued racial tension within the country (ADLER et al., 2007).

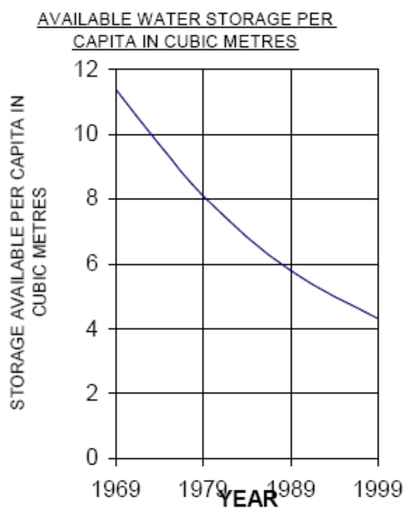


Figure 4 - Available water storage per capita between 1969 and 1999. There is a steady drop indicating lack of construction of new storage facilities to match the population increases
Source: WWAP (2006)

6 WATER QUALITY AND POLLUTION

Mining affects the environment in many ways (Table 4). The potential impacts of mining on the water environment are subdivided into those associated with phases of mining operations, namely (OELOFSE, 2008):

- The act of mining itself;
- Seepage of contaminated water from mine residue deposits (waste rock dumps and tailings dams) resulting from mineral processing/beneficiation;
- dewatering of active mining operations; and
- rewatering (flooding) of defunct/closed mine voids and discharge of untreated mine water.

Not only is the quantity of freshwater fundamental for the development of all sub-regions, but the quality of the resource is equally important (PIETERSEN et al., 2006). Deterioration of the quality of water resources resulting from further increases in salinity and nutrient loads from irrigation (irrigated agriculture) and the domestic, industrial and mining sectors will significantly deplete available resources and increase water scarcity (PIETERSEN et al., 2006). The mining and industrial sectors, in particular, produce high concentrations of wastes and effluents that act as nonpoint sources of water quality degradation and acid mine drainage.

Table 4 - Mining impacts on environment

(continue)

ENVIRONMENTAL IMPACTS	POLLUTION IMPACTS
Destruction of natural habitat at mining and waste disposal sites	Drainage from sites (acid mine drainage and mine water)
Destruction of adjacent habitats as a result of emissions and discharges	Sediment runoff from mining sites
Destruction of adjacent habitats arising from influx of settlers	Pollution from mining operations in riverbeds (dredging)
Changes in river regime and ecology due to siltation and flow modification	Effluent from mineral processing operations
Alteration in water tables	Sewage effluent from the site
Change in landform	Oil and fuel spills
Land degradation due to inadequate rehabilitation after closure	Soil contamination from treatment residues and spillage of chemicals

(continuation)

ENVIRONMENTAL IMPACTS	POLLUTION IMPACTS
Land instability	Leaching of pollutants from tailings and disposal areas and contaminated soils
Danger from failure of structures and dams	Noxious emissions from minerals processing operations
Abandoned equipment, plants and buildings	Dust emissions from sites close to habitats
Water table depression as a result of pumping water through shafts.	Release of methane from mines
Waste dumps have potential for generation of acidic leachate with elevated metals concentrations	Destruction of potable water sources and/or river sources
Final mine voids have potential for migration of saline and/or acidic water from final pit lakes	Pollution of groundwater and surface water by mineral processing effluent and raw sewage
Tailing storage facilities have potential for seepage of tailings liquors with elevated cyanide and other process chemicals	Heavy metal and hydrocarbon pollution
Old mine workings and tailings pile can have leachates generated by the oxidation of sulphides	Artisanal workings are potential sources of low pH high iron and high mercury seepage
Receding of lake levels (WWAP, 2006)	Sulphate, in many arid environments, can become the dominant contributor to salinity in the vicinity of the discharge (BOWELL, 2000)
Corrosive effect of high sulphate waters, particularly towards concretes (BOWELL, 2000)	

Source: partly modified from SID (2009)

6.1 CASE STUDY 1: GHANA

A study was carried out in an area in western Ghana that has a long history of mining activity (Figure 5) (ASKLUND; ELDVALL, 2005) where there were fears that the mining activity was acidifying the groundwater and causing serious metal pollution to the water resources by for example arsenic, lead, cadmium, mercury and cyanide.

Pollutant sources from large scale gold mines were identified as follows (ASKLUND; ELDVALL, 2005):

- AMD (Acid Mine Drainage) from solid waste from sulphidic ore leaching heavy metal and acidity into water and soil;

- Grease and oils from various activities in the mine. Roasting of ore containing pyrite gives a rise to the production of SO_2 in the atmosphere which produces acid rain. The acid water then releases high levels of toxic ions from the rock matrix in the groundwater;
- Impact due to processing technique includes contamination of water bodies and soil by release of cyanide (see below), arsenic, sulphates, and heavy metals as Pb, Cu, Zn and Fe;
- Cyanide spillage. There have been a number of accidental cyanide spillages in Ghana. The major spillages occurred in 1989, 1991, 1994, 1996, 1999 and 2001.

Pollutants from small scale gold mining were identified as follows (ASKLUND; ELDVALL, 2005):

- Pollution of rivers and streams by mercury;
- Mercury in groundwater from accidental spillage during gold processing (AKOSA et al., 2002);
- AMD from solid waste from sulphidic ore leaching heavy metal and acidity into water and soil (AKOSA et al., 2002);
- Siltation of surface waters (AKOSA et al., 2002);
- Estimated 5 tonnes mercury is released from small-scale mining operations in Ghana each year (HILSON, 2001). High concentrations of mercury have been found in sediments and fish in the vicinity of small-scale mining activities using amalgamation as their main technique.

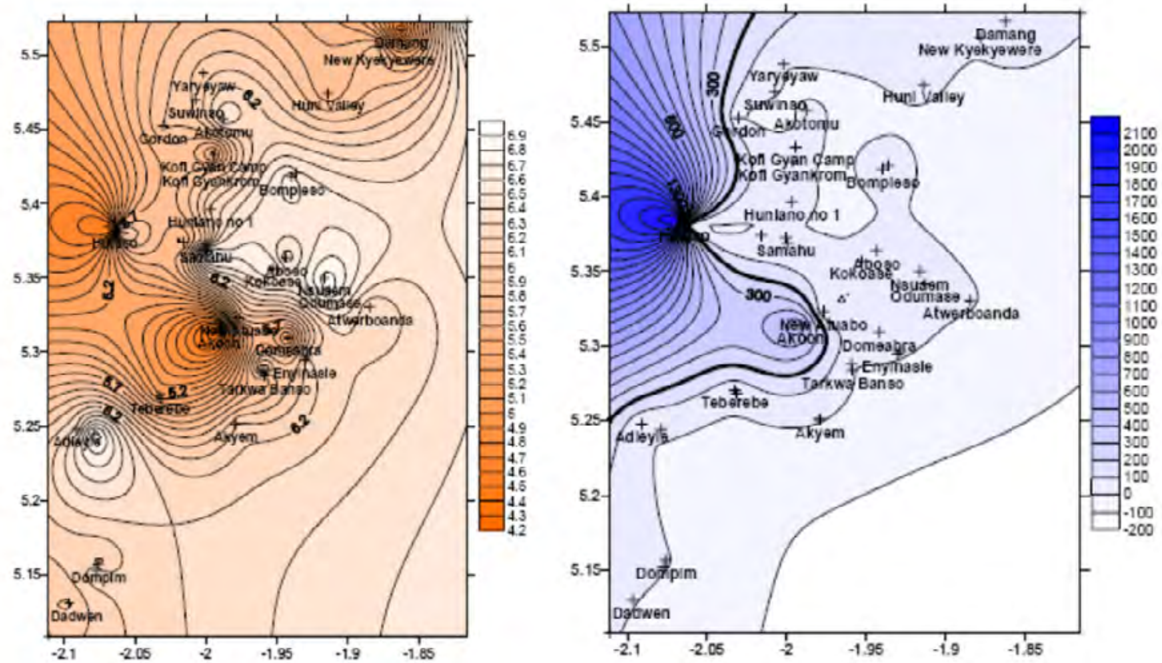


Figure 5 - pH (left panel) and concentration of As(tot) (µg/l) (right panel). Bold line indicates WHO's guideline
Source: Asklund and Eldvall (2005)

6.2 CASE STUDY 2: TANZANIA

In Tanzania, the large scale mining camps are often plagued by poor sanitation, lack of clear and safe drinking water, high congestion, and poor hygiene (SID, 2009). Mining companies have been accused of polluting the environment in the localities where they conduct their operations and thus endangering the lives of the local people, such as at the Barrick mining site in North Mara where the tailings dam runs freely into the pastures and fields used by the local population and the heavily contaminated waters from the processing plant, leaking into their water sources, adversely affect them and their livestock (SID, 2009). Independent experts have confirmed the presence of high levels of toxic chemicals in the area surrounding Barrick Gold Corporation's North Mara gold mine in Tarime district, Mara region, where levels of nickel have risen 260 times, levels of lead are up 168 times and chromium levels have also multiplied by 14 compared to the last time tests were conducted in the area about seven years ago (SID, 2009). Panning and sluicing requires a lot of water, which is drawn from existing rivers that are also sources of water for domestic use in the mining centre.

An example of small scale mining pollution in Tanzania is the Rwamagasa village, a typical small-scale mining village with approx 27,000 inhabitants, where artisanal and small-scale miners use mercury to extract gold from the ore (SID, 2009). The extraction of the gold with mercury releases large amounts of toxic liquid mercury fumes into the local environment. There is no clean and safe drinking water, no waste disposal for the toxic mercury or any other waste or human discharge. Hygienic standards are extremely low and are the cause of many infectious diseases such as diarrhoea, typhoid and parasitism (SID, 2009). Miners working for many years in the amalgamation or smelting process showed severe symptoms of mercury intoxication, and the exposure of the whole community to mercury is reflected in raised mercury levels in the urine, and early symptoms of brain damage like ataxia, tremor and movement disorders (SID, 2009).

6.3 CASE STUDY 3: SOUTH AFRICA

South Africa is the third-biggest coal producer in the world. More than a century of open-cast and underground mining has impacted on the surrounding environment in the Highveld in Mpumalanga, in which up to 90% of the country's saleable coal is mined (HOLTZHAUSEN, 2007). Collieries exploiting the Northern Witbank Coalfields have to continuously pump out this water to reach the coal seams. According to South African environmental law, this water has to be suitable for release back into the environment, and may need to be managed and treated before being released so as to reduce pollution of the country's scarce water resources (HOLTZHAUSEN, 2007). This has become even more important in the Upper Olifants catchment, where many of these mines are situated, as the area suffers from a chronic shortage of water.

The majority of the coal mines in the Olifants river basin occur in the Witbank area, at the head of the Olifants River (ASTON, 2000). Over the years, runoff from these mines has had adverse affects on the quality of the surface water though it has become more and more controlled: now the water pumped from the mines must be treated before it may be put into the river system and there is a pilot project underway that is using this mine water (with neutralised pH) as irrigation water (ASTON, 2000). When the mines are operational, there is only movement of water from the ground into the mines because the mines are being constantly pumped to keep them dry, so an operational mine's water does not go directly into the surrounding groundwater. However, as mines close and pumping stops they become filled with highly acidic mineralised water which can have a direct affect on the regional groundwater quality when there is an aquifer adjacent to a mine (ASTON, 2000). The closed mines eventually have a large quantity of stored water that could potentially be an attribute to the local irrigation efforts. Obviously, treatment is required to some degree, but the chances are that less treatment would be required if the water were to be used for certain irrigation rather than allowed to overflow from the mines into the natural water system (ASTON, 2000).

7 EXAMPLES OF WATER TREATMENT

The Emalahleni Water Reclamation Project in South Africa will see, for the first time, the abstraction and treatment of mine-water from existing and old mines to a level that is fit for use by the local municipality (HOLTZHAUSEN, 2007). Most mines in this catchment area have a water quality associated with calcium-magnesium-sulphate. This makes the water more treatable than other mine-water high in sodium chloride (a typically characteristic of AMD from gold mines, for example), as more treatment processes can be used to desalinate the waters. The acidic water will firstly undergo a neutralisation process using CSIR's lime/limestone treatment process (Figures 6 and 7). This increases the pH allowing metals such as iron, aluminium and manganese to precipitate out. Following clarification, the water will be treated using ultrafiltration (UF) to remove any remaining metals. This process will also remove any bacteria that might be in the water. This will be followed by reverse osmosis using spiral membranes to remove remaining salinity. The membrane treatment process is repeated three times to ensure maximum yield and maximum brine concentration. Two identical process trains are being established, each capable of producing a minimum of 14 Mℓ/day. The acidic water will firstly undergo a neutralisation process using CSIR's lime/limestone treatment process. This increases the pH allowing metals such as iron, aluminium and manganese to precipitate out. Results from the demonstration plant indicated that the pH levels of the water was boosted from 2,9 to between 6,5 and 7,5. The total dissolved solids count was reduced from as high as 4 500 mg/ℓ to 135 mg/ℓ while the sulphate content was reduced from 3 500 mg/ℓ to 80 mg/ℓ. The treated water is within the SABS 241 Class 0 drinking water quality limit.

Figure 6 - Flows of 120 m_3/day were achieved at the demonstration plant

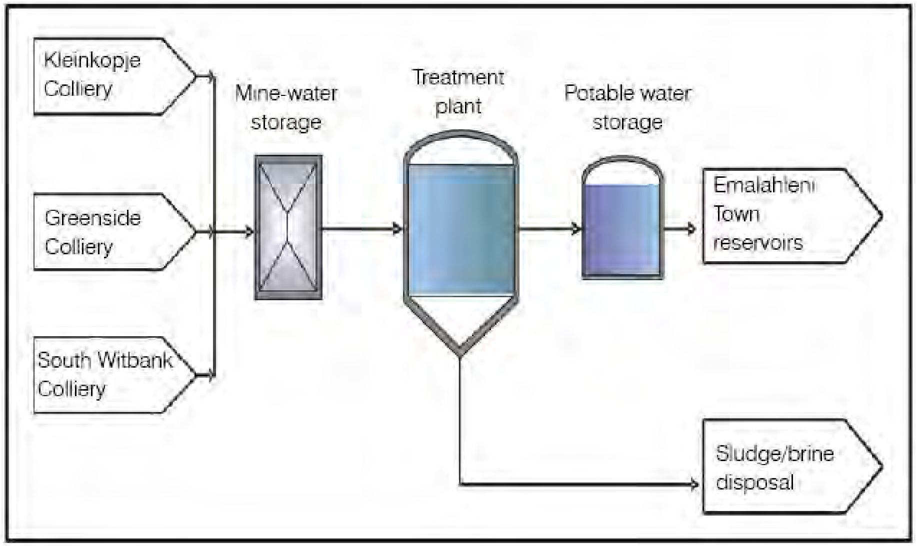


Figure 7 - Main components of the Emalahleni Mine-water Reclamation Project

8 WATER CONFLICTS

Limited water resources have been a source of international conflict for centuries, often as part of wider religious, ideological, political, or economic challenges. The first recorded accounts of such disputes can be traced to Sumeria around 3000 BC, although water resources continue to underlie disputes (ADLER et al., 2007). Due to the continent's geography and climate, as well as its severe poverty, Africa's variable and unreliable resources have contributed to numerous conflicts, predominantly water, agriculture, and livestock.

In some areas of Kenya, a stage has reached where availability of water is the limiting factor for any development activities: in such areas conflicts have risen amongst the various competing sectors and users of water (WWAP, 2006). This is further compounded by the fact that prior to 2002 water resource management responsibilities were fragmented amongst several agencies, further resulting into a multiplicity of institutions all claiming responsibility of management of the same resource, a situation which was a major impediment to integrated water resources management. Therefore, effective implementation and coordination mechanisms were not clearly defined (WWAP, 2006). In South Africa, Aston (2000) states that if a significant portion of the population remains without access to potable water and the mining industry continues to visibly pollute and modify the water table without consequence, the government risks losing its legitimacy, with potential knock-on effects such as loss of foreign direct investment in South African industries to social unrest, or even civil war.

It is clear that water resources (both surface and groundwater) are unevenly distributed spatially in some countries such as Kenya (WWAP, 2006). Increasing human activities especially in urban areas has led to a situation whereby the demand for water is being met from water abstracted from a different catchment or drainage basin (WWAP, 2006). Thus, inter- or intra-basin water transfers can also be potential sources of conflict if not well managed.

9 NEGATIVE EXTERNALITIES TO THE MINING INDUSTRY

The negative externalities associated with mining activities, including but not limited to contamination of ground and surface water and the subsequent damage to human and environmental health and ground stability, as well as socioeconomic, political, and financial effects (ADLER, et al. 2007). Inadequate water resources management imposes a huge cost on national economy: the economic costs of poor preparedness to climate variability entails disruption in water supply, energy production and industrial output, agricultural and livestock output (WWAP, 2006).

From an economic viewpoint, the reforms of the 1980s and 90s have opened up many African countries to private mining investment, yet this shift has not always been beneficial as governments are forced to make major concessions to attract mining capital into their economies due to strong global competition for such capital (ECA, 2009). Taxation of the minerals industry remains an issue between governments and mining companies due to the perceived conflict between what constitutes just compensation for the risks mining companies take and equitable resource rents accruing to the owners of mineral wealth. There is a trend, though it lacks unanimity, towards sharing tax revenues between central, regional and local governments with local communities receiving a proportion of mining taxes (ECA, 2009).

10 ENVIRONMENTAL STEWARDSHIP

Increase in the negative environmental impacts caused by mining activities, coupled with disruption of local social values, traditional norms and livelihoods have resulted in environmental and social requirements becoming major features of national mining legislation (ECA, 2009). Such requirements include environmental and social impact assessments (ESIA) prior to the granting of mineral licences and environmental and social funds. The increased use of ESIAs has partly benefited from companies subscribing to international standards, such as the UN Global Compact, the Global Reporting Initiative, the IFC Performance Standards, the Equator Principles, and the Universal Declaration of Human Rights and associated agreements, and the OECD Guidelines for Multinational Enterprises (ECA, 2009). This has had the effect of improving corporate social responsibility, with mining companies taking the view that corporate social responsibility (CSR) is part of doing good business. Also, communities around mining areas have a newly found sense of entitlement and increasingly demand economic benefits, a healthy environment and respect for human rights around resource extraction areas. A negative environmental trend, however, is the increase in energy consumption, due to the minerals boom. This has caused greater reliance on fossil fuels (hydrocarbons and coal) with concomitant deleterious environmental impacts (ECA, 2009).

Water is often a major, if not the major, issue facing a mine or milling operation (BOWELL, 2000). It is, therefore, important to seek for alternative water sources. For example, rainwater harvesting systems can be installed to capture run-off from paved surfaces in nearby towns and collected in dams for use in the mining process. Sewage effluent from towns can be recycled and used in mineral processing plants. Rain and groundwater that collects in mine pits can be pumped out for use at the processing stage.

11 GOVERNANCE AND MANAGEMENT

As earlier mentioned, many African countries have undertaken recent reforms in the water sector with a view to streamlining water management, enhancing its availability and quality, as well as protecting the resource. The expected outcomes of the reform process in Kenya are shown in Figure 8 below.

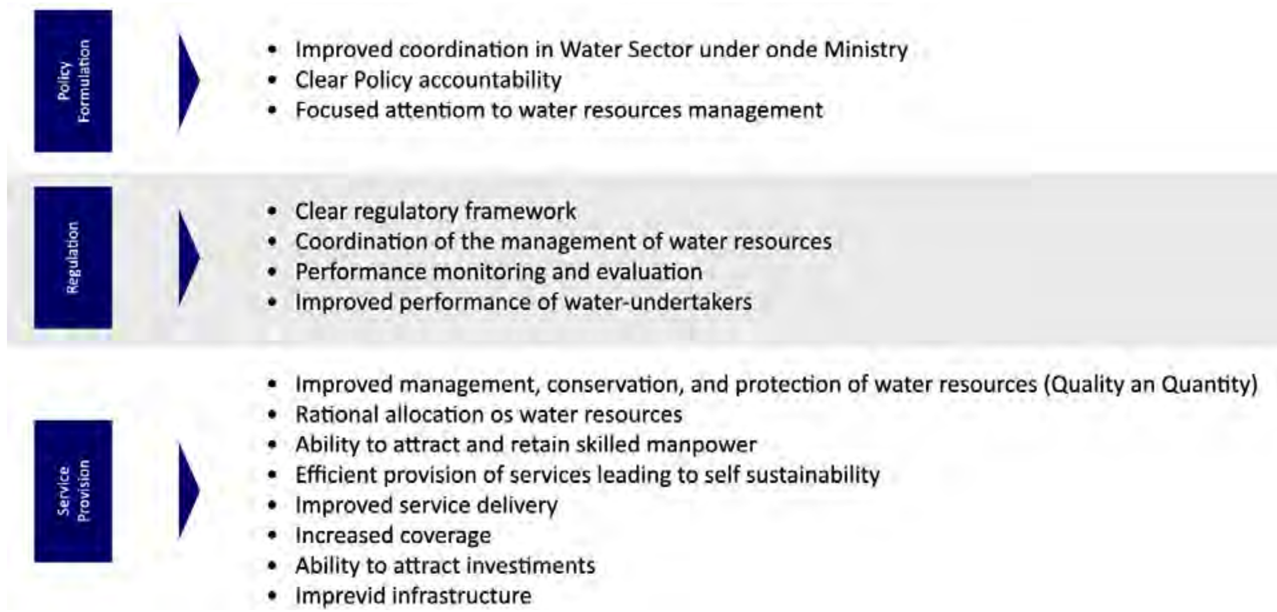


Figure 8 - Expected outcomes under the Kenya Water Act 2002
Source: WWAP (2006)

Water conservation and demand management techniques in all their forms involve (WWAP, 2006):

- Unaccounted-for water within water distribution systems;
- Efficient irrigation methods;
- Rain water harvesting including roof catchment for domestic purposes;
- Delineating and zoning areas for water conservation;
- Water shed management (protection against catchment deforestation and degradation).

Threats to good management and regional cooperation include climate variability (with droughts over the past 30 years) because it results in a decrease in water availability and an increase in competition over water, political instability, and low priority given to water and sanitation in terms of investment in infrastructure and maintenance (PIETERSEN et al., 2006). The high rates of population growth and subsequent increased demand from the agricultural and domestic sectors for freshwater resources, have increased the pressure on the resources, even in areas like Central Africa with its relative abundance of water resources. Water-sector reforms have been constrained by various factors, including internal resistance from executives of institutions, the lack of political will, frequent changes in government, and dependence on development partners to find the resources for the reforms (PIETERSEN et al., 2006). Other common obstacles for effective water resource management are the fragmentation of water management administration among various institutions, the absence of mechanisms for coordination, inadequate institutional capacity and resources, and the lack of an integrated approach towards water management (PIETERSEN et al., 2006). In order to reverse this trend of water resources depletion under erratic climatic variations, there is need to put in place (WWAP, 2006):

- Effective management of water catchment areas;
- Construction of dams and pans to increase our water storage capacities;
- Curb water pollution by ensuring adherence to all waste water standards before disposal into our water bodies;
- Rational apportionment of our water resources thereby avoiding water use conflicts.

Transparency and accountability is also important: contracts between governments and mining companies are often performed in secrecy, with confidentiality clauses that prevent the public (the owners of mineral wealth) from knowing exactly what revenues are given to the State and what rights and privileges have been awarded to the mining companies (ECA, 2009). To increase transparency and accountability, there has been a trend towards increased membership of the Extractive Industries Transparency Initiative (EITI) and the emergence of EITI++ and KPCS (Kimberly Process Certification Scheme). There has also been an increase in the participation of civil society organizations, non-governmental organizations (NGOs), and communities in initiatives such as Revenue Watch and PYP (ECA, 2009). There has also been a trend towards improved multi-stakeholder interactions with greater community participation in benefit sharing, consultations moving from a paternalistic to a partnership approach, and increased multi-stakeholder involvement in the development of mineral policy and legislation (ECA, 2009). African participation in ownership of mineral assets has increased (usually as part of the so-called Black Economic Empowerment (BEE)), as has gender awareness and female involvement in mining and mine ownership.

Artisanal and small-scale mining (ASM) is usually a labour-intensive sector and hence presents a greater opportunity for job creation than do large-scale operations, especially in rural areas. There is the realization that strategies for artisanal and small-scale mining need to be rooted into broader rural development plans and that there is need to provide greater support to address a range of shortcomings including technology, marketing, and skill deficiencies, as well as to address the poor environmental and health practices and use of child labour that are characteristic of ASM (ECA, 2009).

12 CONCLUSIONS

One of the biggest challenges, that must be addressed if the targets of the Africa Water Vision and the MDGs are to be met, is the lack of adequate human (technical and managerial), financial and material resources water authorities face, in particular as this relates to planning and implementing water and sanitation policies and programmes (PIETERSEN et al., 2006). There is generally a lack of know-how and institutional "strength", particularly in the area of IWRM, and this has limited the success of water resource management initiatives (PIETERSEN et al., 2006). Africa is also faced with the problem of retaining trained and highly skilled personnel, as many leave to work in countries where financial rewards and research opportunities are offered (PIETERSEN et al., 2006).

Research is also essential if African countries wish achieve their long-term development targets, investigating issues such as: the application of appropriate and modern technology in WRM, and effective and efficient methods of catchment protection, pollution control, conservation and water use efficiency.

Long-sighted businesses in Africa are already engaging with the challenges posed by water scarcity and stress (BEERS, 2011). In addition to securing water required for operations, businesses will increasingly need to engage on broader water challenges to maintain a social licence to operate, and support the generation and growth of dynamic markets (BEERS, 2011).

SUMMARY

REFERENCES

Bowell, R.J. (2000) Sulphate and salt minerals: the problem of treating mine waste. Mining Environmental Management, pp11-13.

De Beers (2011) Water. Diamond Dialogues – De Beers Issue Brief No.1, December 2011. De Beers family of companies.

ECA - Economic Commission for Africa *(2004)* Assessing Regional Integration in Africa. ECA Policy Research Report. Addis Ababa, Ethiopia. ISBN 92-1-125090-0. *www.uneca.org/aria1/.*

ECA - Economic Commission for Africa (2009) Africa Review Report on Mining (Summary). Committee on Food Security and Sustainable Development (CFSSD-6)/Regional Implementation Meeting (RIM) for CSD-18, Sixth Session, Addis Ababa, Ethiopia 27-30 October 2009. E/ECA/CFSSD/6/7, 29 September 2009.

George M. Ochieng, Ephrahim S. Seanego and Onyeka I. Nkwonta (2010) Impacts of mining on water resources in South Africa: A review. Scientific Research and Essays Vol. 5(22), pp. 3351-3357, 18 November, 2010. Available online at http://www.academicjournals.org/SRE ISSN 1992-2248 ©2010 Academic Journals.

Holtzhausen, Lani (2006) From toxic to tap – Mine Water becomes a Commodity. The Water Wheel, May/June 2006.

John J. Aston (2000) Conceptual Overview of the Olifants River Basin's Groundwater, South Africa. An Occasional Paper for the International Water Management Institute (IWMI) in conjunction with the African Water Issues Research Unit (AWIRU). African Water Issues Research Unit (AWIRU), University of Pretoria, South Africa. http://intranet.iwmi.org/library/.

Kevin Pietersen, Hans Beekman, Allali Abdelkader, Hesham Ghany, Alfred Opere, Eric Odada, Tenalem Ayenew, Dagnachew Legesse, Luc Sigha-Nkamdjou, Lekan Oyebande, Ahmed Abdelrehim (2006) Africa Environment Outlook – 2: Chapter 4 – Freshwater. Division of Early Warning and Assessment (DEWA), United Nations Environment Programme. ISBN: 92-807-2691-9.

Lange Siri (2006) Benefi t Streams from Mining in Tanzania: Case Studies from Geita and Mererani. Bergen, Chr. Michelsen Institute R 2006: 11. Obura et al.

Ochieng, G.M., Seanago, E.S. and Nkwonta, O.I. (2010) Impacts of mining on water resources in South Africa: A review. Scientific Research and Essays, 5(22): 3351-3357.

Ragnar Asklund and Björn Eldvall (2005) Contamination of water resources in Tarkwa mining area of Ghana. Department of Engineering Geology, Lund University, Lund 2005. Printed by KFS AB, Lund 2005, Sweden. ISRN LUTVDG/TVTG--5092—SE.

Rebecca A. Adler, Marius Claassen, Linda Godfrey, and Anthony R. Turton (2007) Water, mining, and waste: an historical and economic perspective on conflict management in South Africa. The Economics of Peace and Security Journal, 2 (2) p. 33-41. ISSN 1749-852X

Ripley, E.A. et al. (1996), Environmental Effects of Mining. Delray Beach, Florida: St. Lucie Press.

Society for International Development (2009) The Extractive Resource Industry in Tanzania: Status and Challenges of the Mining Sector. Society for International Development, Regional Office for Eastern Africa, Nairobi, Kenya.

Suzan Oelofse (2008) Emerging Issues Paper: Mine Water Pollution. Department of Environmental Affairs and Tourism, Republic of South Africa.

World Bank 2002. World Development Report 2002. Washington, D.C.

World Water Assessment Programme (2006) Kenya Water Report 2005. Water for Wealth Creation and a Healthy Environment for a Working Nation. Prepared for the 2nd UN World Water Development Report 'Water: A shared responsibility'(2006), UN WATER/WWAP/2006/12

SUMMARY

MINING INDUSTRY IMPACTS ON SURFACE WATER QUALITY IN SOUTH PART OF ARMENIA

Nalbandyan M. A.[1]

[1] The Institute of Geological Sciences, National Academy of Sciences of RA.
Baghramyan ave., 24a, 0019, Yerevan, Armenia. E-mail: marinen3@yahoo.com.

ABSTRACT

Water links Africa's economic fortunes and climate change challenges, and contributes enormously to economic productivity and social well being of the human populace as both social and economic activities rely heavily on the quantity and quality of water. With the increasing growth in population and the subsequent socio-economic pursuits (including urbanization, industrial production, tourism and agricultural activities) demand for water has increased rapidly. Africa is well endowed with mineral resources and mining plays a crucial role in many African economies. Africa is experiencing some robust economic growth, and consequently, the continent's demand for water will increase to support water-intensive industrial and agricultural development. Mining by nature is inherently unsustainable in that the life of the mine is limited and will eventually come to a close; however, its sustainability can be ensured by the linkages (downstream, upstream and side stream) it forms with other sectors of the economy, including the water sector, and social and environmental aspects. Climate variability and increasing demand for water as a result of development and population pressure are factors that have increased water demand. The growing population increases the demand for water for domestic use, food security and industrial development. However, water storage and delivery infrastructure has remained in a poor state, being inadequate and in some cases being on a declining trend for many years. The mining and industrial sectors produce high concentrations of wastes and effluents that act as point and non-point sources of water quality degradation and acid mine drainage, and as such water treatment technologies are required. In some areas, due to variable and unreliable resources, conflicts have arisen over the resource. Inter- or intra-basin water transfers can also be potential sources of conflict if not well managed. Increase in the negative environmental impacts caused by mining activities, coupled with disruption of local social values, traditional norms and livelihoods have resulted in environmental and social requirements becoming major features of national mining legislation. Effective water management systems that embrace transparency and accountability need to be put in place, as well as development of human capital, the knowledge base, and participation by all stakeholders is important if Africa is to cope with the challenges and impacts of water in the mining sector.

1 INTRODUCTION

It is recognized that the mining industry is an important risk factor of environmental pollution, particularly this regards to water resources. Armenia is not an exception in this regard. The main mining centers in Armenia are concentrated in the north and south. The southern Armenia presents particular point due to a whole complex of mining industry in Kapan, Kajaran, Meghri, Agarak, etc.

In this paper we demonstrate the level of pollution of the River Voghchi and its tributaries under impact of Zangezur copper-molybdenum plant (near the town Kajaran) and Kapan mining and dressing group of plants (near the town Kapan), situated in the river watershed.

The River Voghchi forms on eastern slopes of the Zangezur range and falls into the River Araks. The river length is 85 km. The mean annual water discharge makes 10.4 m^3/sec. The river plays an essential role in water economy. The Voghchi is fed predominantly through melted snow and rain.

The River Voghchi and surface waters in watershed undergo great pressure from untreated industrial wastewaters. Runoffs from tailing storage sites which carry a great amount of toxic substances present special threat.

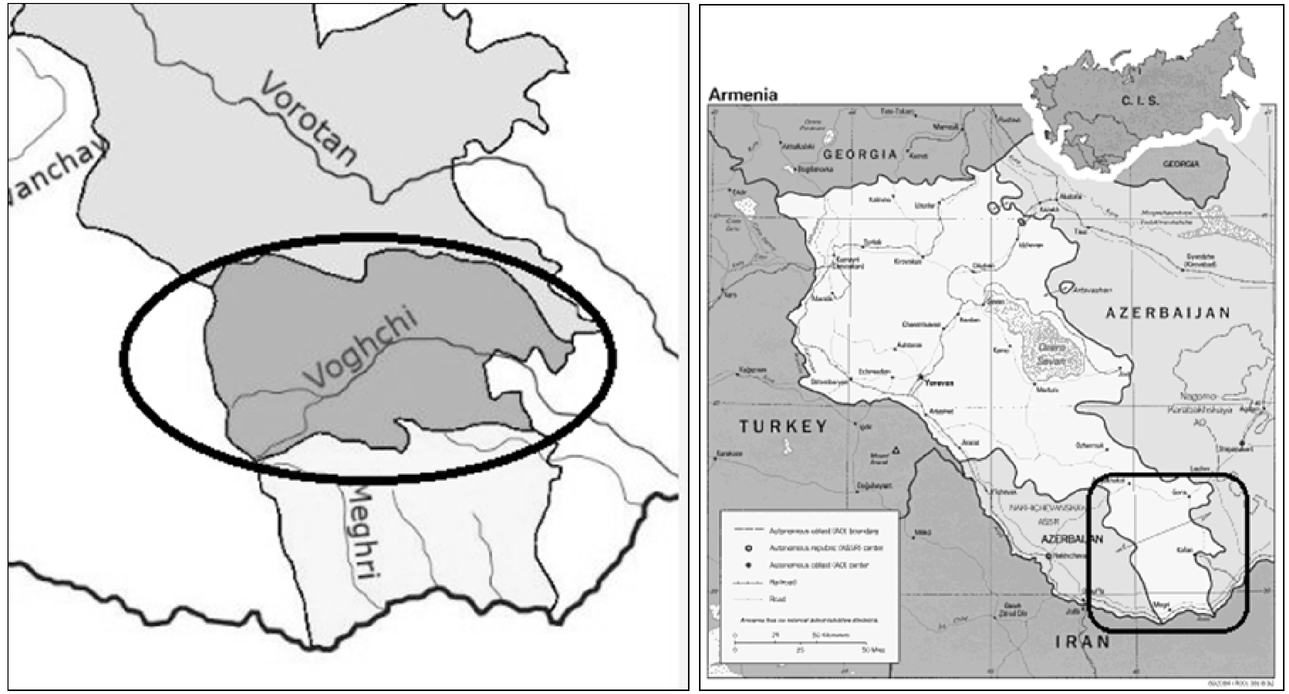


Figure 1 - Maps of region and south part of Armenia with Voghchi river basin

2 MATERIALS AND METHODS

The performed river water research was underpinned by monthly monitoring data of common ions (Ca, Mg, Na, Cl, K, SO_4, HCO_3) and heavy metals (HMs) (Cu, Mo, Cr, Ni, Mn, Zn, Co, Cd, Pb, Ag, Hg, As) in waters of the River Voghchi and its tributaries for 2003-2011.

Samples were collected, conserved, transported and stored following Standard Operational Procedures (SOPs) developed based on the methods of International Standardization Organization (ISO) (MANUAL FOR SAMPLING METHODS, 1998).

Water discharge was measured on a USGS-type AA Current Meter using a Data Storage Computer of AquaCala 500 model (Rickly Hydrological Co).

Table 1 - Applied analytical methods and detection limits (DL) for waters

Variable	Extraction	Methods	Detection limit and unit
Mo	Dissolved	Atomic absorption	0,5 µg/L
Hg	Dissolved	Atomic absorption	0,6 µg/L
Ag	Dissolved	Atomic absorption	0,1 µg/L
Co	Dissolved	Atomic absorption	0,7 µg/L
Cr	Dissolved	Atomic absorption	0,06 µg/L
Ni	Dissolved	Atomic absorption	0,3 µg/L
Cu	Dissolved	Atomic absorption	0,5 µg/L
Cd	Dissolved	Atomic absorption	0,02 µg/L
Pb	Dissolved	Atomic absorption	0,3 µg/L
As	Dissolved	Atomic absorption	0,7 µg/L
Mn	Dissolved	Flame photometry	0,5 µg/L
Zn	Dissolved	Flame photometry	1,6 µg/L

Samples for determination of mercury were collected into a glass container, acidified by HNO_3 until reaching pH<2, and then $K_2 Cr_2 O_7$ was added. While determining concentrations of the rest HMs, the samples were filtered through membrane filters with a pore diameter 0,45 µm, then acidified by HNO_3 (1:1) until reaching pH~2 and stored in polyethylene containers. HMs were determined on a PE Aanalist 800 through the atomic-absorption method with graphite atomizer, and flame photometry. Analyte concentrations were measured following the developed ISO-based SOPs (FOMIN, 2000). HMs pollution lever was assessed by MPC (MAXIMAL PERMISSIBLE CONCENTRATION, 2003).

Statistical data treatment was performed based on non-parametric Spearman correlation, statistical program Statistica 6.0.

To assess the degree of impact of mining industry on the quality of surface waters in the region a comparative analysis of the level of contamination over three periods was conducted. The periods include: 1. 2003-2008, the time of unstable economy; 2. 2009-2011, the period of stabilizing and increasing volumes of production of the mining industry.

3 RESULTS AND DISCUSSION

3.1. STUDYING COMMON IONS CONTENTS IN RIVER WATER

Figure 2 shows the content of sulphates, chloride and hydrocarbonates in the waters of the river system over the period 2005-2007. According the results the concentrations are within the normal range except for the one of tributaries where some excess of sulphates in water is observed. Potassium , sodium, calcium are also within accepted limits of the norm.

The content of magnesium for this period significantly exceeds the maximum threshold values just in some tributaries (SAGHATELYAN et al., 2007).

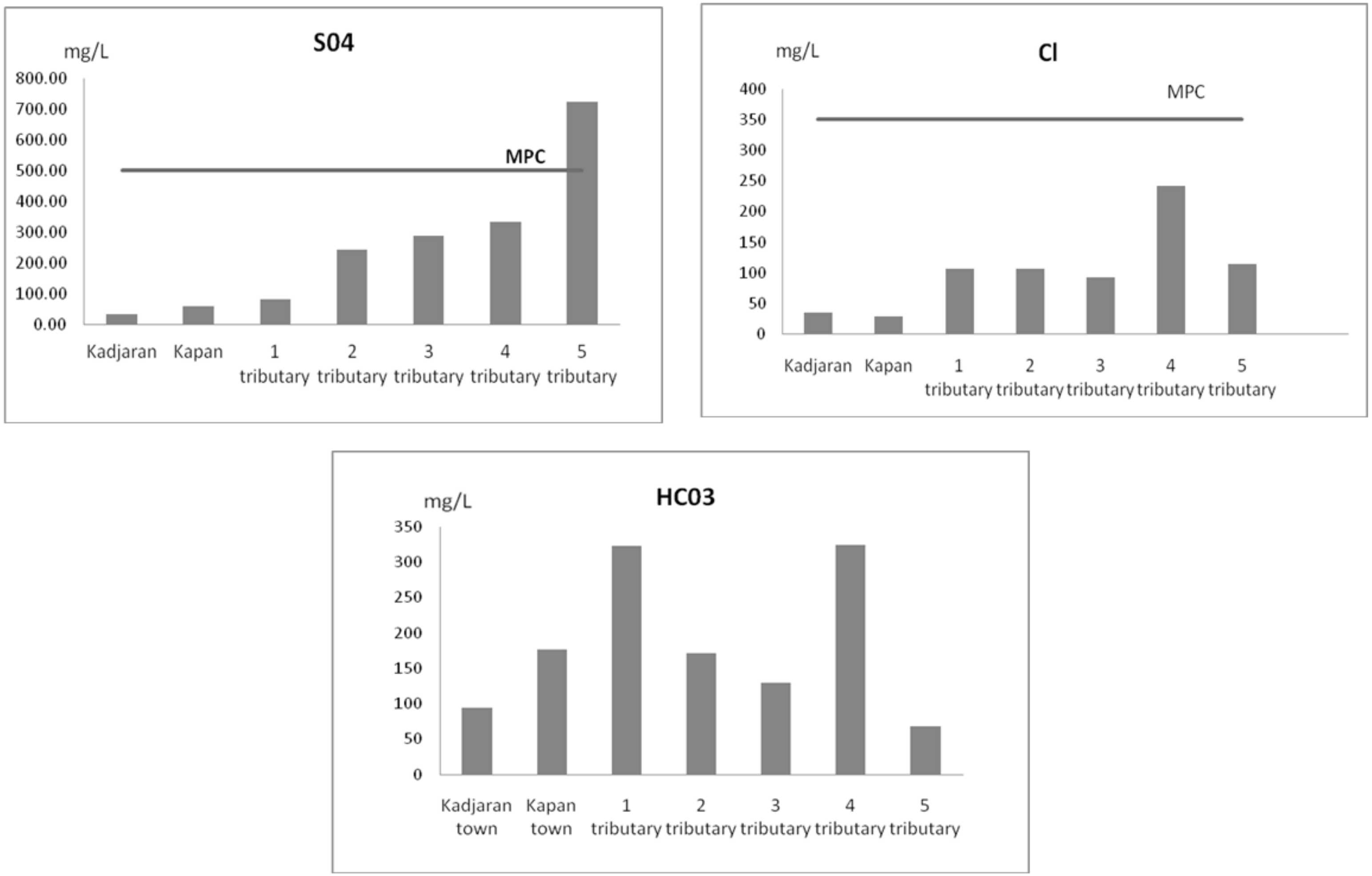


Figure 2 - Contents of anions in the River Voghchi waters near Kadjaran town, Kapan town and in its tributaries for 2005-2007

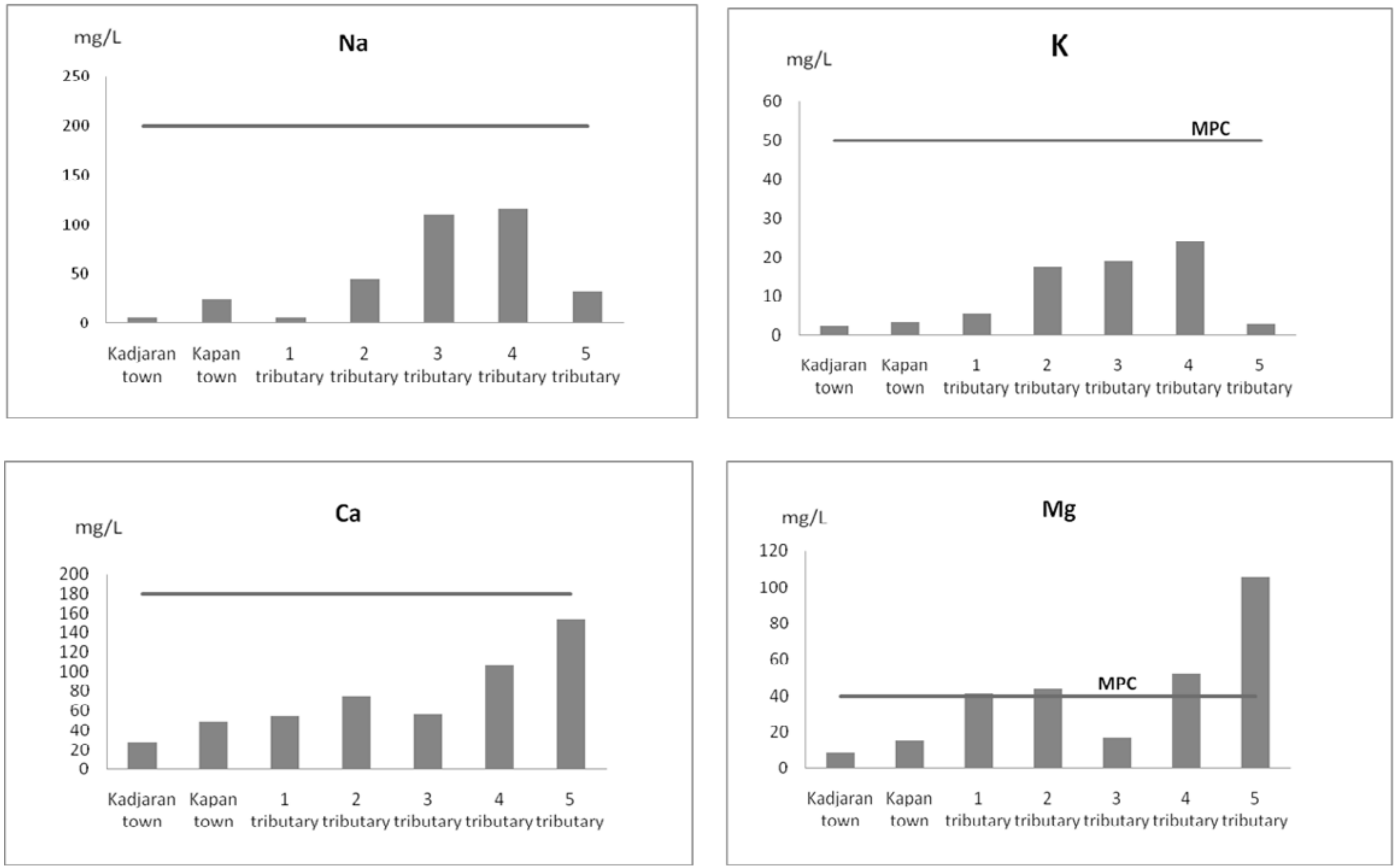


Figure 3 - Contents of cations in waters of the River Voghchi near Kadjaran and Kapan town and in tributaries for 2005-2007

3.2 STUDYING THE LEVEL OF HM CONTENTS IN THE RIVER WATER

3.2.1. Studying the level of HM contents in the river water for the period of unstable economy

For the studied period HMs contents in the waters of the River Voghchi have been investigated and assessed. The investigations of HMs contents in the waters of the river near the town Kadjaran during the period of unstable industry development shows that concentrations of HMs were varied in the limits of MPC. Anyway, high concentrations of copper, manganese, molybdenum and zinc were indicated (Fig. 4). The same results were obtained from other authors for 2007 (SAGHATELYAN, et al., 2008).

The water of some tributaries of the River Voghchi (Arstvanik, Barabatum) was characterized with excessive HMs (cadmium, copper and zinc) in 2006 (SAGHATELYAN et al., 2007).

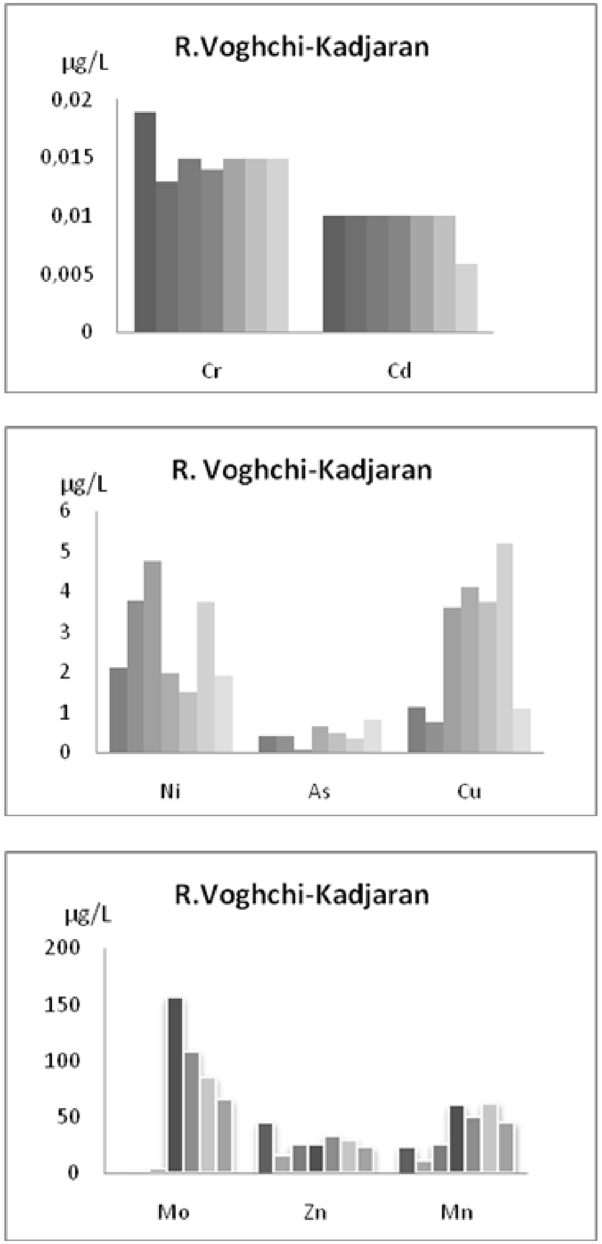


Figure 4 - The level of concentrations of HMs in the River Voghchi water near Kadjaran town for 2003-2008

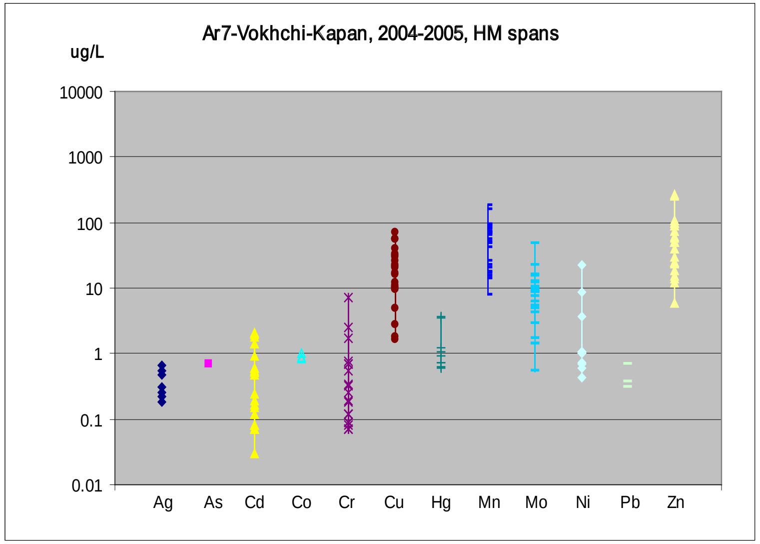


Figure 5 - Variation of HMs in the River Voghchi water near Kapan town for 2004- 2005

Studies of HMs in the monitoring site near Kapan town were conducted in the frame of NATO SfP 977991 project "South Caucasus River Monitoring". Data on HMs is presented as spans (Fig. 5). Such type of interpretation allows assessing real variations of each heavy metal in fixed monitoring sites.

The River Voghchi water near Kapan town is characterized by high concentrations of copper, manganese and zinc. High concentrations are linked to presence of copper-molybdenum deposits within the river basin as well as operation of mining enterprises. The contents of HMs in the River Voghchi waters here are not excessive vs. MPC.

3.2.2. Studying the level of HM contents in the river water for the period of stabilization of economic development

The study of the level of water pollution with HMs in the River Voghchi in the period of stabilization and some increase in volumes of the mining industry were carried out, based on *Environmental Impacts Monitoring Center's Annual Reports.* The results of data analysis allow indicating very high concentrations of HMs near the town Kapan, Kajaran and one of the tributaries of the River Voghchi - the River Artsvanik. This figure shows results indicating the current disastrous environmental situation (Fig. 6.) The copper content in the period from 2009 to 2011 exceeded the threshold values in77, and 128 times (Fig. 6,c). The content of manganese exceeded the threshold value, 15.2, 15.5 and 15.7 times, respectively (Fig.6,b). In the waters near the town Kajaran over the same period values exceeding the permissible limits on the content of zinc in water were found. For 2010 and 2011 it made 7 and 12 respectively (Fig.6,d). In the River Artsvanik multiple exceeding concentrations of permissible values for copper were also revealed (Fig. 6,a).

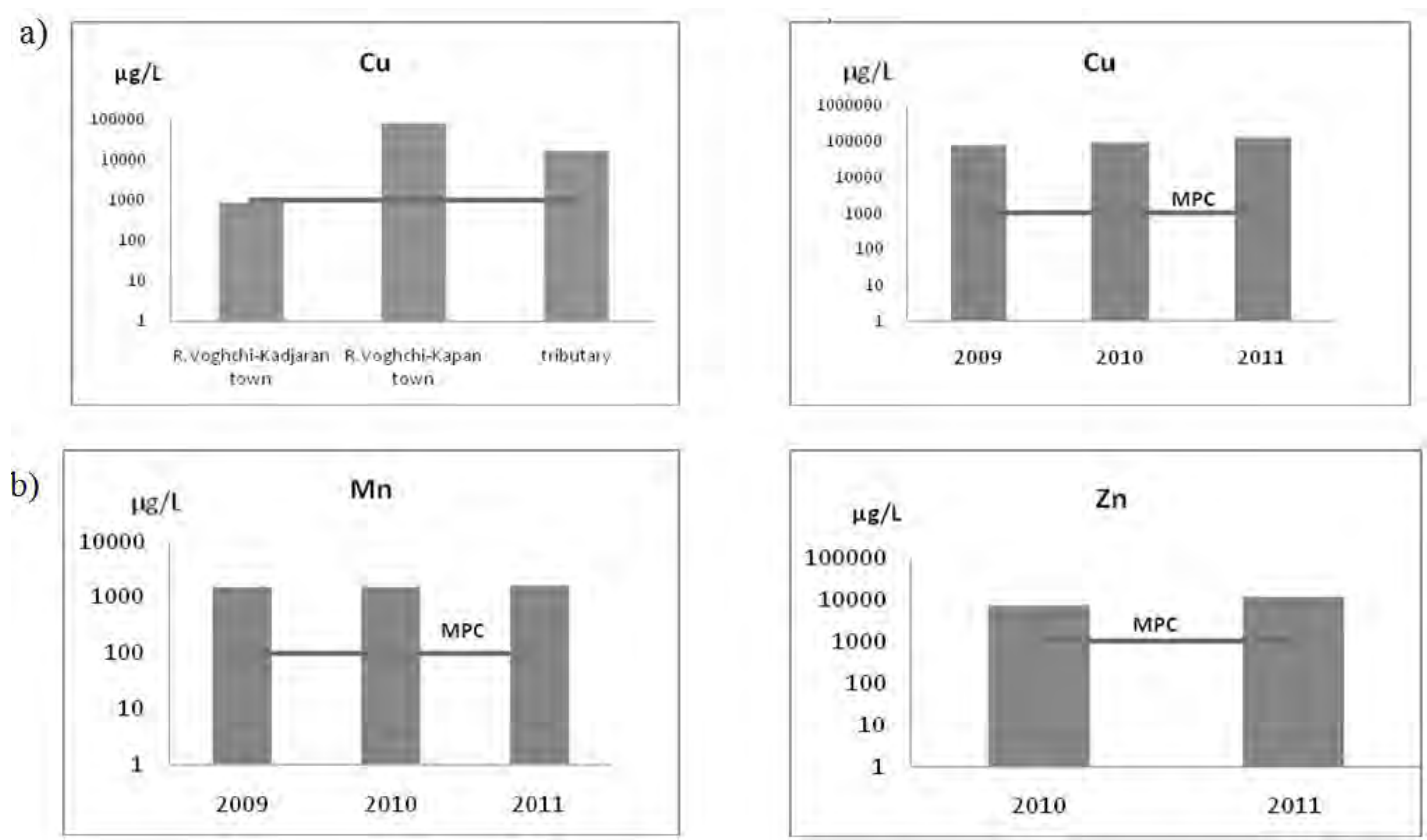


Figure 6 - Cu, Zn and Mn in the River Voghchi in period 2009-2011

3.3 THE OUTCOMES OF STATISTICAL DATA TREATMENT

This chapter highlights the outcomes of statistical analysis of data on the River Voghchi waters. Statistical data treatment was performed through the non-parametric Spearman correlation. High positive correlation coefficients between salinity and some HMs, salinity and Ec, and negative correlation coefficients between water discharge and salinity were established (Fig. 7).

The behaviour of Zn in natural waters is in a way analogous to that of Cu, both Zn and Cu are known to be characterized by peak biochemical activity, but Zn is more active in water due to better solubility of its oxides and hydroxides. An essential chemical property of Zn and Cu is the ability to be accumulated by surface-active matter (ROEVA et al., 1996).

For separate elements from a group of HMs – manganese, zinc, copper, chromium, nickel and cobalt- determined in the river water, credible positive correlation dependence were established.

A positive correlative dependence between Zn and Cu was indicated in winter, between Zn and Mn - in summer and fall. The dependence is based not only on similar behaviour of the noted metals but also on the fact that they belong to chalcophyle group of elements and met in combination in mineralised zones.

a)

	Valid	Spearman	t(N-2)	p-level
TDS & T	12	0.65035	2.70733	0.022034
Ec & Salinity	12	0.75262	3.61449	0.004733
TDS & Cr	12	0.86865	5.54462	0.000246
Mn & Co	12	0.616042	2.47310	0.032930
Mn & Zn	12	0.781087	3.95568	0.002705
Ni & Cr	12	0.631579	2.57603	0.027604

b)

	Valid	Spearman	p-level
Q & Co	11	0.83	0.00
Ec & Salinity	11	0.77	0.01
Salinity & As	9	0.75	0.02
Salinity & Cr	11	0.78	0.00
Salinity & Ni	11	0.79	0.00
Cr & Ni	11	0.75	0.01
Cu & Zn	11	0.78	0.00
Mn & Zn	11	0.79	0.00

c)

	Valid	Spearman	p-level
Eh & Co	11	0.75	0.01
Ec & Salinity	12	0.90	0.00

d)

	Valid	Spearman	t(N-2)	p-level
Q & Salinity	12	-0.75394	-3.62915	0.004619
TDS & T	12	0.72154	3.29551	0.008074
Ec & Salinity	12	0.75262	3.61449	0.004733
Cr & Co	12	0.703041	3.12622	0.010759
Cr & Ni	12	0.765125	3.75773	0.003736
Mn & Zn	12	0.763574	3.73944	0.003850
Ni & Co	12	0.759284	3.68964	0.004179

Figure 7 -The outcomes of correlation analysis of data on basic parameters and HMs in river for different seasons (a) fall, b) winter, c) spring, d) summer) in period 2004-2007

Mn is widely spread in soils and plays an essential role in formation of their chemical composition. Mn often plays a role of “a trap” with respect to HMs due to its high sorption activity (VENECIANOV et al., 2002) and like Ni it becomes more soluble in the presence of pH-decreasing humid acids (IVANOV, 1996).

We also performed the cluster grouping of the studied HMs for the River Voghchi.

The groups given in Dendrogram reflect closeness of levels of excessive concentrations of separate HMs vs, the background concentrations (Fig. 8). As seen from Dendrogram, Mn and Zn form a group, Ni and As directly adjoin the group. The dependence between Mn, Zn and Ni indicated in the dendrogram verifies the indicated positive correlation between the noted metals.

Statistical analysis results will be used for HMs transfer modeling and pollution prediction.

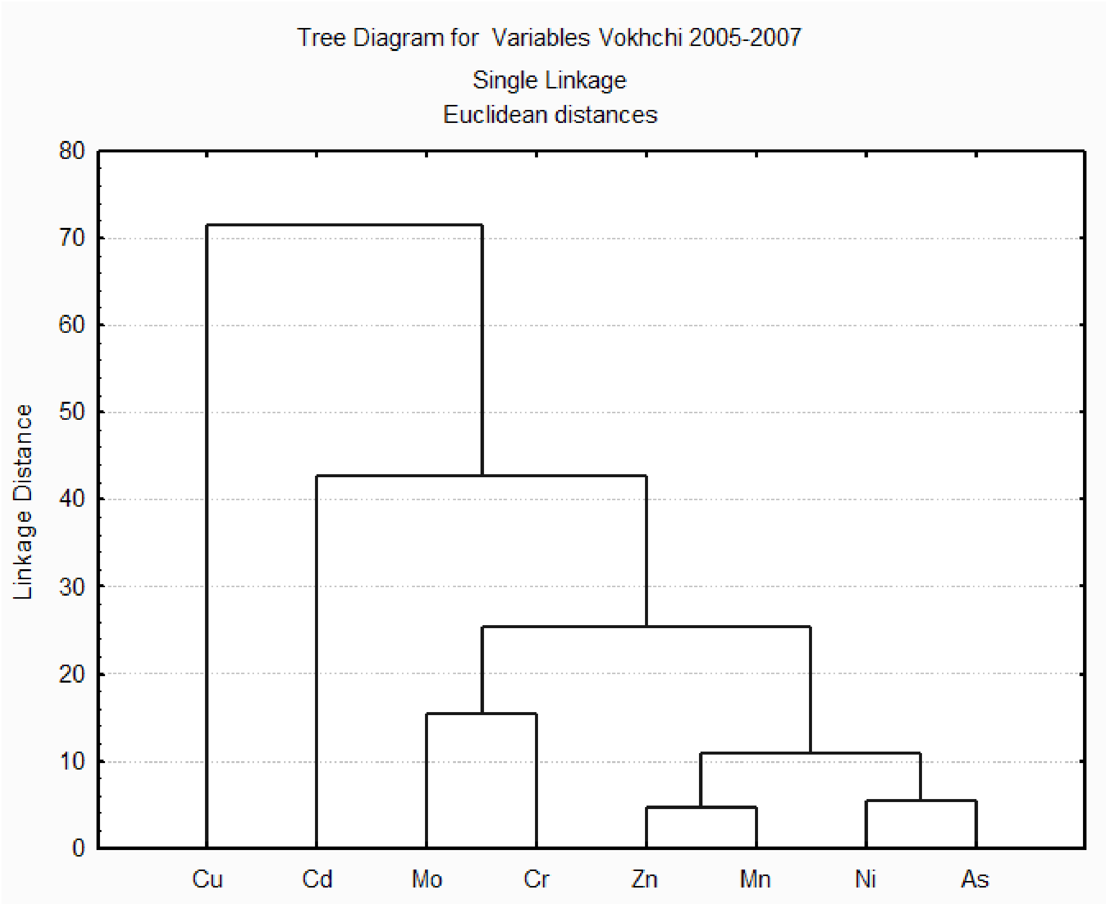


Figure 8 - Dendrogram of cluster analysis by HMs concentration coefficient values in River Voghchi waters for 2005-2007

4 CONCLUSIONS

Studying the level of HM contents in river water for the period of unstable economy allows concluding the following. Though high concentrations of certain heavy metals (copper, zinc, molybdenum, manganese) found in the main river flow of the River Voghchi basin, exceeded the background values, yet they remained within the MPC. Insignificant temporary changes in values exceeding the bounds were registered only for several tributaries.

The period of industry stabilization in the region is characterized by an abrupt increase in the level of pollution with copper, manganese and zinc of surface waters of the River Voghchi and tributaries, expressed in extremely dangerous concentrations exceeding MPC.

It should be also noted that tailing dumps are located in seismically hazardous areas which increases the risk of environmental pollution in the region under conditions of observed increasing frequency of earthquakes.

Statistical analyses detected stable correlations both between main indicators of the water quality and between some heavy metals. The obtained results will be used further in the models of estimate and prediction of pollution of the River Voghchi.

In connection with the stated above it is necessary to carry out a new detailed geo-ecological research of the river basin directed to assessing the current ecological state. Such studies will make basis for development of the Integrated Water Management program for the River Voghchi eco-system pollution control.

REFERENCES

Manual for sampling methods, Manual for sample conservation and storage. Standard operational procedures for river water sample collection, conservation and storage, ISO-5667-1, ISO-5667-2, ISO – 5667-3 (1998).

Fomin G.S. (2000).*Water*. Control of chemical, bacterial and radiation safety by international standard. Standard operational procedures for determination of basic ions and biogenic elements in surface waters, ISO-6878, ISO-9297, ISO-7150-1, ISO-7890-3, ISO-6777, ISO-9963-1, ISO-9964-3, 6058, 6059, 9280, Moscow, Pub,h,"Protector", (in Russian).

Fomin G.S. (2000).*Water*. Control of chemical, bacterial and radiation safety by international standard. Standard operational procedures for determination of heavy metals in surface waters, ISO-8288, ISO-9174, ISO-5961, Moscow, Pub,h."Protector", (in Russian).

Venecianov E.V., Lepikhin A.P. (2002). Physico-chemical fundamentals of modeling heavy metal migration and transformation in natural waters. Yekaterinburg, (in Russian).

Roeva N.N., Rovinskiy F.Ya., Kononov E.Ya. (1996). Specific peculiarities of heavy metal behavior in different natural environments. Journal of analytical chemistry. vol,51, N4, pp.384-397, (in Russian).

Ivanov V.V. (1996). Ecological geochemistry of elements, Book 4, Moscow, "Ecology" (in Russian).

Accepted Maximal Permissible Concentration (MPC) for chemical substances in water of water objects used for economic, drinking, cultural and household purposes (2003). (**GN 2.1.5.1315-03**, Russia).

Saghatelyan A. et al. (2007). Assessing environmental impact of tailing storage sites from mining and dressing production and activities of the Kapan copper enterprise on the territory of Kapan town. OSCE Report, Yerevan,.

Saghatelyan A. et al. (2008). Ecological and geochemical assessment of environmental state of the city of Kajaran. Yerevan,.199 pp.

MINING AND WATER RESOURCES IN A CHANGING WORLD: THE CHALLENGE TO COPE WITH WATER SHORTAGES, ENVIRONMENTAL IMPACTS, AND BIODIVERSITY CONSERVATION

Virginia S.T. Ciminelli[1]
Francisco A. R. Barbosa[2]

[1] *Professor - Department of Metallurgical and Materials Engineering - Universidade Federal de Minas Gerais/UFMG. National Institute of Science and Technology on Minerals Resources, Water and Biodiversity - INCT- Acqua. E-mail: ciminelli@demet.ufmg.br.*

[2] *Professor - Department of General Biology, Institute of Biological Sciences - Universidade Federal de Minas Gerais/UFMG. National Institute of Science and Technology on Minerals Resources, Water and Biodiversity - INCT- Acqua. E-mail: barbosa@icb.ufmg.br.*

ABSTRACT

The competitiveness of mining/metallurgical operations is increasingly dependent on social approval. The industry is driven to positively respond to stakeholders concerns, with comprehensive approaches to deal with the complex, multiple boundaries of mining operations with watersheds, nearby urban, protected and culturally valued areas. This challenge creates unique opportunities for scientific and technological development, and capacity building. New analytical tools are strongly required to assess the environmental impacts and to guide innovative approaches for the recovery of impacted areas. Industrial processes should be redesigned for a better environmental performance, and finally, relevant information should be made accessible to all stakeholders. The needs for solutions that allow for the specificities of each mining site, empower local communities as well as the local chain of technology and knowledge suppliers. The trend, supported by experiences worldwide, is to establish a model for industrial development reconciled with the preservation of water resources, biodiversity and cultural heritage.

1 INTRODUCTION

Even today water in some mining operations is still considered only a commodity without what mining cannot be performed. The major challenge for ecologists is therefore to convince decision makers of this sector that water is in fact, much more than this and deserves better attention and conservation thoughts in order to improve efficiencies through saving waste products apart to decrease environmental impacts to surrounding areas. In this paper we shall demonstrate the need to change paradigms. We hope to make it clear that even within mining areas water must be taken considering the ecological views of water quality and the existing biodiversity, which deserves efforts to be protected and used in a sustainable way.

The access to secure and stable water supply has been always critical to mining operations. More recently it is becoming evident that water and the services it delivers are also fundamental for many stakeholders as well as for the environmental protection. This new understanding becomes evident in the document from the ICMM-International Council on Mining and Metals (ICMM, 2012): "Water is essential to life on Earth. Availability of and access that meets quality and quantity requirements is a critical need across the world. We all share responsibility for meeting this need."

When the Millennium Institute – Water a mineral approach – presented similar concepts, in 1999, they looked new. At that time, we anticipated a paradigm shift the minerals industry would become a supplier of good quality water. Now the aforementioned statements together with the examples provided further in this paper indicate a clear trend that will ultimately permeate the whole mineral industry.

As previously pointed out, water has been recognized a strategic issue for the mining sector as most unit processes and operations, from mineral processing to the recovery of metal, need water. The management of large volumes of water during the development of the mine pit and the consequences of these interferences will have in the region where the mine is located is also to be pondered. Water is, in fact, one of the most sensitive issues and interfaces with the neighborhood communities. Therefore, water management has a direct influence on how society perceives mining operations. And, finally, if social license to operate, a permit that goes beyond legislation, will be granted.

The present paper discusses the use of water in the mining and metallurgical industries as well as the potential impacts of these activities on water resources. Moreover, it calls attention for the need to increase the interest and concern on the advantages of assessing and protect the existing biodiversity within the mining areas. Examples of recent strategies to guaranteeing access to water supply are presented. These examples also illustrate advances in understanding the social, ecological, and cultural values of water and, more importantly, how access to secure water supply will depend more and more on a broad agreement involving the private sector, government and society. Finally, the main challenges to be faced in the future are highlighted.

The conclusions are supported by experience elsewhere as well as on that gained with the National Institute of Science and Technology – INCT-Acqua, which contemplates the interactions existing between mineral resources, water and more recently the existing biodiversity in mining areas. The institute is part of a program launched in 2008 by the Brazilian Ministry of Science, Technology and Innovation – MCTI, which selected over a hundred Institutes in practically all areas of knowledge. The Institutes are expected to be at the forefront of scientific and technological knowledge in "strategic areas for the sustainable development of the country". Contributions to innovation and education (at all levels) are expected to be distinguishing marks of the INCT's.

A novelty proposed for deep consideration within the INCT-Acqua is the fully recognition that water in mining areas continues to be an environment and as so holds a certain biodiversity, which must be assessed and protected. Actually this is a paradigm shift since, in previous years, water was considered just as a commodity essential for industrial operations and so just relevant to take its quantities issues. This old view is proposed to be replaced by a contemporary ecological view according to which water is deeply more than a commodity but an environment thus holding not only a quantifiable quality standard, important for the whole operation, but also holding diversified aquatic communities that deserves to be known, protected and used through sustainable ways.

2 WATER'S ROLE IN THE MINING AND METALLURGY AND POTENTIAL IMPACTS

The management of very large volumes of water resources is associated with all of the phases of mining activities: from the initial phase of mining, very often associated with water emergence, to the final phase of concentration and metal production, associated to water consumption (CIMINELLI et al., 2013).

Mining operations are however unique in a sense that in lowering the water table, water often becomes available. Water can be released into a receiving water source, used as process water, in mining operations for dust control, or for municipal supply. Potential difficulties may come from the reduction of the levels of groundwater and surface water and also on how quality and quantity will affect the receiving environment. The magnitude of water flow in mining operations is illustrated by the *Vazante* Mine of *Companhia Mineira de Metais* in the municipality of Vazante, state of Minas Gerais, where approximately 9 million liters of water per hour are pumped by underground mining activities (MARTINS, 2013). A number of examples are provided by the literature. (FERNANDEZ RUBIO, 2006). The exceeding water becomes an asset to be used in the subsequent stages of mineral processing and metallurgy, in dust control, reloading of aquifers, in water supply to nearby communities and to nearby enterprises, as well as and many other social and economic uses. The consequences of water pumping on the regional water balance should be understood as it may affect water supply to other users. Subsidence may also occur as large amounts of groundwater are withdrawn, especially when the aquifer in hosted within karstic rocks or fine-grained sediments.

The majority of stages in a process flow sheet are carried out by using water, thus meaning consumption, and in large scale. In the mineral processing operations, large amounts of water are used, especially in the concentrators, where the separation of the ore, into valuable and non-valuable fractions, is carried out. In a typical iron ore concentrator, the ratio of consumed water: processed ore may reach 5:1, on a tonnage basis. But despite the large specific consumption, water recycling is in the range of 60-80% (CIMINELLI et al., 2013).

In the extraction of metals, such as gold, aluminum, uranium, zinc, copper, rare earths by hydrometallurgical processes, water is both a reagent and a medium, where the separation of the valuable constituent is carried out. In the iron/steel industry, as well as in other pyrometallurgical processes, approximately 90% of the consumed water is used for cooling. In the steel industry in Brazil, water recycling has reached values of 96% of fresh water and 20% of seawater/brackish water. In 2011, specific water consumption was 91.68 m^3/t steel (seawater/brackish water) and 5.87 m^3/t steel (freshwater) (CNI, 2012b). As an illustration of recent advances in water management in metallurgy, in China, responsible for 45% of the world steel production, a decrease of new water consumption from 8.03 to 4.43 t water/t steel in a period of 5 years is reported (BANK OF CHINA INTERNATIONAL, 2012).

Water is also used for transport. Slurry pipelines are increasingly adopted due to various advantages in comparison to other terrestrial transport options, such as reduced costs and energy demands, and less environmental interferences. Slurry pipelines requires significant amounts of water in the preparation of the slurry, which consists of approximately 30% of water and 70% of ore, on a weight basis. The Samarco Mineração SA (BHP Billington and Vale

SA) in the municipality of Mariana, Minas Gerais, reports a total water consumption of approximately 16 million m^3 of water to produce 23 million t per year of pellet-feed and of concentrate. The ore concentrate is transported by means of two pipelines of approximately 400 km linking the concentrator, in the state of Minas Gerais, to the port, in the state of Espírito Santo. Water recirculation is approximately 90% (SAMARCO, 2012).

Finally, one has also to consider the water associated with the tailings impoundments. There may be losses associated with evaporation, especially in arid areas or, in some cases, with infiltration. Contamination should be evaluated and prevented.

Various factors should be taken into account in managing water in mine sites (ICMM, 2012): "The water cycle of a mine site is interconnected with the hydrologic water cycle of a watershed. Consideration of other water users within the area, such as communities and the environment is critical when using and managing water at this scale." Aligned with this concept, INCT-Acqua understands that the assessment of environmental impacts in general should go beyond the mine site and so be measured within the framework of the territory where the mining site is located. This holist approach takes into account the social, economic and cultural context of the region, thus contributing to a contemporary view of mining and sustainability.

Contamination of water related to mining and metallurgical operations as well as to tailings disposal should be prevented and treated properly. As for water consumption, the volumes are large. The steel industry, for instance, is reported to produce an effluent volume of approximately 2.5 m^3 per tonne of steel (CNI, 2012a). The major sources of contamination of superficial and groundwater associated to the various stages of ore processing, metal extraction and tailings disposal are:

I. Mining – lubricants, oil, explosives, acid drainage, dissolved metals and anions, and waste rock;
II. Mineral processing and metal extraction - reagents, soluble metals and other substances, and tailings;
III. Storage lagoons, waste dumps, tailing impoundments - seepage or leakage with dissolved metals and anions;
IV. Transport - spillage of chemicals and fuels;
V. Closed mines - dissolved metals and anions following water ingress in former mining sites with subsequent dissolution of tailings.

Water quality associated with tailings dam and final pit depends on the nature of the ore. Contamination may be a problem thus requiring water treatment even after the mine has been closed. Acid rock drainage-ARD is the acid stream or seepage produced by oxidation of metal sulfides. The acid stream may lead to further leaching reactions with the incorporation of toxic elements that may, in turn, contaminate both ground and surface waters. The Uranium Mine at Caldas, Brazil, was shut down in 1996 but the problem of acid mine drainage persists until today: 300 m^3/h of acid drainage (pH of approximately 3) containing dissolved uranium (12 a 14 mg/L) and manganese (100 a 140 mg/L).

There are well-established techniques that can be applied to effluent treatment, such as precipitation, adsorption, filtration, electrolysis and electroosmosis, flotation, and advanced oxidation processes (RUBIO et al., 2010). A number of less conventional techniques have been also proposed and tested. The main challenges remain as the removal and fixation of radioactive or very toxic substances, with no commercial application; the economic removal of trace amounts of inorganic and organic compounds from large volumes of effluents, and the treatment of corrosion products for increased water recycle (CIMINELLI et al., 2013).

3 COMPREHENSIVE SOLUTIONS TO WATER MANAGEMENT IN MINE SITES

The minerals sector has been providing a number of examples of comprehensive and innovative solutions to water management, as indicated by some of the examples described in the following paragraphs (AMORIM, 2006; ANDRADE et al., 2006; ICMM, 2012). Significant reductions in water consumption and in the amount of water associated to tailings are advances that should be highlighted.

The Pico iron ore mine in the Iron Quadrangle mineral province, Brazil, provides a good example of long-standing, multiple use of mine water. Water is used for ore processing; landscaping (Codornas lake is a reservoir created for hydroelectric energy generation and more recently integrated in a residential development); electric energy generation by a power plant built more than 100 years ago by a gold mining company; and, finally, water supply to the city Belo Horizonte - the capital of the state of Minas Gerais with a population of approximately 2.5 million people.

Capão Xavier is an iron mine also located in Iron Quadrangle mineral province, Brazil. The excess water derived from the water level reduction of this mine has been used for public water supply of the nearby residential areas. The lake created after mine exhaustion will become a reservoir integrated to the water-supply system aimed at regulating flow during dry seasons. The tailings (from ore beneficiation) and the waste rock (from mining) from the processing unit of Capão Xavier will be used to topographically reconstruct the Mutuca mine (AMORIM, 2006). In this way, the risks of *tailings storage are significantly minimized. In addition to the multiple use of water, water quality and environmental management also benefit by the elimination of disposal areas and the rehabilitation of the mining pit.*

The eMalahleni Water Reclamation Plant (EWRP), Witbanks coalfield, South Africa, owned and operated by Anglo American, was commissioned in 2007. The plant has been designed to manage both water from Anglo American and BHP Billiton operations as well as water from other coalmines. The ingress of 140,000 million liters of groundwater in Anglo American's Thermal Coal workings poses serious challenges to active mines, but more so to closed mines, where without adequate management and resources it can cause the dissolution of metals and salts, leading to potential contamination of ground and surface water, with subsequent costs for treatment. In contrast, the region surrounding eMalahleni is a water stressed area as a result of reduction in annual rainfall, fast increasing population, and events with flooding risks. Water management in this region should comply with the long periods of drought, with events of high amounts of rain. As a result of an agreement of the private sector with the local municipality to ensure water security to both community and operating facilities, treated mine water is delivered to local municipality's drinking water system. This agreement brings also many benefits to the mining companies that would have to face the issues of exceeding water and mine closure water quality (ICMM, 2012).

Conversely to what was described in the previous paragraph, there are examples where treated municipal water is used by mining operations. This approach guaranteed water supply - 1 m^3 */s of treated municipal water - to the large expansion of Freeport-McMoRan, Sociedad Minera Cerro Verde copper and gold mine in Peru. Treating municipal wastewater for municipality and mine supply contributes to water security in the region. This approach also improves river water quality, reduces water-related illness, and enhances agriculture products in the area. The reuse of effluent is being promoted by the local government as a sustainable water supply for the mining sector.*

Seawater and brackish water has been extensively used by the mining/metallurgical sector as an alternative to fresh water but few involve the direct use of saline waters in ore processing. The copper-gold Esperanza mine is located 180km from the city of Antofagasta in an area of the Atacama Desert, one of the driest places in the world. The operation requires approximately 20 million cubic metres (billion liters) of water a year to produce 190,000 tonnes of copper concentrate and 230,000 ounces of gold. Seawater is pumped 140 km via a pipeline that climbles 2300 m to reach the industrial facility. Only 8% of total seawater is treated by reverse osmosis for human consumption and operations such as concentrate washing and few others.

The Trekkopje Uranium Mine provides an example of biodiversity preservation. The mine will be one of the largest in Southern Africa, and the 10th in the world. The ore body covers a surface area of approximately 42 square kilometers. Both mining and the processing technique require significant volumes of high-quality water in a water-scarce area. Neither saline nor seawater can be used in ore processing, as chlorides disrupt ion exchange process used after heap leaching; freshwater aquifers do not yield enough water to all users. Seawater desalination was the only clear option. The Namibio Erondo desalination plant (a combination of reverse osmosis and extreme filtration) was likely the first example of this kind to supply both the mine and local community water supply. The unit is capable of producing 20 million cubic metres (billion liters) of water - 70% used by the mine and the excess water used to meet nearly half the water requirements of the Erongo Region. This estimate includes the needs of other industrial sites. One aspect to be emphasized in this example is that the plant project was designed to fit into the landscape, to minimize the noise level in the nearby community, and the impact on the Wlotzkasbaken lichen field, which has a globally unique species richness and density. Pipeline was shifted south and forms the southern boundary of the lichen field and prevents access (ICMM, 2012).

4 LOOKING AHEAD: THE ECOLOGICAL VISION

Population growth, economic development, and climate change will drive water stress to increase. Moreover, climate change adds additional stress - from reduction in rainfalls, which implies in adequate storage for drought or stress periods, to occurrences of more severe rainfalls, with flooding events and other accidents. Water management has to take into account all these factors. There are various issues to be addressed that will depend on continued research and technological developments and some will be highlighted in the following paragraphs.

Improving water accounting (quality and quantity) - Approval of a new enterprise or the expansion of a given one in a region with many water users should not be based on net water balance. Considering the relatively large footprint of a mining operation, net water balance may be positive as a result of one spot with excess water compensating for another one under deficit. The local deficit may affect other users. The deficit or surplus may be also seasonal or vary with time. Furthermore, these effects are magnified in regions where the number of mining sites has been increasing as well as their proximity. In these situations, water management will require a detailed identification and estimation of the present and future water demands in the territory, based on all type of user groups and the specificities of the various sub-regions. Characterization of surface and groundwater resources with respect to availability, quality, and sustainability is also needed. It is worth to mention that so far Brazil has not yet defined water quality standard, which must consider seasonal differences as well as the distinct uses by sectors. Furthermore, there are considerable differences when we are talking concerning the industry or agricultural sectors, the former much more aware of the constraints then the agriculture, which worldwide uses more and more water to sustain the impressive growth. Moreover, and specifically considering quantity, real time metrics are wanted since there are still debates what metrics shall be used to gauge the amounts of water that can be withdraw from the rivers and what limits shall be adopt to guaranteeing the minimum rivers flow to maintain natural wildlife within these ecosystems. Finally it must be emphasized that the information should be available to all stakeholders and the public in general. There are for sure different ways of making information available all depending on creativity and the level of importance given by the sector. An example maybe to be followed we could use is the largest uranium plant in Australia (world), Olympic Dam where water use in the facility is exhibited in a monitor at the entrance.

What is the Value of Water? The value of water should include not process costs but the social, environment, and ecosystems services water provides. Metrics, models, perhaps designed for a specific situation should be developed and tested. A more precise definition of the value of water will provide society with tools for decision-making. Despite the geographical fixation of an ore deposit, there are situations where social, cultural and biodiversity values will lead to a no to mining activity or to a modification of an existing project. The aforementioned example in Namibia illustrates a situation where a compromise was achieved between the mining activity and the preservation of social and biodiversity values.

Finally, stakeholders' engagement and access to information should be highlighted. License to operate is already a reality in many regions in the world. But stakeholder's engagement demands information and knowledge. However, the essential information for decision-making is often not fully accessed or available in a format that it cannot be fully comprehended by society.

Technology is required to identify long-term solutions for water management; solutions that will last after mine closure. Innovation is needed to create less costly solutions, to increase water recycle in industrial operations, to maximize multiple uses of water, to increase access to saline waters. It is also needed for contamination assessment of trace and sub-trace substances, and for water resources accounting. Finally, innovation is essential to make information accessible to society – a key condition for stakeholders' engagement.

Universities and research centers have a very important role - that is to create new knowledge and to make the relevant information accessible to all stakeholders. This is a requirement to a transparent, proactive and constructive approach to water management in the minerals industry.

A positive outcome is that local solutions are needed; no universal solution is available to respond to local specificities. The need for local solutions empower local communities and the chain of local technology and knowledge suppliers. This creates a seed for the build-up of local, sustainable development.

5 ACKNOWLEDGMENTS

The authors are grateful to the Brazilian government agencies — CNPq, CAPES and FAPEMIG — and to the INCT-Acqua for financial support.

REFERENCES

Amorim, L. Q. (2006). Atuação da MBR na Bacia do Rio das Velhas: Compatibilidade entre Água e Mineração (MBR in the Rio das Velhas Watershed: compatibility of water and mining). In: Domingues, A. F.; Boson, P. H. G.; Alipaz, S. (org.). *A Gestão dos Recursos Hídricos e a Mineração*. Brasília, DF: ANA- Agência Nacional de Águas. Cap. 5, p. 139-156.

Andrade, M. C.; Sampaio, J. A.; Luz, A. B.; Andrade, V. L. L.; Santos, M. L. P.; Grandchamp, C. A. P. (2006) A mineração e o uso da água na lavra e no beneficiamento de minério (Mining and the use of water in mining and ore processing). In: Domingues, A. F.; Boson, P. H. G.; Alipaz, S. (Org.). *A gestão dos recursos hídricos e a mineração*. Brasília, DF: ANA- Agência Nacional de Águas. Cap. 4, p. 89-122.

Bank of China International (2012). *Steel Industries Outlook* (available in www.bocigroup.com, accessed in 15/04/2013).

Ciminelli, V.S.T.; Salum, M.J.G.; Rubio, J.; Peres, A. E. C. (2013). Água na Mineração (Water in Mining). In: Tundisi, J.G. *et al*. *Águas Doces do Brasil*, 4ª. ed., 2013. (*in press*).

CNI- Confederação Nacional das Indústrias (2012a). *A indústria de Aço no Brasil (The steel industry in Brazil)*, Instituto Aço Brasil, Brasília, CNI, 2012, 48pp.

CNI- Confederação Nacional das Indústrias (2012b). Relatório de Sustentabilidade (Sustaintability Report), Instituto Aço Brasil, Brasília, CNI, 2012, 95p.

Fernández Rubio (2006). A Gestão dos Recursos Hídricos na Mineração: Visão Internacional (The management of water resources in mining: international view) In: Domingues, A.F.; Boson, P. G.; Alípaz, S.. *A Gestão dos Recursos Hídricos e a Mineração*, IBRAM e ANA, Brasília – DF, p.19 – 50.

ICMM- International Council on Mining and Metals (2012). *Water management in mining: a selection of case studies.* 32 pp. (available at www.icmm.com, accessed July, 2012).

Martins, E. 2013 (personal communication).

Rubio J.; Oliveira C.; Silva, R. (2010) Aspectos ambientais no setor mineiro-metalúrgico (Environmental aspects in the mineral-metallurgical sector). In: Chapter 17 *Tratamento de Minérios*. CETEM - Centro de Tecnologia Mineral. (Org.). Rio de Janeiro, p. 753-793.

Samarco Mineração SA (2012). *Sustainability report* 2011. (available at www.samarco.com.br. accessed in 15/04/2013).

SESSION 9

MANAGING WATER IN URBAN AREAS AND METROPOLITAN REGIONS: AN EVER-GROWING CHALLENGE

SUMMARY

CHALLENGES AND OPPORTUNITIES FOR SUSTAINABLE GROUNDWATER MANAGEMENT IN AFRICA

Cheikh Bacaye Gaye[1]
Callist Tindimungay[2]

[1] Département de Géologie, FST – Université Cheikh A. Diop, Dakar, Sénégal.
[2] Water Resources Planning and Regulation, Ministry of Water and Environment, Uganda.

ABSTRACT

Groundwater plays a fundamental yet often little appreciated role in economic development, human well-being in both urban and rural environments, as well supporting many aquatic ecosystems in Africa. Thus, groundwater has high relevance to the development and wellbeing of Africa, if adequately assessed and sustainably exploited. Whilst the potential for groundwater resources development continues to be reported in the literature, a quantitative understanding of these issues remains poor. Similarly, although groundwater systems respond to human and climatic changes slowly (relative to surface water systems), climate change still could affect groundwater significantly through changes in groundwater recharge as well as groundwater storage and utilization. Groundwater resources in Africa also face an increasing threat of pollution from urbanization, industrial development, agricultural and mining activities as well as from poor sanitation practices. Furthermore, groundwater is susceptible to over exploitation due to the ever increasing demand for human and agricultural needs. However, despite the existence of a number of groundwater management issues, groundwater resources in Africa are still generally under-developed and can be better managed to meet the various needs in a sustainable manner. Thus, strategies to ensure sustainable development and management of groundwater resources need to be put in place. These include among others establishment of groundwater monitoring systems, better understanding of the role of groundwater storage and groundwater discharges in sustaining aquatic ecosystems, mapping and management of transboundary aquifers, assessing and addressing climate change impacts on groundwater, assessing the impact of increased pumping from various aquifer systems on the sustainability of groundwater abstraction, and capacity building in groundwater management.

1 INTRODUCTION

Groundwater is an essential part of the natural water cycle and is nearly present everywhere beneath our feet. As part of the water cycle, groundwater is a major contributor to flow in many streams and rivers and has a strong influence on river and wetland habitats for plants and animals. It forms the largest available store of fresh water on the Earth. About 23,400,000 km^3 of ground water exist on Earth, 54 percent is saline, with the 10,530,000 km^3, about 46 percent, being freshwater (GLEICK, P. H., 1996).

However, it is a hidden asset, out of sight and all too often out of mind. This store of groundwater comes mostly from rainfall that has filtered down through the ground. Providing it is not pumped directly out of the ground, for different human uses, most groundwater eventually discharges into continental surface waters (~80%) or into the sea (~20%). Here it supports river flows, and maintains ecosystems. It is the primary source of water for rivers and lakes in summer or at times of drought. Groundwater is therefore important to wildlife.

Groundwater is an important strategic resource. Three-quarters of all the groundwater pumped from boreholes or taken from springs is used for mains water supply. It directly supplies the majority of the population in Africa and its use for irrigation is forecast to increase substantially to combat growing food insecurity in the continent. In some areas it is the only available drinking water resource. It supplies nearly all those who do not have mains water. Groundwater is also used for bottling and food processing as well as in other industrial activities. There are advantages in using groundwater for both public and private supplies: compared to surface water, it is of relatively high quality and usually requires less treatment prior to use, even for drinking and other potable purposes (EA, 2011).

The total water resources in the world are estimated in the order of 46000 km^3/year, including about 36000 km^3 for surface waters and 10000 km^3 being groundwater (TRENBERTH et al., 2007). These resources are distributed throughout the world according to the patchwork of climates and physiographic structures. At the continental level, America has the largest share of the world's total freshwater resources with 45 percent, followed by Asia with 28 percent, Europe with 15.5 percent and Africa with 9 percent. In terms of resources per inhabitant in each continent, America has 24 000 m^3/year, Europe 9 300 m^3/year, Africa 5 000 m^3/year and Asia 3 400.1 m^3/year (FAO, 2003).

The distribution of precipitation follows a rather simple pattern in Africa. Maximum rainfall is observed in Equatorial regions, notably around the Gulf of Guinea and Mont Cameroon, where it can exceed 4 meters annually. From there the precipitation decreases northward towards the Sahara and southward towards the Kalahari.

In the Northern winter (Dec.-Feb.) the heaviest rainfall is in Central Africa from 0° to 10° S., where the centre of lowest pressure is located. This part of Africa receives both south-east trade winds from the Indian Ocean and monsoons from the Arabian Sea. The extreme north receives some rain from the Mediterranean, but the whole belt of the Sahara from the Atlantic to the Red Sea as far south as Lake Chad is almost rainless.

At the same time the coast of Guinea, as far south as the Congo, gets a moderate rainfall from the prevailing south-east winds, drawn in by the lower pressure on the land. In South Africa, Natal, the cost of Cape Colony, and the Transvaal have their wet season, but the west from Cape Town to the tropic is dry, the winds being off-shore.

In the Southern summer there is a centre of high pressure over the cool southern plateau in Cape Colony and the Transvaal. This diminishes the force of the trade winds, and gives a dry season in Natal and along the east coast generally as far north as the equator. South-west Africa is now almost rainless, except for a small district around Cape Town, which at this season just comes within the zone of westerly winds, and therefore has a wet (winter) season, like the Mediterranean countries.

The zone of heaviest rainfall has now moved north with the sun, and lies in July along the coast of Guinea and in the lower Niger basin. The whole continent from 0° to 15° N. has a fairly heavy summer rainfall (least in Somali- land), but north of 20° there is virtually no rain, owing to the intense heat and the dryness of the north-east winds.

The equatorial belt has no really dry season, but two distinct wet seasons (about March and September) separated by two less wet seasons.

Globally the rainfall is strongly function of altitude: it doubles on average every 2000 m, therefore the mountains and highlands (Fouta Djalon, Kilimanjaro, Mount Cameroon, Ethiopia) are the "water towers".

Extremes of high temperatures in Africa do not occur in the equatorial belt, but near the southern margin of the Sahara. The average temperature of Timbuktu in May is about 46°.

Nearly the whole of Africa drains to the Atlantic basin. Only three major rivers, the Zambezi and Limpopo, flow to the Indian Ocean, and the Nile to the Mediterranean sea. There is a wide range of hydrological situations in Africa and it could be divided into 24 major hydrological units or basin groups: 8 major river basins, draining to the sea (Senegal, Niger, Nile, Shebelle-Juba, Congo, Zambezi, Limpopo and Orange rivers); 9 coastal regions grouping several small rivers, also draining to the sea; 5 regions grouping several endorheic drainage basins (Lake Chad, Rift Valley, Okavango, South Interior and North Interior).

2 KEY GROUNDWATER MANAGEMENT ISSUES

- **Geological and hydrogeological setting**

The availability of groundwater depends primarily on the geology. Groundwater is stored within pore spaces and fractures in rocks. Where the pores or fractures are interconnected, groundwater can flow easily and the rocks are said to be permeable. Fractured or porous rocks (such as sandstones and limestones) therefore have a high potential for groundwater development. The availability of groundwater also depends to a certain extent on the volume and intensity of rainfall.

The hydrogeology of Africa has been classified according to geological environment (Fig. 1).

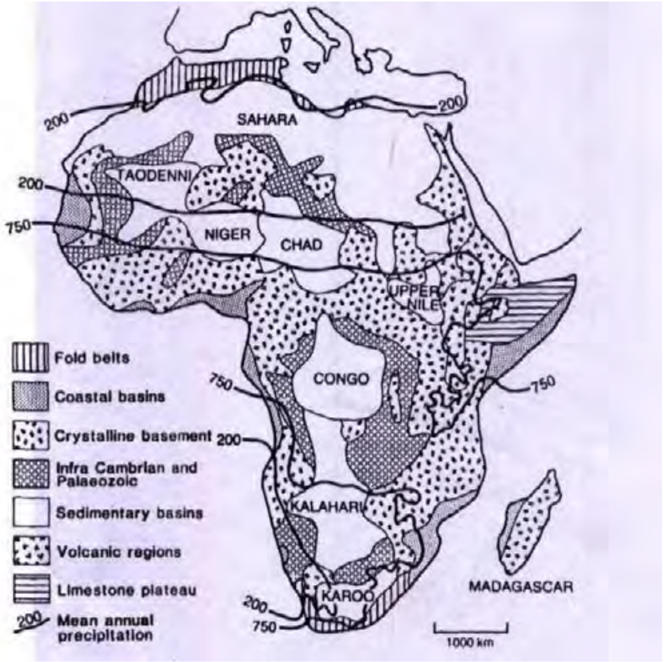


Figure 1 - Groundwater regions of Africa
Source: after Dijon-Les Eaux Souterraines de l'Afrique in Wright (1992)

Reviews of the regional hydrogeology are available in the literature (UNESCO, 1991; GUIRAUD, 1998; MACDONALD; DAVIES, 2000; MAC DONALD et al., 2011; 2012). Guiraud (1998), on the basis of their geological and stratigraphical features, has identified about 12 principal aquifers ranging from the crystalline and metamorphic rocks of Precambrian age in most of West Africa to the Post-Hercynian volcanic formations in East Africa, providing the most complete description of the aquifers in Africa. However, the simplified classification given by Mac Donald and Davies (2000) is used here. These authors have identified, mainly based on their geological characteristics, four provinces represented by the Precambrian “basement” rocks; volcanic rocks; unconsolidated sediments; and consolidated sedimentary rocks.

Precambrian crystalline basement rocks occupy 34 % of the land surface of Africa and are found in West Africa, Eastern Africa (Uganda, Tanzania) and Southern Africa (Malawi, much of Zimbabwe, northern Mozambique and northern South Africa). They comprise crystalline rocks with very little primary permeability or porosity (MACDONALD et al., 2012). Basement aquifers are developed within the weathered overburden and fractured bedrock of crystalline rocks of intrusive and/or metamorphic origin which are mainly of Precambrian age. Sedimentary cover rocks, even when consolidated and of comparable age, usually differ in certain key aspects, most notably in mineralogy with a preponderance of components of lower susceptibility to chemical weathering (quartz sands and clays). Un-metamorphosed volcanic rocks can also be distinguished since they may have significant primary porosity and layering along with associated sedimentary intercalations. Additionally, recent volcanic rocks occur mainly in upland areas where any weathering products tend to be rapidly eroded. Yields of properly sited boreholes in Precambrain basement rocks are commonly 0.1–1 l/s, but can occasionally be as high as 10 l/s.

Consolidated Proterozoic and Palaeozoic sedimentary rocks occupy 37 % of the land area of Africa. Four major categories of aquifers are hosted by these formations. The aquifers within fractured thick sandstone formations such as the consolidated sandstones of the Upper Proterozoic and those of the Cambro-Ordovician contain considerable volumes of groundwater and support high-yield boreholes of 10–50 l/s. The springs flowing from the bottom of the Assaba cliffs (Mauritania) and the Banfora cliffs (Burkina Faso) are outlets of these aquifers. The fractured aquifers in schisto-pelitic formations are often unproductive or only support yields of less than 0.5 l/s. Karstic aquifers are found in thick carbonaceous intercalations and where the dolomitic limestones drain water contained in fractured sandstones. Boreholes in the region of Kiffa (Mauritania) and North of Burkina Faso have provided high-yield fractures (100 m^3/h for the Christine borehole). Aquifers of this kind are encountered among others in RDC, Zambia, Angola, Namibia (Etosha

Basin), Transvaal and Algeria. Aquifers are also found in the loosely cemented sandstones and conglomerates of Upper Palaeozoic around the region of Agades in Niger, the Karoo basin in South Africa, Madagascar and East Africa. The Karoo series often correspond to multilayered aquifer with very variable yields. Volcanic rocks are also present and can contribute as drains. The largest groundwater volumes are found in the large Saharian sedimentary aquifers (North Western Sahara Aquifer, Nubian sandstones Aquifer, Senegalo Mauritanian Aquifer). These aquifers contain fossil water that has infiltrated up to million years ago and have very little present day recharge (GUENDOUZ; MICHELOT , 2006; STURCHIO et al., N. C., 2004)

Unconsolidated sediments are probably the more productive aquifers in Africa and occur in southern Mozambique, central Democratic Republic of Congo, and across much of the Sahel. Unconsolidated sediments are also found along major and minor rivers and in coastal areas, but are often fine textured and therefore of low permeability. Groundwater is associated with sediments, which vary from coarse gravel and sand to silt and clay. They are easy to drill and hand drilling is possible where aquifers are shallow.

Volcanic rocks can be important aquifer resources but the complexity of the geology leads to a high variability in groundwater potential which is related to the presence of fractures. These aquifers are mainly located in the Ethiopian and Kenyan highlands and Southern Africa.

- **Role of groundwater**

Groundwater is important for drinking water, livestock water, and irrigation in Africa. It is of vital importance in meeting the Millennium Development Goals (MDGs) target of accessing clean water, as most of rural Africa and a considerable part of urban Africa are supplied by groundwater. Groundwater also plays a major role in improving food security through expansion of irrigation supplied by shallow and deep wells. Thus, groundwater has high relevance to the development and wellbeing of Africa, if adequately assessed and sustainably exploited. Whilst the potential for groundwater resources development continues to be reported in the literature, a quantitative understanding of these issues remains poor. MacDonald et al (2012) give have estimated the total groundwater storage in Africa to be within a range of 0.36–1.75 million km^3. In most cases the groundwater resources are of excellent microbiological quality and generally adequate chemical quality for most uses. Health problems are associated with elevated concentrations of arsenic and fluoride, or the deficiency of iodine. In some places the total salt content of the water is high and makes the water unsuitable for drinking.

- **Current groundwater use/groundwater use in Africa**

Groundwater development in Africa has been ongoing since the 1930s mainly for rural water supply through deep boreholes and springs (ADELANA; MACDONALD, 2008). However, the current levels of groundwater resource development in Africa are low (except in localized areas and around some major towns and cities. Most of Sub-Saharan Africa is experiencing ‘economic water scarcity’ due to lack of infrastructure investment – rather than ‘water resource scarcity’ as reflected by average rainfall and population density (GWMATE, 2011). The ‘classic problems’ associated with major and excessive groundwater development are, for the moment, very localized, and the priority must be more effective planning and sustainable implementation of groundwater development (often in minor aquifers) to help meet critical social welfare targets and livelihood opportunities. Managed groundwater development, to meet a variety of demands, will be vital in the overall future development process – but priorities and rates of implementation will vary considerably with differing national socio-economic trajectories (GWMATE, 2011). An issue which has generally impeded groundwater development in Sub-Saharan Africa is the high cost of water-well construction compared for example to that elsewhere (most notably in India). The cause is complex – but one factor which can easily be remedied is inappropriate well design and construction, with excessive drilling depth in some ground conditions, and insufficient use of low-cost technology options.

There has however been an increase in intensive groundwater abstraction mainly for town water supply since early 1990s due to the need to have piped water supply systems that can easily be operated and managed by the users (TINDIMUGAYA, 2008). In addition, groundwater normally has good quality and requires little or no treatment unlike surface water. This therefore makes investment and operational costs of groundwater-based systems much lower than those of surface-water based systems. Boreholes with yields greater than 3 m^3/hour are thus normally considered for installation with motorized pumps for piped water supply. The recent drilling of high-yield boreholes (> 20m3/hour) for town water supply has been made in former river channels in various parts of the continent.

- **Groundwater pollution**

In Africa, on average 65% of the population depends upon in-situ sanitation (mainly the basic pit latrine) and around 10% have no sanitation system whatsoever, while 25% of the population is reported as having a ‘flush toilet’ (ADELANA; MACDONALD, 2008; GWMATE, 2011). Some of the population is connected to septic tanks, and it is only in the larger cities of middle-income countries (and a few exceptions) that waterborne sewerage systems exist, and even there, not all dwellings in the nominal area of coverage are connected. In urban areas, only a minor proportion of pit latrines are emptied (and contrary to operational guidelines sometime after construction most are connected to supplementary pits). This information implies a very large subsurface contaminant load and threat of groundwater pollution, especially in situations of highly-populated peri-urban areas underlain by shallow aquifers. Thus, the main groundwater pollution problems are high nitrate concentrations (coupled with other chemical contamination) and the hazard of faecal contamination from pit latrines. The pollution load from unsewered sanitation in some places is variously augmented by industrial effluent disposal, hydrocarbon spillage/ leakage and leachates from solid-waste tipping. The risk of faecal pollution of groundwater, however, should be limited to the most vulnerable hydrogeological conditions – but it currently remains a much more widespread problem because of inappropriate in-situ sanitation unit design/operation and inadequate water well sanitary completion, including the definition of a protective zone (or perimeter) around each water supply well, where pit-latrine or any polluting activity should be prohibited.

3 GROUNDWATER MANAGEMENT CHALLENGES

Intensive groundwater development for domestic water supplies in Africa began in the 20th century in association with urbanisation. Groundwater is a common low-cost alternative to surface water for urban water supplies as it is widely distributed and generally of potable quality. Despite growing dependency upon groundwater for urban water supplies however (TAYLOR et al., 2004), concerns remain over the sustainability of these supplies not only in terms of the magnitude of abstraction but also its quality. Sub-Saharan Africa is the most rapidly urbanising region in the world – 320% from 2000 to 2050 (UNITED NATIONS, 2007). This rate of growth presents major challenges to the provision of not only safe water supplies but also sanitation. First, few reliable groundwater data exist upon which abstraction policies can be based (MACDONALD et al., 2001). Indeed, there has been comparatively limited investment in monitoring infrastructure for groundwater resources relative to surface water resources. Recent research from Uganda highlights the importance of aquifer storage at the borehole catchment scale in determining the sustainability of intensive abstraction for town water supplies (TINDIMUGAYA, 2008). Second, inadequate community hygiene in many rapidly urbanising centres makes urban water supplies derived from shallow groundwater vulnerable to contamination (HOWARD et al., 2005).

At national to regional scales, limited technical and institutional capacities constrain sustainable groundwater development and management in Africa. Since major gaps exist in current knowledge of groundwater resources in Africa and their relationship to climate variability and change, major investments are required in programmes of applied, interdisciplinary research in groundwater and climate. As demand for expertise in hydrogeology and climatology rises with the inevitable increase in groundwater use in Africa, similar investment is also required in training and capacity building in hydrogeology, climatology and allied fields in water policy and management. Such efforts need to recognise that considerable time lags can occur between changes in groundwater resources and their impact on surface water resources and these complicate integrated water resources management including issues around 'cause and effect'.

Furthermore, the development of effective institutions to manage transboundary groundwater resources in Africa is an added challenge. So far over 40 transboundary aquifer systems have been identified in Africa (BGR; UNESCO, 2006) although unilateral, national development and management of these resources currently predominates. This problem is not helped by the fact that surface water catchments are used to define membership to international basin commissions (e.g. Lake Chad Basin Commission) yet discrepancies exist between surface water and groundwater basins. In light of the often interconnected nature of groundwater and surface water resources, one country's use of the resource may impair another country's ability to utilise the resource to meets its demands. For example, international conflict could arise over groundwater use from an aquifer that is not strictly transboundary – groundwater abstraction that denies base flow to a river crossing an international boundary.

Thus, specific groundwater management challenges in Africa include:

a) Inadequate Groundwater Information- One of the challenges to sustainable groundwater resources management and development in Africa is inadequate data and information to guide the planning process. For example, it is unclear how far should production boreholes be sited from one another to prevent competitive abstraction and how far potential sources of pollution should be from groundwater abstraction points. There are thus key practical questions concerning the protection and development of groundwater resources for water supplies, which need to be addressed namely:

- What area around wells and springs must be restricted from competitive abstraction by other wells under different pumping conditions so that either over development of the resource or undesirable reduction in the pumping water level does not occur?

- How many wells can be constructed in one area (i.e., a well-field) without reducing pumping water levels to unacceptably low levels through competitive pumping?

b) Groundwater Pollution – There are increasing incidences of reported outbreaks of water-borne diseases resulting from the consumption of contaminated groundwater in both urban and rural areas. This is attributed to poor location of sanitary facilities, especially pit latrines, whose contents infiltrate and mix up with groundwater. Pollution of groundwater in urban areas is also attributed to dilapidated sewerage systems and solid waste disposal sites whose contents and leachates easily infiltrate and mix up with groundwater.

c) Complex Geology - Groundwater in about 30% of Africa occurs in fractures and weathered zones found in complex geological formations. The complex geology makes understanding of the nature of groundwater occurrence and movement very difficult. This, in turn, presents a serious challenge to sustainable groundwater management and development.

d) Inadequate Technical Capacity - Technical capacity for sustainable groundwater development in Africa is limited. The number of Hydrogeologists is not only small but also their expertise is in most countries low due to the nature of training they receive with most undergraduate education being in geology whith only short courses in hydrogeology. This state of affairs inevitably results in poor quality professional work and hence unsustainable groundwater development.

e) Climate change impacts on groundwater - Current assessments of the impacts of climate variability and change on water resources commonly exclude groundwater. This omission is of particular concern in Africa where current usage and future adaptations in response to climate change and rapid population growth, place considerable reliance upon groundwater to meet domestic, agricultural, and industrial water demands. Climate change and variability have already been observed in Africa and are projected to increase considerably over the course of this century (TAYLOR et al., 2009). Rainfall intensities in most parts of sub-Saharan Africa are projected to increase as a result of global warming and will give rise to more variable (but not necessarily less) river discharge and soil moisture (TAYLOR et al., 2009). The former will exacerbate intra-annual freshwater shortages and the risk of flooding whereas the latter threatens food security through reduced crop yields (TAYLOR et al., 2009). However, current evidence, suggests that the shift toward more intensive precipitation enhances groundwater recharge. As a result, groundwater in Africa could play a strategic role in the adaptation to changing freshwater availability and improving food production and security through groundwater-fed irrigation. Since small-scale farming accounts for 70% of agricultural production in sub-Saharan Africa (UNESCO, 2001), discrete low-yielding aquifers in weathered crystalline rock and fluvial aquifers in river beds may prove fit for purpose as they are self-regulating, naturally solving the age-old problem of allocation and restricting the impacts of local overdevelopment. There is a long history of low-intensity groundwater development (e.g. hand pump abstraction) for domestic water supplies in Africa. Low recharge fluxes (<10 $mm \cdot a^{-1}$) required to sustain such development (TAYLOR; HOWARD, 1996), are expected to occur because rainfall in most of Sub-Saharan Africa exceeds 200 $mm \cdot a^{-1}$. There is little evidence of water-level decline from such low-intensity abstraction; localized depletion is often due to anomalous geological conditions or faulty infrastructure rather than broad-scale resource depletion. Due to the noted variability in Africa's hydrological systems, inter- and intra-annual contributions of freshwater from storage are critical to the sustainability of water supplies and maintenance of aquatic ecosystems (TAYLOR et al., 2009). Considerable inter-annual variability in recharge fluxes has been estimated and observed in Africa (TAYLOR; HOWARD, 1999). From a water management perspective, balancing highly variable and episodic recharge with groundwater withdrawals over decadal rather than annual timescales would likely prove more instructive but there are currently few long-term studies of recharge in Africa to inform such an approach. A quantitative understanding of the relationship not only between climate and groundwater but also the impact of abstraction is severely constrained by the near-absence of very few reliable estimates of groundwater storage in Africa.

f) Management of transboundary groundwater resources- so far over 40 transboundary aquifer systems have been identified in Africa but many of these are managed unilaterally by individual countries. This problem is made worse by the fact that groundwater is often not included in river basin management programs yet it may contribute substantial amounts of water to river flows as is the case in the Lake Chad Basin. Thus, uncoordinated management and development of transboundary groundwater resources will certainly result in conflict over groundwater use in situations where the aquifer is transboundary or where groundwater abstraction affects base flow to shared river courses.

4 OPPORTUNITIES FOR IMPROVING GROUNDWATER MANAGEMENT IN AFRICA

- **Africa Groundwater Commission**

The African Groundwater Commission was established under the jurisdiction of the African Ministers' Council on water (AMCOW) to pay greater attention to the management of groundwater in Africa. This is an opportunity to promote groundwater management in Africa.

- **Mapping and management of transboundary aquifers**

Substantial amounts of groundwater resources occur in transboundary aquifers shared by two or more countries. There are a number of transboundary groundwater resources management programs in Africa aimed at mapping and management of transboundary aquifers and these provide opportunities for sustainable management of groundwater

- **Groundwater monitoring**

Groundwater Monitoring is done with the prime objective of understanding how water levels in aquifers respond to climatic changes and to groundwater abstraction in order to provide quantitative information for effective water resources management. However, most African countries lack groundwater monitoring stations and this limits understanding of the response of groundwater to human and natural conditions. For example, Uganda has a groundwater monitoring network comprising 30 wells from which data is collected monthly and stored in a database. This data provides a basis for decision making regarding sustainable development of groundwater resources. Such monitoring networks and the resultant data sets can be used to raise awareness about the benefits and importance of groundwater monitoring.

In addition to long-term monitoring networks that assess long-term changes due to natural and man-made changes, specific monitoring is done as part of groundwater abstraction licensing. In most countries the water law requires monitoring at all abstraction points based on powered pumps (flow, total pumped volumes and levels) and if well done, these would help to assess the impacts of intensive groundwater abstraction therefore providing guidance on the most effective means of developing groundwater resources. Improvement in the monitoring of groundwater abstractions in pumping wells is clearly needed.

Furthermore, groundwater quality needs to be monitored as well as quantity data. The monitoring is aimed in determining the physical, chemical and microbiological properties of groundwater that determine its fitness for use.

- **Groundwater assessment**

In general, the knowledge of groundwater resources on the African continent is limited although the situation is getting better with improvements in assessment techniques and capacity. There exist a number of groundwater assessment programs, both regional and national, which can provide some useful information on availability and development potential of groundwater. Thus, groundwater assessments need to be given more priority in order to be able to quantity the available groundwater resources that can greatly assist the African countries to meet their water needs, especially in view of the impacts of climate change. Some countries in Africa such as Uganda, for example, are carrying out national groundwater resources assessment aimed at quantifying groundwater resources availability and demand, assessing the quality of groundwater resources, identifying hotspot areas vulnerable to droughts, assessing the economic value of groundwater resources and preparing a strategy for sustainable development of groundwater resources to meet the current and future water demands. Such studies have resulted into a better understanding of groundwater resources in the specific areas. More assessments need to be done regionally and nationally to enable a wider understanding of groundwater for sustainable use.

- **Capacity building in groundwater management in Africa**

A number of groundwater related capacity building institutions and networks exist in Africa contributing greatly to the improvement of the human capacity to manage and develop the continent's resources. These include Africa Groundwater Network (AGW-Net) inaugurated 2008, Cap-Net (UNDP), BGR, WaterNet, WA-Net, Nile IWRM-Net, GWP-SA, as well as Burdon Network of the International Association of Hydrogeologists. These networks and institutions will support the Africa Groundwater Commission in its role of promoting groundwater management and development in Africa.

5 CONCLUSIONS AND RECOMMENDATIONS

Groundwater is important for drinking water, livestock water, and irrigation in Africa. It is of vital importance in meeting the Millennium Development Goals (MDGs) target of accessing clean water, as most of rural Africa and a considerable part of urban Africa are supplied by groundwater. Groundwater also plays a major role in improving food security through expansion of irrigation supplied by shallow and deep wells. Thus, groundwater has high relevance to the development and wellbeing of Africa, if adequately assessed and sustainably exploited. Whilst the potential for groundwater resources development continues to be reported in the literature, a quantitative understanding of these issues remains poor. Although groundwater systems respond to human and climatic changes slowly (relative to surface water systems), climate change still could affect groundwater significantly through changes in groundwater recharge as well as groundwater storage and utilization. These changes result from changes in temperature and precipitation or from changes in land use/land cover, and increased demand. There is therefore a need for ensuring sustainability and proper management of groundwater resources through instituting proper aquifer management practices such as the establishment of groundwater monitoring systems, better understanding of the role of groundwater storage and groundwater discharges in sustaining aquatic ecosystems, understanding the interactions between various aquifers (including transboundary aquifers) and assessing the impact of increased pumping from various aquifer systems on the sustainability of groundwater abstraction. This paper provides an overview of the regional hydrogeological framework, the current state of knowledge of aquifer systems, their development potential and climate change impacts on groundwater, research gaps, and policy implications.

Despite the importance of small-scale farming in Africa, there is little information on the present and potential role of ground water in agriculture. In contrast to its socioeconomic and ecological importance, ground water has remained a poorly understood and managed resource. Widespread contamination of groundwater resources is occurring, and the important environmental services of groundwater are neglected. There appear to be critical shortcomings in the organizational framework and the building of institutional capacity for groundwater. Addressing this challenge will require a much clearer understanding and articulation of the role of ground water's and contribution to national and regional development objectives and an integrated management framework, with top-down facilitation of local actions.

6 ACKNOWLEDGEMENT

Revision of a previous manuscript by G. de Marsily is gratefully acknowledged.

REFERENCES

Adelana, S.M.A. and MacDonald, A.M., (2008) - Groundwater research issues in Africa. In: Applied Groundwater Studies in Africa. IAH Selected Papers on Hydrogeology, Volume 13 (S.M.A. Adelana & A.M. MacDonald Eds.). CRC Press / Balkema, Leiden, the Netherlands.

BGR and UNESCO, (2006) - Transboundary aquifer in Africa. BGR Hannover / UNESCO, Paris.

Environment Agency, (2011) - Groundwater protection: policy and practice (GP3) Part 2 – technical framework. Almondsbury, Bristol BS32 4UD, UK

FAO, (2003) - Review of World Water Resources by Country. Rome

Gleick, P. H., (1996) - Water resources. In Encyclopedia of Climate and Weather, ed. by S. H. Schneider, Oxford University Press, New York, vol. 2, pp.817-823.

Guendouz A, Moulla AS, Edmunds WM, Zouari K, Shand P, Mamou A (2003) Hydrogeochemical and isotopic evolution of water in the Complexe Terminal aquifer in the Algerian Sahara. Hydrogeol J 11:483–495

Guendouz, A., Michelot, J.L., 2006 - Chlorine-36 dating of deep groundwater from northern Sahara. J. Hydrol. 328, 572–580.

Guiraud R (1988) - L'hydrogeologie de l'Afrique. Journal of African Earth Sciences, Vol 7, (3) 519- 543.

MacDonald AM, Bonsor HC, Calow RC, Taylor RG, Lapworth DJ, Maurice L, Tucker J and Ó Dochartaigh BÉ. (2011) - Groundwater resilience to climate change in Africa. British Geological Survey Open Report, OR/11/031. 25 pp. Keyworth, Nottingham., UK

A M MacDonald, H C Bonsor, B Dochartaigh and R G Taylor (2012) - Quantitative maps of groundwater resources in Africa. Environ. Res. Lett. 7 (2012) 024009 (7pp)

A M MacDonald and J Davies (2000) - A brief review of groundwater for rural water supply in sub-Saharan Africa. BGS Technical Report WC/00/33 (30pp). Keyworth, Nottingham., UK

GWMATE (2011) - Appropriate Groundwater Management for Sub-Saharan Africa in face of demographic pressure and climatic variability. World Bank Strategic Overview Series Number 5. Washington D.C., USA

Sturchio, N.C., Du, X., Purtschert, R., Lehmann, B.E., Sultan, M., Patterson, L.J., Lu, Z.-T., Mueller, P., Bigler, T., Bailey, K., O'Connor, T.P., Young, L., Lorenzo, R., Becker, R., Alfy, Z. El, Kaliouby, B., El, Dawood, Y., Abdallah, A.M.A., 2004 - One million year old groundwater in the Sahara revealed by krypton-81 and chlorine-36. Geophys. Res. Lett. 31, L05503, doi:10.1029/2003GL019234.

Taylor, R.G. and Tindimugaya, C., 2011. The impacts of climate change and rapid development on weathered crystalline rock aquifer systems in the humid tropics: evidence from southwestern Uganda. In: International Contributions to Hydrogeology, Vol. 27, Climate change effects on groundwater resources: a global-scale synthesis of findings and recommendations, (eds. H. Treidel, J. Luis-Bordes and J. Gurdak). CRC Press (Chapter 2), pp. 17-32

Taylor, R.G, and Tindimugaya, C (2009) - Groundwater and climate change: Proceedings of the Kampala Conference, June 2008), IAHS Publ. 334, IAHS, Wallingford, UK

Tindimugaya, C. (2008) - Groundwater flow and storage in weathered crystalline rock aquifer systems of Uganda: evidence from environmental tracers and aquifer responses to hydraulic stress. Unpulished PhD thesis submitted to the University of London, UK

Tindimugaya, C. (2004) - Groundwater and water resources management in Uganda- An African Perspective. Paper presented during the Annual Groundwater Seminar for the Irish Association of Hydrogeologists. Dublin, Ireland. Unpublished

Tindimugaya C (2000) - Assessment of groundwater development potential for Wobulenzi town, Uganda. MSc, UNESCO- IHE, Deft, Netherlands, 108pp.

Trenberth, K. E.; Smith, L.; Qian, T.; Dai, A. and Fasullo, J. (2007) - Estimates of the global water budget and its annual cycle using observational and model data. J. of Hydrometorology special section, Vol. 8 p. 758-769.

Wright, E. P. (1992) - The hydrogeology of crystalline basement aquifers in Africa. p1-27. Geological Society, London, Special Publications 1992, v.66; doi: 10.1144/GSL.SP.1992.066.01.01

SUSTAINABLE GROUNDWATER MANAGEMENT

Robert W. Gillham[1]

[1] Executive Director the Water Institute - University of Waterloo. Waterloo, Ontario, N2L 3G1. E-mail: rwgillha@uwaterloo.ca.

ABSTRACT

In 2006, at the request of Natural Resources Canada, the Council of Canadian Academies (CCA) appointed a fifteen-member expert panel to address the question, “What is needed to achieve sustainable management of Canada’s groundwater resources, from a science perspective?” The resulting report, CCA (2009), provides a comprehensive discussion of the principles of sustainable groundwater management, of methods to achieve sustainability and Canada’s status with respect to sustainable management of groundwater. This paper relies heavily on the content of the CCA report, with supplementary material of a more general and international nature.

1 GROUNDWATER SUSTAINABILITY

Groundwater has been used for human consumption and for irrigation for close to 3000 years (the quanats of Persia for example). Nevertheless, aquifer depletion and the sustainability of groundwater resources have been issues of increasing concern for only the past fifty to one hundred years. This interest has been spawned by declining water levels in many aquifers around the world and in response to an explosive increase in the use of groundwater for municipal, industrial and agricultural purposes.

Traditionally, the sustainability of groundwater supplies has been closely associated with aquifer depletion; however, in recent years the trend has been to include other environmental services (ecological health, for example) in considerations of groundwater sustainability. Consistent with modern considerations of environmental sustainability, the Expert Panel of the CCA developed five broad and inclusive sustainability goals:

1. Protection of groundwater supplies from depletion: Sustainability requires that withdrawals can be maintained indefinitely without creating significant long-term declines in regional water levels.
2. Protection of groundwater quality from contamination: Sustainability requires that groundwater quality is not compromised by significant degradation of its chemical or biological character.
3. *Protection of ecosystem viability:* Sustainability requires that withdrawals do not significantly impinge on the contribution of groundwater to surface water supplies and the support of ecosystems. Human users will inevitably have some impact on pristine ecosystems.

The use of the term “significant” in the three foregoing goals implies a notion of what may be acceptable to society in terms of permissible degradation or depletion of the resource. The mechanisms by which society determines what is acceptable are encompassed in the following two goals:

4. *Achievement of economic and social well-being: Sustainability requires that allocation of groundwater maximises its potential contribution to social well-being (interpreted to reflect both economic and non-economic values).*
5. *Application of good governance:* Sustainability requires that decisions as to groundwater use are made transparently through informed public participation and with full account taken of ecosystem needs, intergenerational equity, and the precautionary principle.

It should be noted that the five goals, as expressed by the CCA panel, are highly interrelated and that sustainable management requires that all five goals be met. The following discussion addresses the individual goals, with a particular focus on goals 1 (depletion) and 3 (ecosystem viability).

2 GROUNDWATER DEPLETION

Within the context of sustainable management, it is particularly important that groundwater be recognized as an integral component of the hydrologic cycle. That is, in general and under natural conditions, water is taken into storage as a consequence of infiltration and recharge, and water leaves storage through discharge to wetlands, streams and lakes. At steady state, the recharge averaged over some appropriate time period, such as a year or some small number of years, is equal to discharge averaged over the same time period, and the volume of water in storage remains constant. When groundwater is removed by pumping, the water can come from captured recharge, from captured discharge or from storage. Indeed, if an aquifer is pumped at a steady rate equal to the average rate of recharge, then over time, a new steady state will be reached in which there is no change in storage, but also no groundwater discharge. Historically, the pumping rate at which the rate of water removal is equal to the rate of recharge has been referred to as the safe yield of an aquifer. Provided an aquifer is pumped at a rate equal to or lower than the safe yield, there will be no long-term decline in water levels and thus safe yield is a useful concept with respect to the depletion criterion for sustainability. It is also an attractive concept in that it has a precise physical meaning and, at least in principal, can be determined conveniently from a consideration of water budgets. In spite of its attractive features, the concept of safe yield has fallen into disfavour in recent years because it neglects the ecological and other services provided by groundwater discharge. As an index of the rate at which water can be safely withdrawn from an aquifer, the concept of “safe yield” has been replaced by “sustainable yield.

Though, as we will see, the sustainable yield of an aquifer is considerably less than the yield that will result in aquifer depletion, a great deal of literature concerning the sustainable use of groundwater is based on observations of depletion. With 7% of the world’s renewable fresh water, but only 0.5% of the world population, it is not surprising that CCA (2009) reported no cases of sustained depletion of major aquifers in Canada. Nevertheless, as a consequence of its geographical size and uneven population distribution, local and generally transient instances were noted. Many countries, and particularly those in sub-humid to arid regions are less fortunate.

Depletion of the High Plains aquifer in the western United States is well known (BARTALINO; CUNNINGHAM, 2003, for example). The aquifer has been developed principally for irrigation, and in some areas water levels have declined by more than 100 ft (30m), while in others pumping has become uneconomic as a consequence of the depth to the water table. Bartalino and Cunningham (2003) report numerous cases of groundwater depletion in the US semi-arid to arid regions of the west and southwest. For example, water table declines of between 300 and 500 ft (100 and 150m) were reported for the Tucson and Phoenix areas, 300 ft (90m) for the Las Vegas area and in excess of 300 ft (90m) in some areas of southern California. While it is not surprising to find cases of groundwater depletion in the dryer climatic regions with intensive agricultural production or rapid urban development, numerous cases of depletion (water table declines) were also reported for humid regions; 900 ft (270m) in the Chicago-Milwaukee area, 200 ft (60m) in the Baton Rouge area and significant declines in the Atlantic Coastal Plain, west-central Florida and the Pacific Northwest.

From a more global perspective, Wada et al. (2010) consider parts of the Sahel, South Africa, the central U.S., Australia, India, Pakistan and North-East China to be regions that experience recurrent water stress, and by inference, areas where groundwater depletion could be anticipated. Indeed, using a water budget approach and considering only the sub-humid to arid regions of the world, Wada et al. (2010) estimated that between 1960 and 2000, global groundwater depletion had increased from 126 ($\pm$32) km^3a^{-1} to 283 ($\pm$40) km^3a^{-1}. It was further estimated that the value for the year 2000 was 39 ($\pm$10)% of the total global groundwater abstraction of that year. The suggestion that on the order of 40% of the groundwater being pumped (in sub-humid to arid regions) is contributing to groundwater depletion is startling and symptematic of a condition that is clearly unsustainable. The groundwater footprint concept introduced by Gleeson et al. (2012) is no less startling. Again based on water budgets, Gleenson et al. (2012) determined the size (area) of an aquifer (the groundwater footprint) that would be required to meet the water needs (including contributions to streamflow). These could then be graphically superimposed on the actual aquifers being used for supply. The results showed several aquifers, upper Ganges, north Arabian and western Mexico for example, where the groundwater footprint was vastly greater than the actual aquifer. Gleenson et al. (2012) calculate the area of the global groundwater footprint to be 3.5 $\pm$ 0.7 times greater than the actual area of hydrologically active aquifers.

As a final example, at an estimated total cost of about US $25bn, the Great Manmade River Project of Libya is perhaps the largest civil engineering project that has been undertaken. Water is pumped from the Nubian sandstone aquifer in the south of Libya and transported through an underground pipe network to the northern coastal cities.

There are in excess of 1,300 wells and 2,820 km of pipeline and the system has a capacity of about 6,500,000 m^3/day. Approximately 70% of the water will be used for irrigation of about 155,000 ha of agricultural land. Of particular note, the aquifer receives little or no recharge and isotope analyses suggest that the water could have been in place for up to 40,000 years. In this case, the rate of depletion is essentially equal the rate of pumping. The volume of water in the aquifer is vast however, and though there do not appear to be reliable estimates of the length of time that the water will last, estimates can be found ranging from 60 to 100 years up to in excess of 4,000 years. It is nevertheless the case that the aquifer will, at some point, be exhausted. In the meantime, a society will have developed that has an expectation of adequate supplies of fresh water and a similarly water-rich economic base. Without appropriate long-term planning major societal upheaval would seem inevitable as the source of water dwindles.

3 ECOSYSTEM VIABILITY

Listed previously as sustainability goal No. 3, "sustainability requires that withdrawals do not significantly impinge on the contribution of groundwater to surface water supplies and the support of ecosystems". Under natural conditions, groundwater discharge is a significant contributor to surface water and in particular, is the primary source of baseflow in streams. Maintaining stream flow can be essential to down-stream users and discharge to streams, wetlands and lakes can be essential to the maintenance of healthy aquatic ecosystems.

Though safe yield, as presented in the previous section, protects against substantial and continuing declines in water levels, it does not acknowledge the essential role of groundwater in sustaining stream flow and the health of ecosystems and has therefore largely fallen into disfavour. A comprehensive discussion of this topic is given in Sophocleous (1997). The concept of safe yield has largely been replaced by sustainable yield (ALLEY; LEAKE, 2004; SEWARD et al., 2006). Ponce (2007) defines sustainable yield as "the groundwater yield which is in agreement with the principle of sustainability". Operationally, it can be viewed as the proportion of recharge than can be withdrawn without having an unacceptable influence on streamflow and ecological communities. Thus, as in the case of safe yield, determining sustainable yield requires a similar knowledge of water budgets, with the additional requirement of determining the acceptable degree of disruption to stream flow and ecological factors. Thus it becomes a somewhat subjective parameter, intersecting with matters of policy, governance, economics and public opinion.

Clearly sustainable yield (expressed as a percentage of recharge), will depend upon the quantity of recharge, the local surface water and ecological conditions and the value that the local population places on the surface water and ecological conditions. Ponce (2007), while acknowledging limited experience, suggested 40% as a reasonable value and a range of perhaps 10% to 70%.

There is ample evidence that many aquifers are being pumped at rates greater than the sustainable yield. All of the examples of depletion presented in the previous section are a consequence of pumping at rates greater than the sustainable yield. Furthermore, Sophocleous (2000) showed a substantial decline in the length of perennial streams over the period from 1961 to 1994, in the region of Kansas affected by pumping of the High Plains aquifer. Bartolino and Cunningham (2003) included two photographs of a reach of the Santa Cruz River, one taken in 1942 and the second in 1989. The first shows what appear to be healthy stands of mosquite and cottonwood along the river, while the latter photographs show the trees to have largely disappeared as a consequence of lowered groundwater levels. In the Snake River basin in Idaho, 750 farmers, businesses and cities were ordered to shut down 1,300 wells in order to restore reduced spring discharge. Up to 450 km^2 of farms, more than 125,000 dairy cattle, several food processing plants and 14 cities were affected (BARKER, 2004, as presented in KONIKOW; KENDY, 2005). While the intentions to restore the depleted aquifer may be commendable, the actions could have serious implications for the livelihood of thousands of residents. Clearly, and as demonstrated by this example, determining appropriate values of sustainable yield will generally require consideration of numerous competing interests. As pointed out in Konkow and Kendy (2005), there is frequently poor coordination between surface- and groundwater use, inhibiting conjunctive management.

The CCA (2009) report did not identify instances in Canada where groundwater withdrawal had resulted in a prolonged and detrimental effect on streamflow and ecological communities. The report noted however that there is an insufficient understanding of the relationships between groundwater and ecosystem health and that there is no standardized method for incorporating instream flow protection into laws and regulations. Similar sentiments have been expressed with respect to other jurisdictions, noting poor coordination between the management of groundwater and surface water (KONIKOW; KENDY, 2005 for example).

4 GROUNDWATER QUALITY

Though the sustainability of groundwater supplies is commonly considered in terms of quantity (safe yield or sustainable yield for example), management of quality is equally important. Indeed, there are both natural and anthropogenic factors that can affect groundwater quality and its sustainability. Arsenic is perhaps the most common and wide-spread of the natural contaminants, with extensive groundwater degradation in parts of Asia (Bangladesh, China, India, Nepal) and in South America (Argentina and Mexico). Arsenic contamination is also common in the U.S. west, midwest and northeast. Fluoride, and to a lesser degree radon, are other examples of natural contaminants. Natural contaminants may occur throughout an aquifer, or across large regions, limiting management options such as locating alternate supplies or dilution to below the drinking water limit with water of better quality. There may be no option other than treatment at the wellhead or at point-of-use, though this can be costly and can introduce significant maintenance problems.

A second type of natural contamination, though one could argue that the cause of quality degradation is anthropogenic, is that induced by pumping. As an aquifer is over-pumped, water is withdrawn from progressively greater depths, and commonly, the dissolved solids content of groundwater increases with depth. Ultimately the water may become unusable. Similarly, in coastal areas, pumping can induce salt water intrusion. Management of these potential problems can involve alternate sources of water or adjustment of pumping rates and schedules. CCA (2009) relates an example from Orange County, California, where a groundwater ridge was created, by injecting a mixture of deep aquifer water and secondary effluent, to prevent further inland migration of saltwater.

Anthropogenic sources of groundwater contamination are commonly separated into distributed and point sources. Of the distributed sources, agricultural chemicals, including nutrients and pesticides are undoubtedly the most common, and of these, nitrate is perhaps the most widely distributed of all groundwater contaminants. CCA (2009) considered Prince Edward Island (PEI) as an example. Prince Edward Island is the smallest of the Canadian provinces, with an area of 5,560 km^2 and a population of 140,204. Of particular relevance to this discussion, virtually the entire freshwater requirements are obtained from groundwater, and agriculture, particularly potato production, is the primary economic base of the province. As shown in CCA (2009), much of the groundwater has elevated nitrate values, and in some catchments as many as 20% of the wells exceed the drinking water limit for nitrate (10 mg/L

NO^-_3 – N). Furthermore, with as much as 70% of streamflow being derived from groundwater, streams have elevated nitrate concentrations, contributing to an increase in the incidence of anoxia and excessive algal growth, leading to significant damage to the shellfish industry. Attempts are being made to control the nitrate problem through improved management practices, or in the case of domestic supply wells, through well head protection zones. It is not yet evident that these actions are having the desired beneficial effect.

The occurrence of elevated nitrate concentrations in groundwater has been recognized for over 50 years, and in areas under intensive agricultural production, is the most common groundwater contaminant. In spite of this prevalence, and a growing concern, attempts to control or reduce nitrate contamination show little evidence of success. Improved nutrient management may prove to be beneficial, but because of the slow movement of groundwater, it may take several years to observe improved groundwater quality in response to reduced application rates. Furthermore, methods of nitrate removal, such as anion exchange, are relatively expensive. With greater intensification of agricultural production, continued contamination of groundwater by nitrate seems inevitable and this could very well lead to reduced sustainability of supply. It should be noted here, that while nitrate contamination may reduce sustainability with respect to human consumption and aquatic ecosystems, the water may be entirely suitable for irrigation and perhaps other industrial uses.

Point sources of groundwater contamination are extremely variable in both size and composition, and though the source area may be small, the zone of affected groundwater can be large, possibly on the order of a few kilometers in length. Common examples of point sources of contamination include private waste disposal facilities, landfills, mine sites, gas stations and industrial sites. Specific contaminants include nutrients such as nitrate, heavy metals and other inorganics, petroleum products and a wide range of synthetic organic compounds including industrial solvents such as trichloroethene. Industrial solvents are particularly problematic in that they were used extensively long before they were recognized to have adverse health effects and before it was recognized that they were entering groundwater. Furthermore, they are relatively mobile and persistent in groundwater environments and as a consequence of low drinking water limits, commonly on the order of 5 μg/L, small quantities of these chemicals can contaminate very large volumes of water. It has been estimated that there are over 100,000 sites in the United States contaminated with industrial solvents, while in Canada, though not limited to industrial solvents, it is estimated that there are 5,000 contaminated sites on federal government lands and 28,000 sites on non-federal lands (ECO CANADA, 2008). Comparable numbers can be found for most developed countries. Though it is clear that point-source contamination can have a significant effect on the sustainable use of groundwater in the developed world, many countries have yet to undertake a systematic survey of groundwater quality, and thus the potential influence, particularly in developing countries, is uncertain.

Various efforts are being made to protect groundwater supplies against point sources of contamination. With the growing awareness of the incidence of contamination (and the resulting cleanup costs), industry is generally operating in more environmentally conscious manner, and thus the occurrences of contamination have decreased markedly over the past decade. Nevertheless, a large number of legacy sites continue to pose a significant risk. In the U.S., management of these sites has been addressed through legislation requiring cleanup of contaminated sites, including contaminated groundwater, while in Canada, a more risk-based approach has been adopted. Though the requirements vary somewhat from province to province, in general, it is required that wellhead protection zones be mapped, that potential sources of contamination within those zones be identified and that the level of risk to the water supply be determined. Corrective action appropriate to the level of risk can be required. This approach presents several challenges. Wellhead protection zones are generally mapped using mathematical models, and while these are becoming increasingly sophisticated, they continue to be approximations of the actual physical/chemical systems, and determining appropriate parameter values for geologic materials that are, with few exceptions, heterogeneous, will continue to be a challenge. Furthermore, historical records of land use are frequently incomplete leading to uncertainty in the identification of potential sources of contamination. When significant risk is identified, corrective action will be determined on the basis of site-specific conditions. Options could include removal of the source of contaminants or various types of in situ or wellhead treatment. These are generally expensive however, and abandonment of the well may be the more practical alternative. It is also common to impose land-use restrictions within wellhead protection zones. This introduces the problem of imposing restrictions on private land, or purchasing the land within the protection zones. The potential economic, social and governance difficulties associated with these measures are exacerbated by the inherent uncertainties in the actual extent of the protection zone.

5 ECONOMIC AND SOCIAL WELL-BEING

The availability of water, including groundwater, has a significant influence on almost all aspects of our socio-economic environment. In addition to the economic benefits derived from the direct use of water, water availability can have a major influence on land values, tourism, small-craft navigation and the hunting and fishing community. Water also has important spiritual, cultural and aesthetic values. The CCA (2009) report noted the importance of respecting all of these values in sustainably managing groundwater. The report also noted that in Canada, there has been no comprehensive attempt to place a value on water and noted in particular, that a method or approach to value the benefits from maintaining healthy ecosystems is poorly developed.

The report also noted that in deriving the net benefit of water withdrawal, the costs needed to be considered. These were considered to fall within two categories; the current cost associated with withdrawal and provision to the user, and secondly, the costs associated with the lack of availability to future users (intergenerational equity). If water is used sustainably, then the benefits should be maximized, and there should be no costs associated with the lack of opportunity for future users.

Frequently there will be competing interests. It may be decided, for example, that for a particular situation, the social and economic benefits of overexploiting on aquifer outweigh the benefits of sustainable management. As noted previously, the High Plains aquifer of the U.S. has been overexploited for several decades, resulting in significantly declining water levels. The primary benefit is the greatly increased value of agricultural production, balanced against the direct costs of extraction and distribution. In this case however, some regions are now facing the reality of intergenerational inequity, as pumping has become impractical in some regions of the aquifer. Current and future generations will not be able to share in the benefits of the water that was once there. The economic benefits realized over the past several decades may well justify the unsustainable rate of development of the aquifer. However, this cannot be determined unless a full accounting of benefits and costs (including intergenerational considerations) is performed.

Though cost-benefit can be performed on an aquifer or even on a national scale, there are also important international considerations. In the High Plains aquifer, as the aquifer is depleted, production is likely to return to dry-land practices. The effect on the economics of production and on the income of producers may not be exceptional, but there will be a large decline in production. Should this be the case in the many large aquifers throughout the world that are being managed unsustainably, then one must consider the potential for a decline in global food production.

6 APPLICATION OF GOOD GOVERNANCE

The development and implementation of policies concerning groundwater management and sustainability are influenced by a wide range of factors, and frequently by competing interests. Restricting permits for withdrawal of groundwater, imposing land-use restrictions in wellhead protection zones, restricting land development in groundwater recharge zones and water pricing are but a few of the issues that are likely to lead to controversy. To address these issues fairly and effectively, the governing bodies must first have complete and reliable information. In addition, criteria for good governance, as listed in CCA (2009) include inclusiveness, participation, transparency, predictability, accountability and the rule of law. Though technical information concerning the groundwater resource and its sustainability are essential for informed decision making it is not sufficient. Community values and socio-economic factors must also be considered in the decision-making process. As noted previously, methods for evaluating ecosystems and ecosystem services are not well developed. Without an appropriate and comparable method for placing a value on ecosystems, decisions are likely to be made in favour of socio-economic factors, at the expense of ecosystem interests. It is also in the character of most special interests, and indeed human nature, to place greater value on near-term gain, at the expense of long-term values. These tendencies clearly conspire against sustainable management of groundwater resources.

Though governance policies and decisions that encourage sustainable management are clearly desirable, as we have seen over the past several decades, the need for water is commonly served at the expense of sustainability. While this is a perfectly valid management decision, it is important that the long-term implications of the decision be recognized and that the policy makers accept responsibility for proposing contingencies for the time when the groundwater resource is no longer viable.

As stated previously, sustainable management of groundwater should be considered within the context of the full hydrologic cycle, and as recommended in numerous reports (including CCA, 2009) management should occur at the scale of a watershed. In general, these criteria are not well served by existing governance structures. As noted by Konikow and Kendy (2005), surface water and groundwater are commonly administered by separate agencies, leading to inefficiencies in management. In Canada, as elsewhere, there are multiple agencies in three levels of government with overlapping responsibilities, leading to inefficiencies, and the absence of a clear set of shared priorities. While some of the difficulties associated with the current fragmentation might be overcome by transferring greater authority and responsibility to local municipalities or watershed authorities, this approach would only be successful if the necessary financial and human resources were made available.

REFERENCES

Alley, W.M. and S.A. Leak, 2004. The journey from safe yield to sustainability. Ground Water, 42: 12-16.

Barker, R., 2004. Farms, business, cities face water cutoff: depletion of Snake River aquifer threatens livelihoods in S. Idaho. Idaho Statesman, March 28, 2004.

Bartolino, J.R. and W.L. Cunningham, 2003. Ground-water depletion across the nation. USGS Fact Sheet-103-03.

CCA, 2009. "The Sustainable Management of Groundwater in Canada." The Council of Canadian Academies, 180 Elgin Street, Ottawa, ON Canada K2P 2K3. 252 pp. Available in electronic form www.scienceadvice.ca.

ECO Canada, 2008. "When Supply Does not Meet Demand: Labour Gaps and Issues in Canada's Contaminated Sites Sector".

Gleeson, T., Y. Wada, M.F.P. Bierkens and L.P.H. Beck, 2012. Sustainable water balance of global aquifers revealed by groundwater footprint. Nature, 488:197-200.

Konikow, L.F. and E. Kendy, 2005. Groundwater depletion: A global problem. Hydrogeology Journal, 13: 317-320.

Ponce, V.M., 2007. Sustainable yield of groundwater. Civil, Construction and Environmental Engineering, San Diego State University.

Seward, P., Y. Xu, and L. Brendock, 2006. Sustainable groundwater use, the capture principle, and adaptive management. Water SA, 32: 473-482.

Sophocleous, M., 1997. Managing water resources systems: Why "safe yield" is not sustainable. Ground Water, 35: 561.

Sophocleous, M., 2000. From safe yield to sustainable development of water resources – The Kansas experience. Journal of Hydrology, 235: 27-43.

Wada, Y., L.P.H. van Beek, C.M. van Kempen, J.W.T.M. Reckman, S. Vasak and M.F.P. Bierkens, 2010. Global depletion of groundwater resources. Geophysical Research Letters, October 2010.

SUSTAINABLE MANAGEMENT OF GROUNDWATER[1]

Uri Shamir[2]

[1] "Enhancing Water Management Capacity in a Changing World: Science Academies Working Together to Increase Global Access to Water and Sanitation", Inter-Academy Panel (IAP), Inter-American Network of Academies of Sciences (IANAS) & Brazilian Academy of Sciences, Sao Paulo, Brazil, 24-27 June, 2012.

[2] Faculty of Civil and Environmental Engineering. Steven and Nancy Grand Water Research Institute. Technion – Israel Institute of Technology. Haifa 32000 ISRAEL.

ABSTRACT

Groundwater aquifers store and convey water, and are important elements in water resources systems, by themselves and in conjunction with surface waters and other sources, including reclaimed wastewater effluents and desalination. Some global data place the abstraction and use of groundwater into proportion. The characteristics of groundwater aquifers are detailed and discussed as they pertain to sustainable management. A few cases are used for demonstration.

1 INTRODUCTION

Groundwater is water that is stored and flows in geological formations underneath the surface, in depths that range from a few meters (sometimes less) to many kilometers. In fact there is no real bottom limit. Still, in the context of water resources management the layer that is relevant may reach 1-5 kilometers, while the layer from which water is extracted seldom goes deeper than 1500 meters from the surface, and frequently no more than 100-200 meters. Wells to depths of 1000-1500 meters are relatively rare. The reasons are the technology of drilling and tapping layers at such depths, the high costs associated with drilling and operating, and the vulnerability of the well equipment to malfunction.

Hence, practical considerations focus our attention of groundwater at depths of tens to hundreds meters. Geological layers may have low permeability (aquitards) or be so dense that they do not hold water of any significant quantity (aquicludes). Layers that hold and convey water are aquifers. Most often, aquifers are interspersed with less pervious layers, with local or large horizontal extent, so the hydro-geological formation is complex.

Groundwater interacts with water at the surface in a variety of ways. First, surface water generated by precipitation in the source of recharge, whether directly from the surface (in phreatic aquifers) or flowing from recharge zones further upstream and from streams which cut the topography and infiltrate part of their water into the ground. Groundwater is the source of springs that are outlets in the topography towards which groundwater flows. Groundwater also flows to streams, rivers and oceans, a process that has an important role in carrying pollutants that have entered the groundwater towards sinks and helps in flushing the aquifer and removing the pollutants to a more receptive environment.

Groundwater is invisible to the popular and untrained eye, hence lacks adequate attention by the public and decision makers alike. In many countries and locations, development of groundwater for water supply comes only after surface waters have been exhausted in quantity or their quality has deteriorated. This was very much true in the first half of the 20th century, started changing towards its latter part, and has now been overtaken by almost universal recognition that groundwater is an important and valuable source and storage reservoir.

In this paper we shall not delve into the physics and hydraulics of aquifers, assuming that the reader has sufficient background and knowledge about aquifers. We will therefore view the aquifer as an entity that has relevance for water resources management, by virtue of storing and conveying water that can be extracted and used, water that is also characterized by the distribution of its quality in time and space.

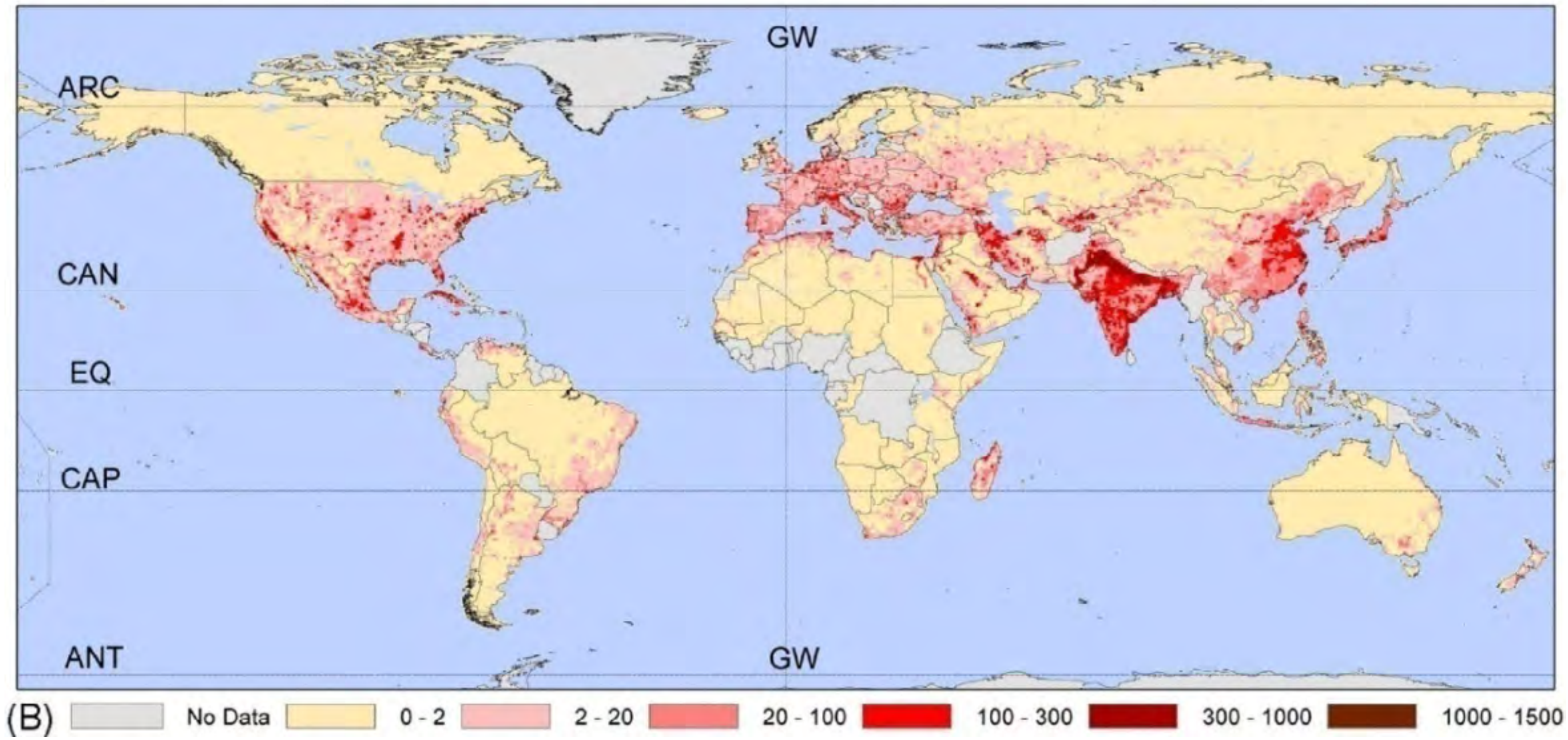


Figure 1 - Groundwater abstraction in 2000 (in mm/year), allocated to 0.5° x 0.5° grid cells by the PCR-GLOBWB model (WADA et al., 2010) [WWDR4, Chapter 3.2.1]

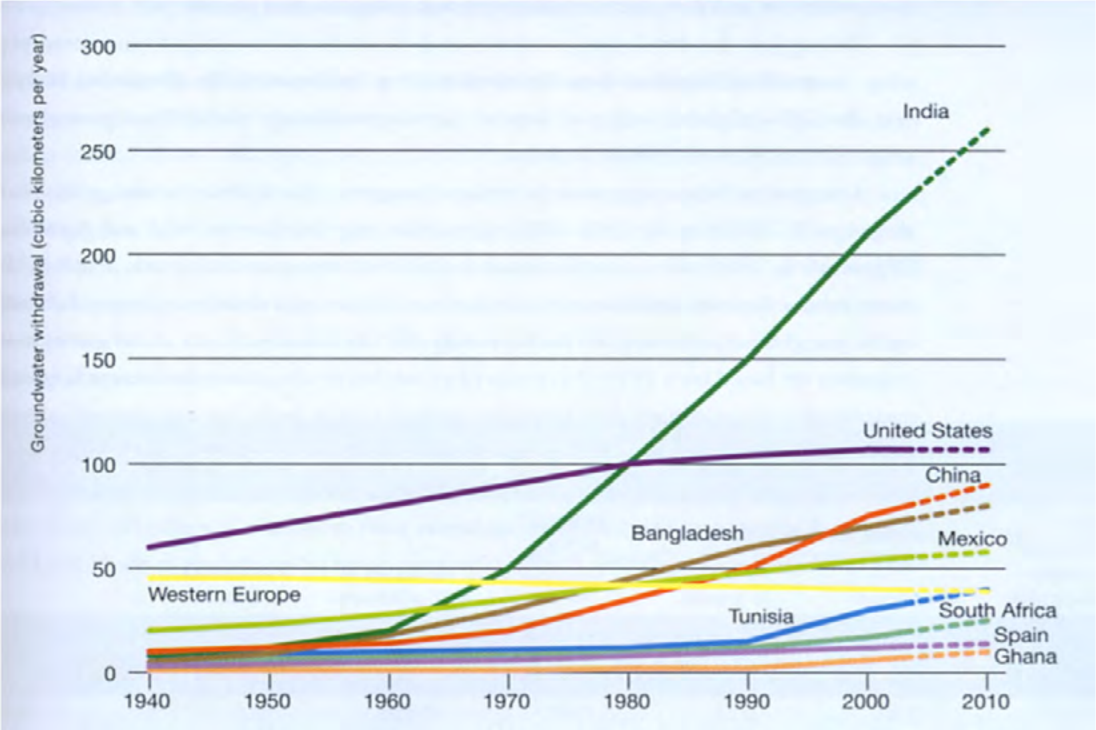


Figure 2 - Groundwater abstraction (km³/year) trends in selected countries (SHAH et al., 2007) [WWDR4, Chapter 3.2.1]

Figure 1 maps the abstraction of groundwater (in mm/year) around the world in 2000, while Table 1 provides the annual abstractions in 2010 (in km^3/year) in the top 10 countries. Figure 2 indicates the rise in groundwater abstraction in the years since 1940. Table 2 shows the 2010 distribution among the continents and world total of total groundwater abstractions, the distribution of uses, and the groundwater proportion compared with surface water abstractions and the total abstractions (WWAP, 2010). Note that figures in absolute terms of groundwater quantity (mm/year or km^3/year) do not tell the whole story, as they should be compared with the annual recharge of the groundwater (or, at least, compared to the annual precipitation) so that sustainability of groundwater abstraction can be estimated. These maps and tables indicate:

Table 1 - Top 10 Groundwater Abstracting Countries as of 2010 [WWDR4, Chapter 3.2.1]

Country	Abstraction (km^3/year)
1. India	260
2. USA	108
3. China	90
4. Iran	80
5. Bangladesh	78
6. Pakistan	74
7. Mexico	57
8. Tunisia	38
9. South Africa	23
10. Saudi Arabia	21

Note: Nearly 70 percent of the global groundwater abstraction takes place in these ten countries

Table 2 - Key estimates on global groundwater abstraction (reference year 2010) [WWDR4, Chapter 3.2.1]

(continue)

Continent	Groundwater abstraction [1]					Compared to total water abstraction	
	Irrigation	Domestic	Industrial	Total		Total water abstraction[2]	Share of groundwater
	km^3/yr	km^3/yr	km^3/yr	km^3/yr	%	km^3/yr	%
North America	78	22	11	111	10	524	21
Central America and the Caribbean	44	10	16	70	6	149	47
South America	16	10	7	33	3	182	18
	km^3/yr	km^3/yr	km^3/yr	km^3/yr	%	km^3/yr	%
Europe (including Russian Federation)	40	50	21	111	9	497	22

(continuation)

Continent	Groundwater abstraction [1]					Compared to total water abstraction	
	Irrigation	Domestic	Industrial	Total		Total water abstraction[2]	Share of groundwater
Africa	86	20	4	110	9	196	56
Asia	544	118	59	722	62	2257	32
Oceania	5	1	2	8	1	26	30
WORLD	813	231	121	1165	100	3832	30

[1] Estimated on the basis of IGRAC (2010), Shah et al. (2007), and Siebert et al. (2010)
[2] Average of the 1995 and 2025 'business as usual scenario' estimates presented by Alcamo et al. (2003)

- the large dependence of certain countries, notably India, on groundwater;
- the great importance of groundwater in the overall balance of water supplies, especially in parts of the world with large and dense populations;
- the huge upward trend of groundwater abstractions in India, and the upward trend in China, Mexico, Bangladesh;
- the flattening of groundwater abstractions in the US;
- the highly uneven distribution of extractions in different parts of the world;
- the paucity of groundwater extraction in Africa and Latin America.

While these figures are of general interest, the real situation of groundwater use is very much more local, over distances no greater than tens, sometimes maybe hundreds, of kilometers. Since aquifers have slow temporal response (see section 2). In a recent publication devoted to a "Water Vision for 2050" (ASCE-EWRI, 2012) George Pinder (2102) stated that there are still open issues for the study of groundwater. Among them:

- Current groundwater management practices are not sustainable: the extraction exceeds the sustainable value;
- The development of a strategy for addressing nitrogen and phosphorous contamination in groundwater remains an open problem;
- Groundwater flow and transport simulation remains an open field for further development;
- Drilling technology is 2050 will be largely as it is today;
- By 2050 the value of GW will be recognized more than today.

The World Water Development Report No. 4 (WWAP, 2012) carries important messages regarding groundwater. Among them:

- About 2 billion people worldwide depend on groundwater supplies, which include 273 transboundary aquifer systems;
- Nitrate is the most common chemical contaminant in the world's groundwater resources;
- An estimated 148 states have international basins within their territory, and 21 countries lie entirely within them;
- During the twentieth century an unprecedented 'silent revolution' in groundwater abstraction took place across the globe. The global groundwater abstraction rate has at least tripled over the past 50 years, significantly boosting food production and rural development;
- No matter how large the volumes of water contained in these aquifers may be the fact that many of them are non-renewable means they can eventually be mined to exhaustion if their use is not managed properly;
- Despite these real concerns over unsustainable abstraction rates and pollution, groundwater resources, if carefully managed, can make a major contribution to meeting the demand for water in the future and to adapting to climate change.

2 CHARACTERISTICS OF AQUIFERS RELEVANT FOR WATER RESOURCES MANAGEMENT

Aquifers as water resources systems have many characteristics that are salient for their management as elements in a local or regional water resources system. Some differentiate groundwater from surface water sources, characteristics that should be borne in mind when the system depends on groundwater alone and even more so when the system has groundwater and surface water sources, and also when the sources include import from adjacent of far sources, and/or desalination plants. The following sections describe and discuss these characteristics.

2.1 LARGE SPATIAL EXTENT

Aquifers have a large lateral extent, and can therefore be developed and managed in conformance with the spatial location of the consumers, and, obviously, in identification of the locations where water can be developed and extracted.

2.2 LARGE VOLUME

Aquifers usually have large to very large volume, hundreds to thousands of cubic kilometers. An aquifer with storativity 0.2 stores over an area of 10 square kilometers 2 mcm (million cubic meters) per one meter of water surface elevation, or: an aquifer of 1,000 square kilometers with the same storativity can yield 2,000 mcm million cubic meters of water when the level is lowered by 10 meters, a very large quantity indeed.

2.3 STORAGE CAPACITY

A common view is that aquifers are sources of water. In fact they should be viewed as storage reservoirs, fed by infiltration of precipitation, return flows from surface uses (irrigation), inflows from adjacent rivers of other aquifers (above, below, sideways), and intentional recharge of captured surface water or even treated sewage. Operation of an aquifer as a storage reservoir requires good information about its properties of storativity, transmission and dispersion, and, in particular the natural flow patterns and how they will change when levels are changed in space and time. Aquifers lose through evaporation and evapotranspiration less than that lost by evaporation from open water surfaces, but may lose more through flow into adjacent water bodies or the ocean, in patterns that are difficult to control. Sea water intrusion in coastal aquifers is a loss of storage volume and possibly pumping capacity in the interface zone, but can also be seen as a useful management strategy in controlling the storage of the aquifer.

Consider some examples of the properties discussed above. The Guarani Aquifer, an international water body, is located in Argentina, Brazil, Paraguay, and Uruguay, covers an area of some 1,200,000 km^2, with a thickness of 100 to 1,000 meters. The water volume is estimated at some 37,000 km^3, probably the largest volume of a single aquifer in the world, at least among those that are accessible for extraction. See Chapter 7 for more detail.

Israel's Coastal Aquifer is very much smaller, but no less important to the population that depends on its water, lies along some 130 km of the Mediterranean Coast with width between 10 and 30 km, a total area of some 1,900 km^2. Its thickness is quite similar to that of the Guarani, namely about 200 meters at the Mediterranean Coast, reducing on its Eastern boundary to a few meters, and has a number of sub-layers (sub-aquifers) separated (at least partially) by impervious layers. It is one of two major aquifers in the area between the Mediterranean Sea and the Jordan Rover, the other being the Mountain Aquifer, which underlies the West Bank, and is shared by Israel and the Palestinians (see Chapter 7).

The Dan Region plant in central Israel treats and infiltrates some 130 mcm/year of wastewater effluents in a SAT (Soil-Aquifer-Treatment) facility, water that is then pumped through a ring of wells around the infiltration areas and delivered for irrigation in the south of the country. The quality of the pumped water meets all current potable water standards, but the decision has been to deliver to agriculture, as there is no certainty with respect to residual materials that may be found in the pumped water at some later time to be harmful to humans.

There also two runoff capture and infiltration facilities in Israel that have been in use for several decades to recharge groundwater. Some dual-purpose wells are also used for recharge of winter flows that are pumped in summer. These last two facilities have seen little use in recent years, due to the severe shortage experienced in Israel and the region, but they are ready to be used when the situation will improve (with the very substantial expansion of the desalination program). It may even happen that desalinated water from the plants will be injected into aquifers, to help in balancing the constant production of the desalination plants and the variable demands at different times of the year.

2.4 OPPORTUNITIES FOR GRADUAL DEVELOPMENT

Since extraction is through wells, each with a relatively small capacity, development of the aquifer as a source is gradual. This makes it possible to adjust the production to the developing requirements, and thereby also spread the cost accordingly. The conveyance systems on the land surface, to deliver well water to a grid, may constitute a relatively large part of the cost, depending on the location of the consumers and of the wells. When individual wells, or a small group of wells, is developed for a consumer who is practically on site - as was almost always the case in the early days of a country or region's development – the whole system develops gradually in accordance with needs and capabilities.

2.5 VULNERABILITY TO POLLUTION

Aquifers have a wide lateral extent, frequently in several managing jurisdictions, are affected by human activities above them that generate pollutants - agriculture, industry, urban development, transportation, landfills – and are "hidden from the public eye". During the development phases of practically all countries of the world, until the middle of the 20th century, states were almost unaware of the pollution "time bomb" that was being created underground by these activities and paid little attention to it. In the latter part of last century it became increasingly evident that the damage to the groundwater as a source of usable water is very substantial and has a strong effect on water supplies. While some of the pollutants occur naturally in groundwater (e.g., arsenic in Bangladesh), most of the cases around the world can be traced to the human activities listed above.

2.6 FILTERING CAPACITY

Flow through porous layers can help in filtering out undesired matter, such as organic matter that arrives with surface water through the unsaturated zone, such that the water in the saturated zone is of better quality. This is especially true when reclaimed wastewater is infiltrated into the aquifer, as is becoming more common in many parts of the world. The Dan Region Wastewater Treatment and Reclamation Facility in central Israel (Mekorot, URL) has an annual capacity for infiltrating up to 180 MCM/year of treated wastewater effluents. The water then resides in the aquifer for a few years, adding Soil Aquifer Treatment (SAT) to the treatment chain. The water is then pumped by a ring of wells around the infiltration basins and delivered over some 100 km for agriculture in the south of the country. The upper layer of the aquifer in the infiltration basins, usually just a few centimeters, acts as the primary filter, so that after a certain time the layer may become clogged and is removed, while the remaining layers are turned over and refreshed to restore their infiltration capacity.

2.7 MIXING OF WATERS WITH DIFFERENT QUALITIES

Water flowing into and in aquifers mixes with other water bodies. Infiltrating water of lower quality into the aquifer, with a well-designed injection and pumping patters (in time and space) can be an effective tool for increasing the total amount of usable water. Some of the examples given above indicate this: treated wastewater effluents injected into a good-quality aquifer or, alternatively, injection of desalinated water into an aquifer with water of inadequate quality for specified uses can yield larger amounts of usable water.

2.8 SLOW TEMPORAL AND SPATIAL RESPONSE

Points at a distance in an aquifer are slow to "communicate". Water extracted at one point has a slow influence on levels at points a few kilometers or even hundreds of meters away. There is an even slower response of water quality, as travel times of solutes or pollutants as quite long. Hence, cells of the aquifer are part of a whole, and should be treated as such, and still the response of changes at one spot is not communicated to other points further way. This in contrast with, say, a lake, where the transfer across time and space is much faster. This difference in temporal response of surface and ground waters is most important for managing a regional water system. While the discharge in a river responds immediately (hours, days) to a drop in precipitation, the groundwater aquifer "feels" it only seasons or even years later. Therefore, a clever operational scheme of a system with surface and ground sources may be to allow the groundwater to replenish over several or many years and be ready to back the surface source when a rare drought occurs. Having provided the backup for the surface supply it can then be allowed to replenish when the surface source bounces back.

2.9 REMEDIATION DIFFICULT

The same properties mentioned in the previous point as being positive for management create a problem when the aquifer is to be replenished by artificial recharge and/or water quality is to be remediated. Once an aquifer is drawn down beyond some desired limit (the lower "Red Line") and/or is polluted it may take years or decades, and even much more, to restore the storage and, even more difficult, to improve the water quality, whether by local (hundreds of square meters) remediation of a pollution patch (e.g., from a leaking fuel storage) or an area-wide plan to restore an aquifer to usable condition after anthropogenic pollution from agricultural or industrial activities. Such remedial actions can take years to compete, and even when they are done the aquifer may still have residual concentrations of pollution, rendering the water usable only by pump-and-treat schemes.

2.10 COMPLEXITY OF STRUCTURE AND PERFORMANCE

Groundwater aquifers are complex physical systems, whose geometry and properties are difficult to ascertain. Even when there are substantial amounts of drilling, flow and quality mentoring data over long periods, there is always uncertainty regarding the properties of the physical system and its response to drivers, including precipitation and recharge from precipitation, response to pumping patters in time and space, chemistry in the natural system and resulting from inflows with different qualities. This has been the attitude in most countries for much of the last 100 years: groundwater is out of sight, too complex to comprehend, and viewed as a source. Still improved understanding of low and transport processes, much more sophisticated models of flow and quality processes, and extended monitoring and data bases have brought aquifers closer to being considered storage reservoirs with slow and long term behavior that should be considered as operational storages.

2.11 CALCULATION OF NATURAL AND INTENTIONAL/PLANNED REPLENISHMENT

Natural replenishment comes from precipitation, streams and lakes, and lateral flows from adjacent groundwater bodies. Losses from aquifers are though evaporation (small) and evapotranspiration, flow to streams, lakes and seas, and to adjacent groundwater bodies, and – obviously – extraction by pumping through wells. Intentional infiltration of surface waters from streams and infiltration facilities, including infiltration of properly treated wastewater effluents, as well as infiltration in urban areas that are designed according to Water Sensitive Planning (WSP) guidelines (CARMON; SHAMIR, 2010). All these enter and exit the groundwater aquifer, whose properties are always known only partially, making it very difficult to calculate the water balance and in it the rate of annual natural recharge from precipitation, which is the primary determinant for management of the aquifer as an element in a water resources system.

There are two methods for calculating the natural recharge from precipitation into an aquifer. The first is to have an extensive monitoring system that can map the changes in water levels from one year to the next, by regular measurements with an extensive network of wells, and/or aided by remote sensing and satellite imagery (BECKER, 2006). Nowadays, satellite imagery can provide a good estimate of the volume of groundwater in an aquifer. The volume in storage can be calculated from the water level map (assuming the storage coefficient is known with reasonable accuracy

– which is not easy), and the difference in storage is the net contribution of all sources and sinks – including, obviously, pumping. Another method for estimating the replenishment from precipitation is by using recharge coefficients that convert the depth of precipitation (in mm/year) to the amount of recharge (also expressed in mm over the area). Application of the two methods (if both are adequate data for application of both) often reveals considerable differences between the two results.

2.12 RENEWABLE VERSUS FOSSIL AQUIFERS

Aquifers that are recharged on an annual or even multi-year basis should be managed as operational reservoirs, with sustainability as one of the leading criteria. This means that over periods of years they should remain in some balance with prescribed limits of levels and quality. On the other hand, fossil aquifers are those that have been filled in geological times and do not enjoy ongoing recharge. Such aquifers provide a one-time reserve that should be considered like any other "mine", which can be allowed to deplete over some period of time (years, decades), providing during this period water and its benefits. There is no absolute imperative to keep such reserves forever. It must, however, be recognized that the generation that is using this one-time reserve is leaving future generations without this asset. A consideration might be that while this water is being used society will be generating wealth that will allow it to leave future generations with less water in storage but with the resources to create (in some fashion) the water that it will need at that time.

2.13 LEGAL STATUS

Laws and regulations governing development, utilization and management of groundwater have developed locally, as communities grew, neighbors began tapping groundwater that was already being drawn by existing users, and increased pumping began to cause interference with existing wells. At that point, and later as whole regions of groundwater were incorporated into regional water resources systems, the law lagged behind and had to be adjusted to the new conditions, The difficulties in understanding the physical aquifer system its properties and behavior, as well as the lateral influence of one user on another caused substantial hindrance in arriving at well formulated laws and regulations. One famous example is what is called "The tragedy of the Commons". It results when each user of a common resource seeks to maximize his own benefit disregarding the effect his decisions have on the common pool.

This results in depletion of the resources, to the detriment of all users. Only a regulatory system that has jurisdiction and power over the users can impose a management strategy that does not allow this to happen and imposed a sustainable management strategy. This is the case with a common groundwater aquifer where each user tries to pump out as much as possible, in competition with the other users, unless there is a regulatory scheme that prevents this; see below the case of the Mountain Aquifer between the Mediterranean Sea and the Jordan River.

2.14 SUMMARY OF GROUNDWATER CHARACTERISTICS

The ensemble of properties and considerations listed above create a wealth of opportunities, on the one hand, and obstacle/dangers, on the other, in sustainable management of groundwater: large geographical extent; large storage; opportunities for gradual development; slow response of quantity and quality; polluted groundwater is difficult-to-impossible to remediate; out-of-sync with surface waters; have complex structure which make it difficult to understand the flow and quality processes; frequent paucity of data. All these make groundwater an important yet challenging element in sustainable development and management.

3 STRATEGIES AND MEANS FOR SUSTAINABLE MANAGEMENT OF GROUNDWATER AQUIFERS

3.1 HYDROLOGICAL INFORMATION

Aquifers are complex and are "hidden" underground. There is a saying that "no one has been down there and seen directly what is going on". This is a misleading statement, since direct and indirect information provide a wealth of information from which understanding can be gleaned. Geological information, well logs, spring flows, response of water levels to precipitation, well water quality and its changes over time – are all sources of information that can be placed in conceptual, mathematical and numerical models that have the ability to explain the aquifers response in the past and forecast its behavior under proposed management regimes. And still hydrological data is essential, and often is missing, partial, and sometimes erroneous. A most important basis for sustainable management of groundwater is investment in creation and maintenance of a good hydrometric network: geology, well logs, precipitation, water level changes.

3.2 PUMPING AND RECHARGE INFORMATION

Aquifers act as storage reservoirs with a long time constant. Therefore, in order to understand their hydrological behavior it is important to have operational data over long period of time, together with the hydrological data mentioned above, including: well discharges and levels during pumping tests. Wells must be monitored continuously and with good accuracy for both water supply purposes and as components in aquifer water balance calculations and models.

3.3 DETERMINATION OF AQUIFER PROPERTIES

Storage, flow patterns, conveyance and dispersion properties of specific aquifer layers and the entire aquifer formation are needed in order to be able to forecast/compute its response to the various forcing drivers: precipitation and recharge, the extraction and recharge distribution in space and time, introduction of waters with quality (e.g., salinity).

3.4 MANAGEMENT OF THE LAND SURFACE

Both phreatic aquifers (open from above, no impervious layer between the surface and the aquifer) and confined aquifers (sandwiched between two impervious layers) are affected by processes at the land surface: land use and land cover in agricultural lands and in built and industrial areas have a significant influence on recharge quantities and quality. A critical step in sustainable management of groundwater is control of these activities. Irrigation technologies and practices have a significant influence on the drainage below irrigated fields and orchards, how much reaches groundwater (if such exists below the irrigated area) and with what quality (NAVEH; SHAMIR, 2004). Urbanization results in impervious areas, increased runoff, increased pollution, and should therefore be planned to minimize its negative effects (CARMON et al., 1997; CARMON; SHAMIR, 1997; SHAMIR; CARMON, 1999). Industrial sites have caused major localized and wide-spread contamination of groundwater in many parts of the developed world, and even more so in less developed areas which became a destination for disposal of toxic wastes. Hence, management of activities at the land surface is a first and most important component in sustainable management of groundwater

3.5 MANAGEMENT OF GROUNDWATER STORAGE

One of the greatest misconceptions, prevalent not only among politicians, administrators and managers, but even among water professionals, is to view groundwater aquifers merely as a source. Indeed, fossil groundwater is a one-time reserve, a source that can be used over a certain period of time (usually years to decades), so that sustainable management does not mean leaving the water in the ground forever. See, for example, the case of the Disi Aquifer in the next chapter.

Aquifers that are being recharged should be viewed as storage reservoirs, precisely like a surface reservoir, albeit with its particular properties. It should be managed in a manner that creates a long-term sustainable balance of inflow-outflow-storage. Limits should be set on minimum water levels, which are located so as to prevent encroachment of lower-quality waters through its borders, from surface and/or adjacent groundwater bodies, and such that the storage is used effectively over time to balance between the variability of replenishment and demands.

4 MODELS FOR SUSTAINABLE MANAGEMENT OF GROUNDWATER AQUIFERS

4.1 SINGLE CELL MODEL

An entire aquifer is depicted as a single cell and a single water balance equation is used to track its storage over time (see Figure 3). The net inflow minus outflows is equated to the change in water level times the storativity (head-storage coefficient). This model is adequate for tracking the total storage of an aquifer over years and decades, including in a stochastic mode, where the time series of annual replenishment is represented either by the historical of synthetic data. This single-cell model was calculate the required development of desalination capacity over the period 2010-2050 needed to cover the increasing gap between the growing country-wide demands and the available natural resources with a prescribed reliability.

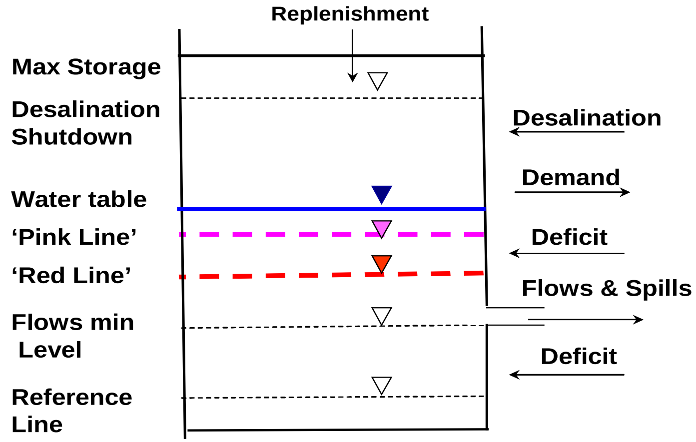
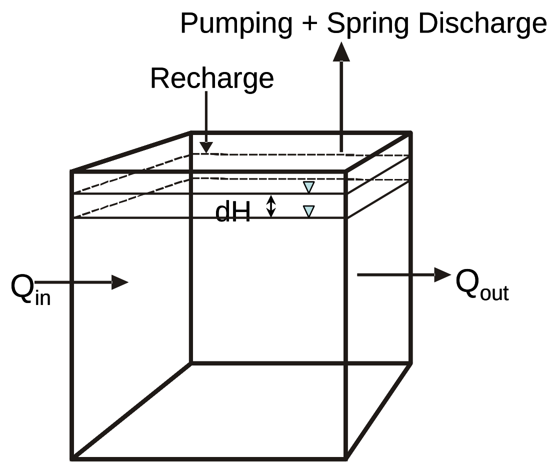


Figure 3 - A single-cell model of the entire water storage in the regional sources, used in stochastic analysis with historical time-series of replenishment

4.2 TWO-DIMENSIONAL MULTI-CELL MODELS

The area of the aquifer is sub-divided into cells (see Figure 5) and the equation of continuity is written for each, with the interactions between adjacent cells representing the inter-flow between them, based on a hydrological flow equation. The entire thickness of the aquifer is treated as a single layer, albeit with variable properties of storage and conveyance in different cells, as required. The cells can be rectangular (as in Figure 4) and the model is called finite-difference. Figure 5 shows the cells of a 2D model of the Coastal Aquifer.

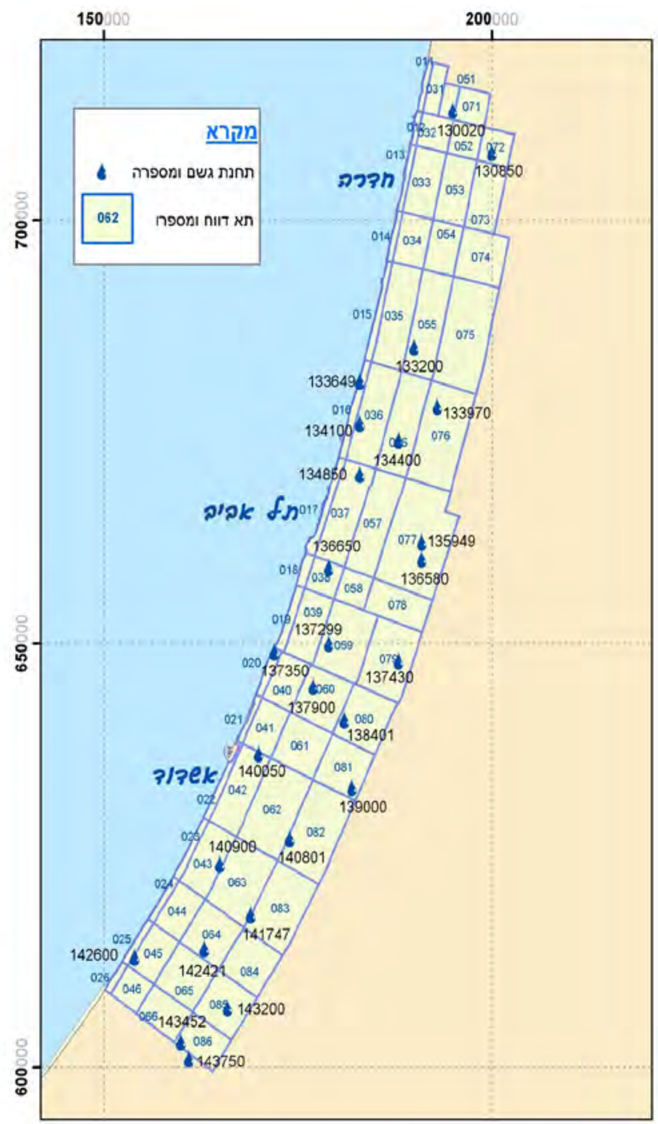


Recharge = A_{Ri} * Rain
Storage Change = A_S * dH

Where:
Q_{in} - inflow from neighboring cells
Q_{out} - outflow from neighboring cells
H - piezometric head
A_{Ri} - rain-recharge coefficient
A_S - head-storage coefficient
$A_{(i-1),i}$ / $A_{i,(i+1)}$ - water exchange coefficients between adjacent cells

$$(\text{Pumping} + \text{Spring Discharge})_i = A_{Ri} * \text{Rain}_i - A_{(i-1),i} * (H_{i-1} - H_i) + A_{i,(i+1)} * (H_i - H_{i+1}) - A_S * (H_i^{t+1} - H_i^{t})$$

Figure 4 - One unit of the Cell Model used by the Israeli Hydrological Service for calculating the annual balance in aquifers [Source: Israeli Hydrological Service, Bachmat Model]



איור 2.14 : תחנות הגשם המייצגות בתאי אגן החוף

Figure 4.2.2 - Cell model of the Israeli Coastal Aquifer
Source: Y. Livshitz, Israel Hydrological Service. 2012

Triangular cells are used in finite-element models, which can fitted to the variable shape and properties of the aquifer more readily. On the other hand, formulation and solution of the mass balance equations is more complex. However, today there is a wealth of computer packages that facilitate construction and solution of aquifer cell model, by finite differences or finite elements that alleviate greatly the dilemma of using models. This has become common practice in practically all hydrologic and groundwater management agencies and consultancies.

4.3 FLOW AND TRANSPORT CELL MODELS

Flow models have been expanded to include transport of contaminants of various types. Conservative tracers, such as salinity, are handled by simple mass balance equations, where the property (e.g., salinity) is carried "piggy-back" on the flow, and distributed by a dispersion equation. This requires having dispersion coefficients, with are more difficult to obtain than flow coefficients. Here too, commercial computer packages are readily available, while their application requires more data and higher expert skills.

4.4 THREE-DIMENSIONAL FLOW AND TRANSPORT MODELS

When an aquifer cannot be depicted as a single layer the models become three-dimensional. Commercial packages are available, but their application is more expensive and data-intensive. The most advanced models, such as SUTRA are "for 2D or 3D saturated-unsaturated, variable density ground-water flow with solute or energy transport. (USGS, on the web site).

5 CASE STUDIES

5.1 THE MOUNTAIN AQUIFER BETWEEN THE MEDITERRANEAN AND THE JORDAN RIVER

The various water sources in the area between the Mediterranean Sea and the Jordan River are shown in Figure 6. Most are aquifers, which provide some 70% of the national supply of natural waters, while the rest is from the Sea of Galilee. The Mountain Aquifer is located under the mountain area between the Mediterranean Sea and the Jordan River, and is used by Israel and the Palestinian Authority. It has three basins (sometimes defined as its sub-basins) whose maps appear in Figures 7 and 8. A schematic East-West cross section appears in Figure 9 which shows a division of the aquifer into West and East flowing basins.

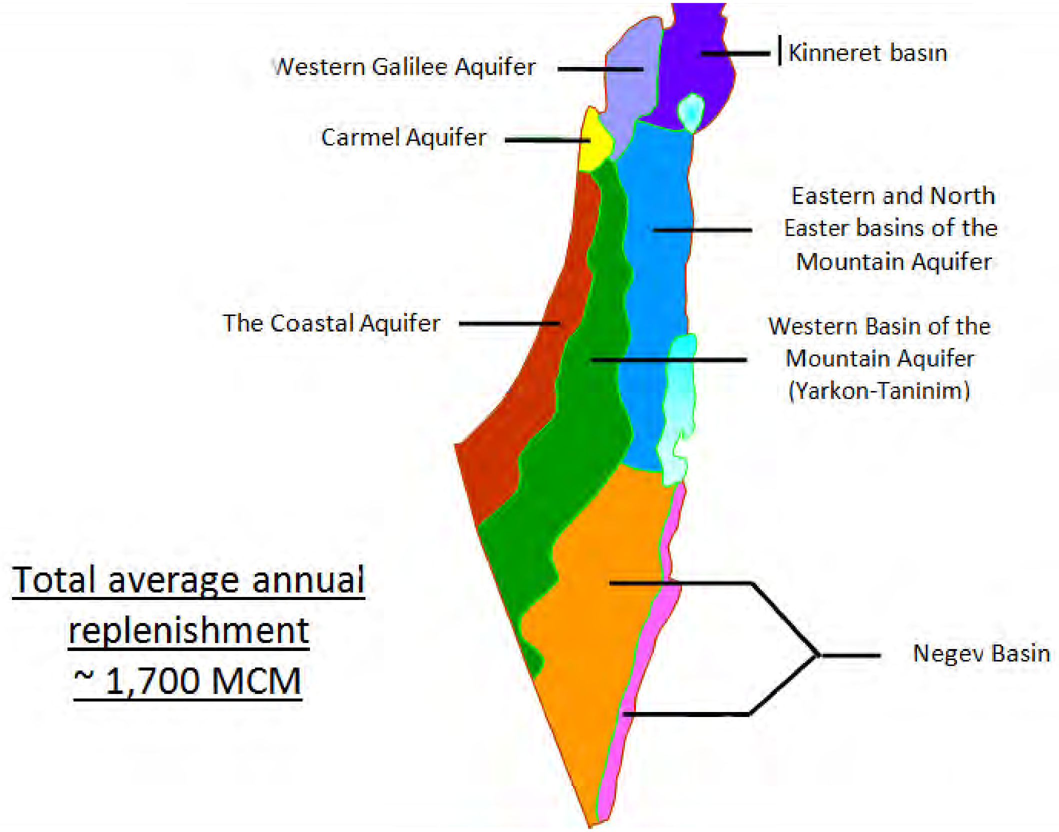


Figure 6 - Water sources between the Mediterranean Sea and the Jordan River, and their average annual replenishment

Figure 7 - Boundaries and recharge areas (in color) of the Western Basin (Yarkon-Taninim) of the Mountain Aquifer
Source: M. Zilberband, Israel Hydrological Service (2012)

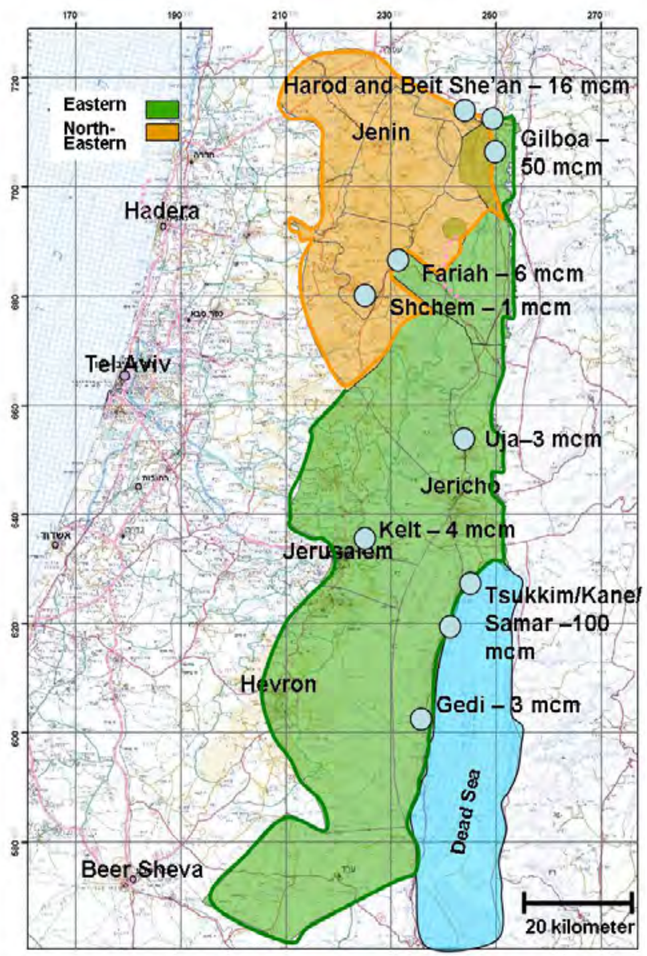


Figure 8 - Boundaries of the Eastern (green) and North-Eastern Basins (ochre) of the of the Mountain Aquifer
Source: M. Weiss , Israel Hydrological Service (2012)

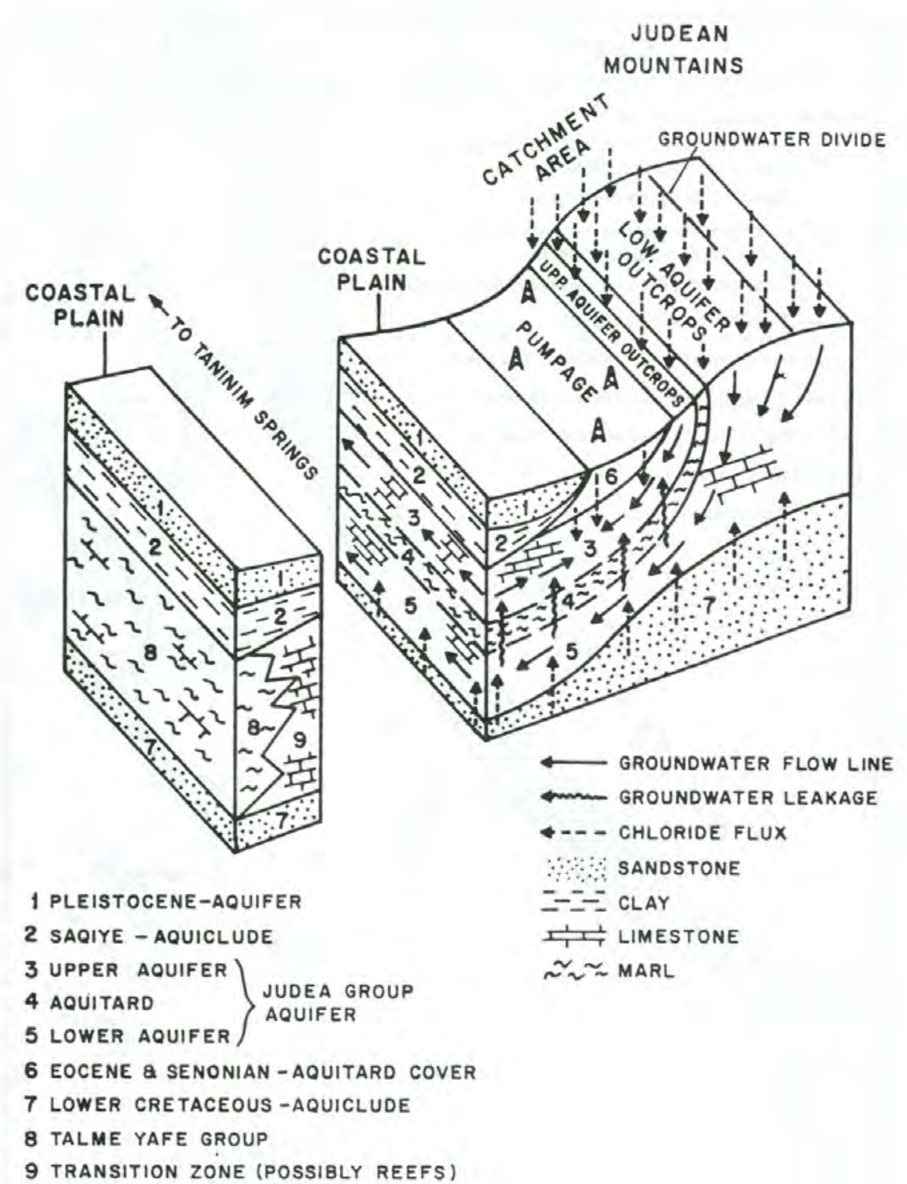


Figure 9 - East-West cross section of the Mountain Aquifer - Western Basin (Yarkon-Taninim)
Source: M. Zilberband, Israel Hydrological Service (2012)

The Mountain Aquifer figures dominantly in the 1995 Oslo II Agreement between The Palestinian Authority and Israel. At the time the agreement was being prepared, negotiated and signed (September 1995), the average annual amount of water that could be used from the three basins of the Mountain Aquifer were estimated and entered as an Appendix to the Agreement. These quantities have come under scrutiny since that time - some 17 years ago. Table 6 provides the data that were used in the 1995 Oslo II Agreement and the updated information that was generated more recently (ISRAEL WATER AUTHORITY, 2012). The following can be noted in the table:

Table 3 - Average annual replenishment of the three Basins of the Mountain Aquifer for three time periods (Hyd. Service 2012), the percentage reduction from the first period to the second, and the values that were used in the Oslo II Agreement (in 1995)

Basin	1973-1992	1993-2009	1973-2009	Oslo II (1995)
Eastern	211	174 (-18%)	192	172
North-Eastern	151	134 (-11%)	142	145
Western	369	333 (-10%)	352	362
Total	731	641 (-12%)	686	679

- There is a decline in the values from the earlier period (1973-1992) to the later one (1993-2009) and thus the figures for the entire period (1973-2009) are between the two;
- The decline may be due to a number of different reasons, whose effect are not easily distinguished, among them: land use and land cover, extraction that is not fully recorded and results in lower figures calculated for the recharge, climate change. There is already some evidence that the precipitation is declining and its distribution in time is such that less of it is recharged and reaches the aquifer, but the exact effect it still to be ascertained;
- The differences between the periods are small yet significant in terms of the availability of water in this dry region;
- The figures that were used in the Oslo II Agreement are close to those for the latter part of the time horizon, the result of a aiming to use a somewhat conservative estimate in the Agreement as compared with the figures available at that time.

5.2 THE ISRAELI NATIONAL SYSTEM

The Israeli National Water System is fed from natural sources (Figure 6) The total available natural water to Israel is about 1,200 mcm/year, on average, with very substantial variability between years. Droughts of 6-7 years have occurred several times in the last decades, creating great difficulties in meeting the increasing demand and resulting in over-utilization of the sources. A major sea-water desalination program began since 2002. Three plats, with a total capacity of close to 300 mcm/year are in operation and two more which are under construction will bring the total installed capacity to about 550 mcm/year, practically half the average natural resource. This supply is more reliable and is located close to the demand centers, thus reducing the cost of transport and distribution.

Still, the natural sources, 60% of them groundwater, remain a strategic asset that will be managed in a sustainable manner. For a long time, the sources were drawn down during series of drought years, leaving small reserves if the drought continues and resulting in deterioration of water quality in the sources. With the development of desalination that will reach more than one-half of the natural average supplies, the system is moving towards a more stable period. Yet, as stated, the national policy is that groundwater resources will be remediated in quantity and quality and then managed in a sustainable manner. The aquifers will continue to serve as storage reservoirs as well as sources of water. Their large capacity helps to balance between the constant production of the desalination plants and the seasonally variable demands. Figure 5.2.1 is a schematic model of the central part of the Israeli national water system that was used to optimize its operation over a period of 10 or more years, with a short summer season with high demands and a longer winter season with lower demands under uncertain hydrological replenishment (HOUSH et al., 2012).

5.3 THE DISI AQUIFER ON THE BORDER BETWEEN THE HASHEMITE KINGDOM OF JORDAN AND SAUDI ARABIA

is some 320 kilometers long and located hundreds of meters below the surface (Figure 5.3.1). It is classified as a fossil aquifer, although there is some recharge, about 50 mcm/year, which is quite small compared to the overall storage and to the amounts that are being extracted today, ~90 mcm/year. Jordan is constructing a system of 50-60 wells in the Disi aquifer and a conveyance system some 320 km long, to deliver 100 mcm/year to Amman and some other cities. Water levels in the aquifer have been dropping, and will drop even more rapidly when the extraction-and-conveyance system is completed (forecasted by the end of 2013). Jordan suffers from extreme shortage of water. Substantial leakage from urban system is being reduced but is still high. The citizens of Amman are provided with water to fill their roof- tanks once every 7-10 days. The Disi project (Figure 11) is expected to alleviate this situation substantially, but in the longer run Jordan will have to seek additional sources of water, possibly from the panned Red Sea–Dead Sea project that is planned to produce desalinated water close to the Dead Sea and deliver some of it to the Palestinians on the West Bank.

The Disi water has some radioactivity, which has and still does cause controversy regarding its use as potable water. The Jordanian Government and water authorities state that the Disi water will be blended with water from other sources to the point where the radioactivity will not be a problem.

Figure 10 - Location maps of the Disi Aquifer in Southern Jordan and Northern Saudi Arabia

Figure 11 - Schematic outline of the Disi to Amman project

5.4 THE GUARANI AQUIFER

Underlies areas of Argentina, Brazil, Paraguay, and Uruguay (Figure 12). It covers an area of some 1.2 million square kilometers, with a thickness of a few hundred up to 1,000 meters. It is arguably the largest aquifer in the world, and presents an important issue for competition and collaboration among the riparian states. They signed in September 2011 an agreement for management of the Guarani Aquifer System (GAS) (WORLD BANK, 2006).

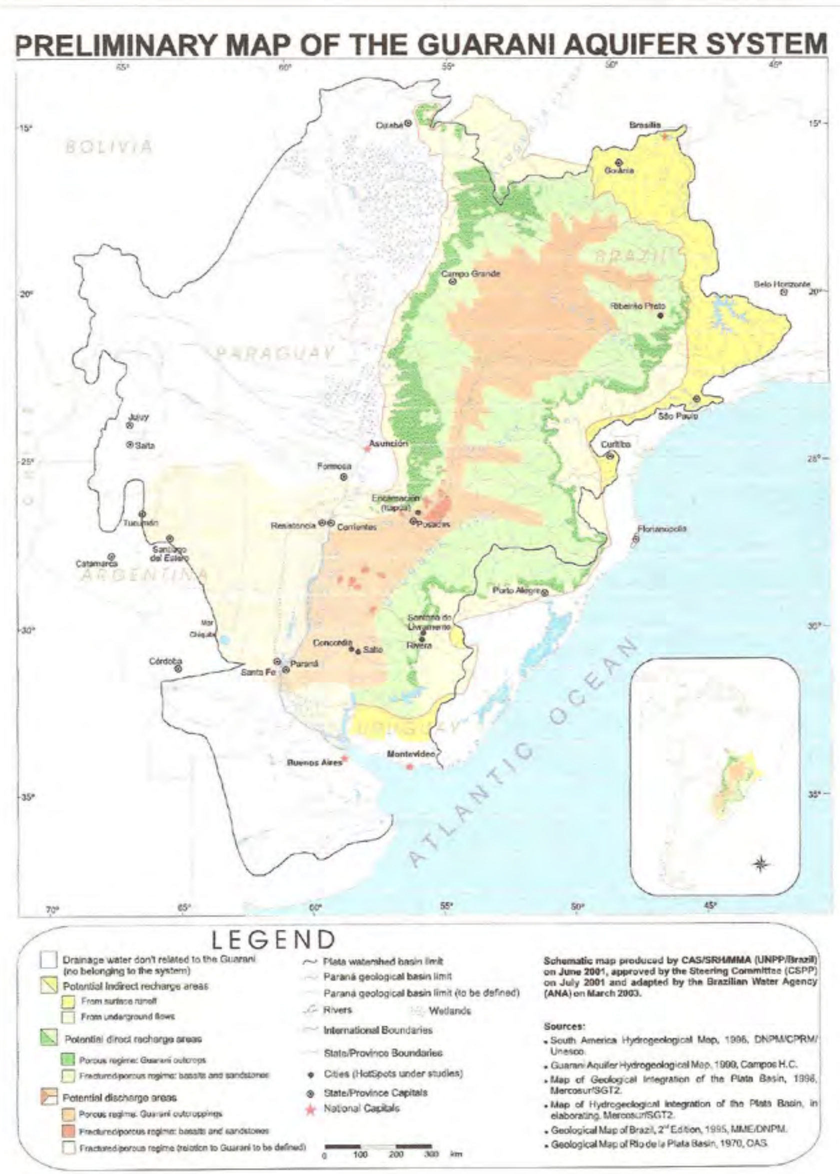


Figure 12 - Location Map of the Guarani Aquifer

REFERENCES

ASCE-EWRI (American Society of Civil Engineers – Environmental and Water Resources Institute) (2012) "Towards a Sustainable Water Future: Visions for 2050", Ed. By W.M. Grayman, D.P. Loucks and L. Saito, 386 p.

Becker, M.W. (2006) "Potential for Satellite Remote Sensing of Ground Water", by Matthew W. Becker, Ground Water, 44(2), 306-318

Carmon, N., U. Shamir and S. Meiron-Pistiner, S.(1997) "Water-Sensitive Urban Planning: Protecting Groundwater", Journal of Environmental Planning and Management, 40(4), pp. 413-434.

Carmon, N. and U. Shamir (1997) "Water-Sensitive Urban Planning: Concept and Preliminary Analysis", in “Groundwater in the Urban Environment: Problems and Management”, Proceedings of the XXVII Congress on Groundwater in the Urban Environment, September 1997, Ed. By J. Chilton et al. Rotterdam: Balkema, pp. 107-113.

Carmon, N. and U. Shamir (2010) "Water-sensitive planning: integrating water considerations into urban and regional planning", Water and Environment Journal 24, 181–191

Döll, P. (2009) "Vulnerability to the impact of climate change on renewable groundwater resources: a global-scale assessment". Environm. Res. Lett. 4 (2009) 035006 (12 pp).

Döll, P. and A. Fiedler (2008) "Global-scale modelling of groundwater recharge", Hydrol. Earth Syst. Sci., 12, pp 863-8854.

Bachmat, Y. (1995) "Hydrologic model of the Western Mountain groundwater basin". Harvard Middle East Water Project. Jerusalem, 43 pp.

Famiglietti, J., S. Swenson, and M. Rodell (2009) "Water storage changes in California’s Sacramento and San Joaquin river basins, including groundwater depletion in the Central Valley". PowerPoint presentation, American Geophysical Union Press Conference, December 14, 2009, CSR, GFZ, DLR and JPL.

Foster, S. and D.P. Loucks (2006) "Non-Renewable Groundwater Resources: A guidebook on socially sustainable management for water policy makers", UNESCO IHP-VI, Series on groundwater No.10.

Housh, M., A. Ostfeld and U. Shamir (2012) "Seasonal multi-year optimal management of quantities and salinities in regional water supply systems", Environmental Modelling & Software 37, 55-67.

IGRAC (2012) Global Groundwater Information System (GGIS). http://www.igrac.net

Israel Water Authority (2011) "Master Plan for the Water Sector" http://www.water.gov.il/Hebrew/Planning-and-Development/Planning/MasterPlan/DocLib4/PolicyDocument-jul-2011.pdf. (in Hebrew, soon to be available at the www.water.gov.il site in English)

Israel Water Authority (2012) "The Natural Water Resources between the Mediterranean and the Jordan River", by Weinberger, G., Y. Livshitz, A. Givati, M. Zilberband, A. Tal, M. Weiss and A. Zurieli http://www.water.gov.il/Hebrew/about-reshut-hamaim/The-Authority/FilesWatermanagement/water-report-MEDITERRANEAN-SEA-AND-THE-JORDAN.pdf

Konikow, L. (2009) "Groundwater depletion: A National Assessment and Global Perspective". The Californian Colloquium on Water, May 5, 2009. http://youtube.com/watch?v=Q5s0Uit8V6s

Konikow L. and L. Kendy (2005) "Groundwater depletion: a global problem". Hydrogeology Journal, vol. 13, pp 317-320.

Llamas and Garrido (2007) Lessons from intensive groundwater use in Spain: Economic and social benefits and conflicts. In: Gordano & Vilholth (ed.), The Agricultural Groundwater Revolution, CABI, Wallingford, UK, pp. 266-295.

Llamas R. and Martínez-Santos (2005) Intensive groundwater use: a silent revolution that cannot be ignored. Water Science and Technology Series, Vol 51, No 8,pp 167-174. International Water Association.

Mekorot Water Company Ltd., Israel (URL) "Shafdan Wastewater Treatment Plant" http://www.mekorot.co.il/Eng/Activities/Pages/WastewaterTreatmentandReclamation.aspx

Naveh, N. and U. Shamir, U. (2004) “Managing Groundwater Levels in an Agricultural Area with Peat Soils”, Journal of Water Resources Planning and Management, ASCE, 130(3), pp. 243-254.

Oude Essink, G.H.P., E.S. van Baaren, and P.G.B. de Louw (2010) "Effects of climate change on coastal groundwater systems: A modelling study in the Netherlands", Water Resources Research, Vol 46, doi: 10.1029/2009WR008719.

Pinder, G.F. (2012) "Groundwater Hydrology in 2050", Chapter 30 in: Grayman, W.M., Loucks, D.P. and Saito, L. (Eds.) "Towards a Sustainable Water Future: Vision for 2050", ASCE-EWRI , pp. 277-287.

Puri, S. and A. Aureli (eds.) (2009) "Atlas of Transboundary Aquifers – Global Maps, Regional Cooperation and Local Inventories". Paris, UNESCO-IHP ISARM Programme, UNESCO. http://www.isarm.org/publications/324

Prüss-Üstün, A., R. Bos, F. Gore, and J. Bartram (2008) "Safer Water, Better Health: Costs, Benefits and Sustainability of Interventions to Protect and Promote Health." Geneva: World Health Organization

Rodell, M., I. Velicogna, and J. Famiglietti (2009) Satellite-based estimates of groundwater depletion in India. Nature, Vol 460, doi:10.1038/nature08238.

Shah, T. (2007) "The Groundwater Economy of South Asia: An Assessment of Size, Significance and Socio-ecological Impacts". In: "The Agricultural Groundwater Revolution: Opportunities and Threats to Development" Edited by M. Giordano and K.G. Villholth, IWMI, Colombo, Sri Lanka. Published by CABI, Wallingford, UK, pp. 7-36.

Shah, T., J. Burke, and K. Villholth (2007) "Groundwater: a global assessment of scale and significance". In: David Molden (ed.) "Water for food, water for life: A comprehensive assessment of water management in agriculture". IWMI, Colombo, Earthscan, London, pp 395-423.

Shamir, U. (1993) "Development and Management of Groundwater Resources: General Principles and the Case of Israel", Seminar on Groundwater, Instituto GeoMinero de Espana, Madrid, April 1, 1993.

Shamir, U. (1997) "Water Agreements Between Israel and Its Neighbors", In: "Transformations of Middle Eastern Natural Environment: Legacies and Lessons", Conference by the Council on Middle East Studies at the Yale Center for International and Area Studies, Yale University, October 30 - November 1, 1997. http://environment.research.yale.edu/documents/downloads/0-9/103shamir.pdf

Shamir, U. and N. Carmon (1999) “Water-Sensitive Urban Planning: The Case of Israel’s Coastal Aquifer”, in “Impacts of Urban Growth on Surface and Groundwater Quality”, IAHS Publication no. 259, Ed. By B. Ellis.

Siebert, S., J. Burke, J. Faures, K. Frenken, J. Hoogeveen, P. Döll, and T. Portmann (2010) "Groundwater use for irrigation – a global inventory". Hydrol. Earth Syst. Sci., 14, 1863-1880.

US Geological Service (on the web site) "A model for 2D or 3D saturated-unsaturated, variable-density ground-water flow with solute or energy transport", http://water.usgs.gov/nrp/gwsoftware/sutra/sutra.html

Wagner, J.W., U. Shamir and H.R. Nemati (1992) "Groundwater Quality Management Under Uncertainty: Stochastic Programming with Recourse and the Value of Information", Water Resources Research, Vol. 28, No.5, pp. 1233-1246.

Wagner, J.W., U. Shamir, and D.H. Marks (1994) "Containing Groundwater Contamination: Planning Models using Stochastic Programming with Recourse", the European Journal of Operational Research, Vol. 77, pp. 1-26.

WHYMAP (2008) "Groundwater resources of the World, Map 1: 25 M". UNESCO, IAH, BGR, CGMW, IAEA. http://www.whymap.org/whymap/EN/Downloads/Global_maps/whymap_125_pdf.pdf?__blob=publicationFile&v=3

World Bank (2006) "The Guarani Aquifer Initiative for Transboundary Groundwater Management" http://siteresources.worldbank.org/INTWRD/Resources/GWMATE_English_CP9.pdf

WWAP (United Nations World Water Assessment Programme) (2012) "Managing Water Under Uncertainty and Risk", World Water Development Report 4 (WWDR-4). http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/wwdr4-2012/

SESSION 10

MANAGING WATER IN URBAN AREAS AND METROPOLITAN REGIONS: AN EVER-GROWING CHALLENGE

ECONOMIC DEVELOPMENT BIODIVERSITY AND MULTIPLE USES OF WATER IN AMAZONIA

José Galizia Tundisi[1]
Takako Matsumura Tundisi[2]
Augusto Saraiva[3]

[1] International Institute of Ecology, São Carlos. Universidade Feevale.
[2] International Institute of Ecology, São Carlos.
[3] Eletronorte, Belém, Pará.

ABSTRACT

The amazon watershed covers an area of approximately 7,000,000km^2 corresponding to 40% of South America an 7 countries: Bolivia, Brazil, Colombia, Ecuador, Guiana, Peru and Venezuela. The lowlands of the amazon watershed occupy an area of quaternary sedimentation where the fluvial valley of the Amazon is located. Large extensions of floodplains and wetlands occur in these lowlands. The main forcing function that is a mechanism of disturbance factor influencing the floodplain and wetlands and aquatic biodiversity is the water level fluctuation. The duration, predictability and amplitude of the floodpulse determine the behavior of aquatic and terrestrial organisms. The amazon floodplain ("varzea[1]") is considered a Holocene deposited. Deposition and erosion of sediments are causes of the permanent changes in the spatial and temporal structure of the aquatic and terrestrial ecosystems with several impacts on the biological and ecological mechanisms. The causes of spatial and temporal variability along the Amazon basin will be examined in relation to climatological, hydrological and physiographic cycles and patterns. The climatological, hydrological and physiographic history of this ecosystem with changes in a equatorial and humid tropical background will be described as a basis to understand the biodiversity. Flooding is combined with a disturbance factor such as sedimentation, erosion, water current that have a impact on community structure. The hypothesis from the origin of biodiversity and its interactions with the fluvial dynamics will be examined in detail. The functioning of the amazon várzea lakes, the biogeochemical cycles specially those related with the aquatic biota such as carbon, phosphorus and nitrogen will be analyzed and the processes that govern the advection, reaction and transition of these elements downstream the Amazon basin and the floodplain lakes will be described and interpreted in relation to the fluvial dynamics and the role of biota. Discussion about the Amazon basin as an "Active Center of Evolution" will be introduced and extended, in order to understand the complexity (spatial and temporal) of the ecosystem and its dynamic nature and structure. The water uses of the Amazon basin, and the hydrosocial cycle, will be discussed specially the ecological, economic and commercial role of the fisheries as well as the use of water for public supply, navigation, recreation and tourism. The harnessing of the water for hydroelectric production will be discussed and the impacts and benefits of the hydropower development will be considered and discussed. Of special interest in this topic is the large scale change in socio-environmental conditions, future developments biodiversity, water uses. The sanitary conditions, impairment of water quality due to infrastructure development such as roads, deforestation and agricultural expansion will be

[1] Varzea: is the regional name for the floodplain areas in the Amazon.

discussed. The impact of mining on water quality will be presented. Finally, recommendations for conservation priorities and protection of biodiversity, minimizing impacts of economic development and promoting new mechanisms for water and biodiversity uses will be made. Future scenarios discussing impacts of climatic changes on water availability, water uses, biodiversity changes will be presented and discussed. The priorities for conservation of strategic sub basins(from the ecological and economic points of view) will be discussed.

1 INTRODUCTION: THE GEOPHYSICAL SETUP

The two major watersheds of the South American continent are the Amazon Watershed and the La Plata watershed. Other watersheds of importance are the Orinoco, Magdalena and São Francisco river basin (Fig. 1).

Figure 1 - Major watersheds of the South American continent
Source: Biogeochemistry of Major World Rivers[2]

[2] DEPETRIS, P. J.; PAOLINI, J. E. Biogeochemical aspects of South American Rivers: The Parana and the Orinoco. In: DEGENS, E. T.; KEMPE, S.; RICHEY, J. E. (Eds.). Biogeochemistry of Major World Rivers. New York: SCOPE42, John Wiley & Sons, p. 105-122, 355pp., 1991.

The amazon watershed covers an area of 7.000.000 km² corresponding to 40% of South America in 7 countries: Bolivia, Brazil, Colombia, Ecuador, Guiana, Peru and Venezuela (Fig. 2).

Figure 2 - Map of the Amazon watershed in South America

The drainage system of the Amazon Basin was consolidated in Pliocene when there was a definitive close up of the connection with the Pacific Ocean and the drainage and flushing took the direction of the Atlantic Ocean (SIOLI, 1984). The concentration of sediments in the amazon watershed was accumulated during the last 500 million years, being mostly composed of clay. The transport, sedimentation, deposition and removal of this sediment in the basin play an important geomorphological, ecological and dynamic role in the basin, being integrated permanently with the fluvial dynamics and the biological/ecological processes (productivity, biodiversity, biomass, species richness, distribution of organisms-plants and animals).

The interaction between terrestrial/aquatic ecosystems is the main fundamental ecological factor. This is a primary forcing function that regulates the regional biodiversity, the evolutionary process, the water flux and water uses. Huge internal deltas, extensive floodplains, wetlands, and creeks in the forest, forms a network of rivers, channels, shallow lakes, that establish a huge biogeophysical complexity with consequences on the productivity of the ecosystems, it their human uses and sets up the hydrosocial cycle which is strongly connected with the natural ecosystem (ROOSEVELT, 1999).

The water level fluctuation is the main forcing function that is the consequence of the interaction climate/ hydrology/fluvial dynamics. The "flood pulse concept" introduced by Junk and Weber (1996) explained the periodic changes in the biogeochemical cycles, the biomass and species composition of the terrestrial/aquatic biota. The chemical and physical environment resulting from the periodic inundation of the floodplain promotes a chain of morphological, anatomical, physiological, geological and ethological adaptations with characteristic structures (JUNK, 2005). The hydraulic energy of the inundation removes and erodes river and creek banks, with effects on the biogeochemical cycle of carbon, nitrogen and phosphorus or other elements. Large inundated areas of the floodplain increase productivity in lakes and wetlands and fisheries production is positively correlated with the inundation pulses. Periodic fertilization of the floodplain enhances productivity in the lakes by macrophytes, phytoplankton, periphyton and stimulates production during the terrestrial phase in the dryer regions of the floodplain ("varzea"). Fig. 3 shows the floodplain morphology and Fig. 4 shows the water level fluctuations at different locations in the amazon basin the amazon floodplain ("varzea") is considered to be a Holocene deposit. Depositions and erosion occurred during different periods with a permanent re - structuration of the large internal deltas, and several impacts in the ecological, biological and environmental functioning of the ecosystem. This ecological dynamics is a fundamental, factor to be considered in the management of the ecosystem. The sediment flux promoted a large scale spatial alteration in the amazon watershed combined with high rainfall and in an equatorial humid climate.

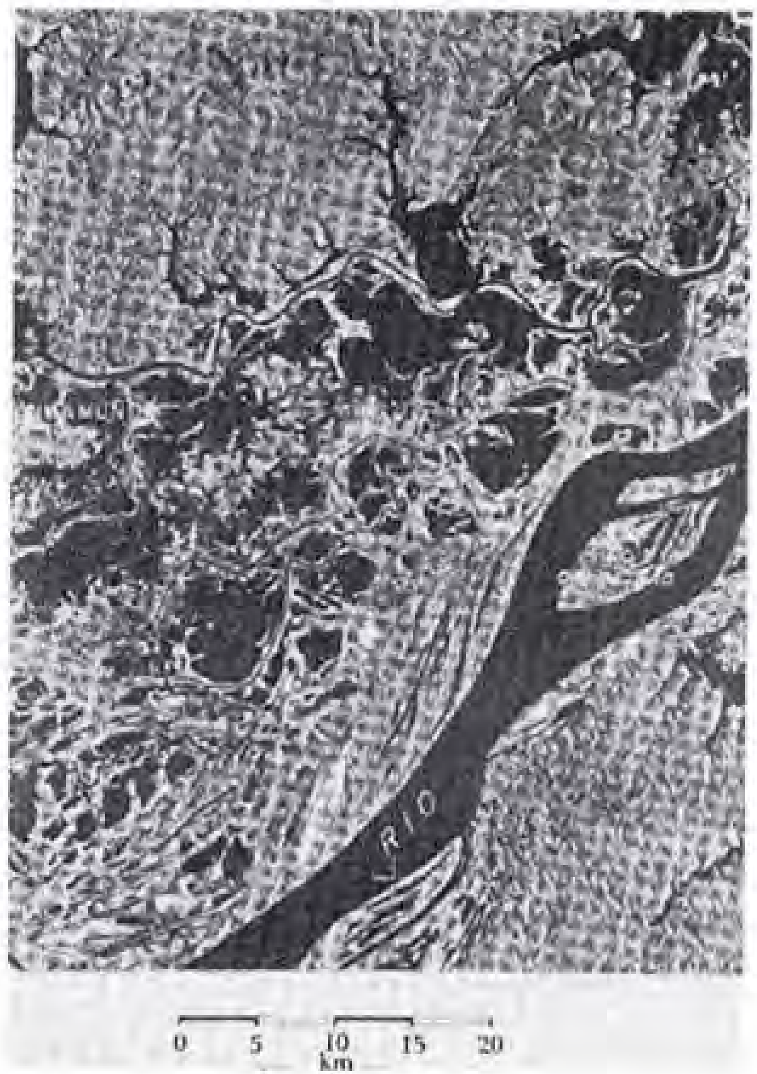


Figure 3 - Floodplain morphology
Source: Limnology and Landscape Ecology of a Mighty Tropical River and Its Basin[3]

[3] SIOLI, H. The Amazon: Limnology and Landscape Ecology of a Mighty Tropical River and Its Basin. Dordrecht, the Netherlands: Dr. W. Junk Publishers, pp. 763, 1984.

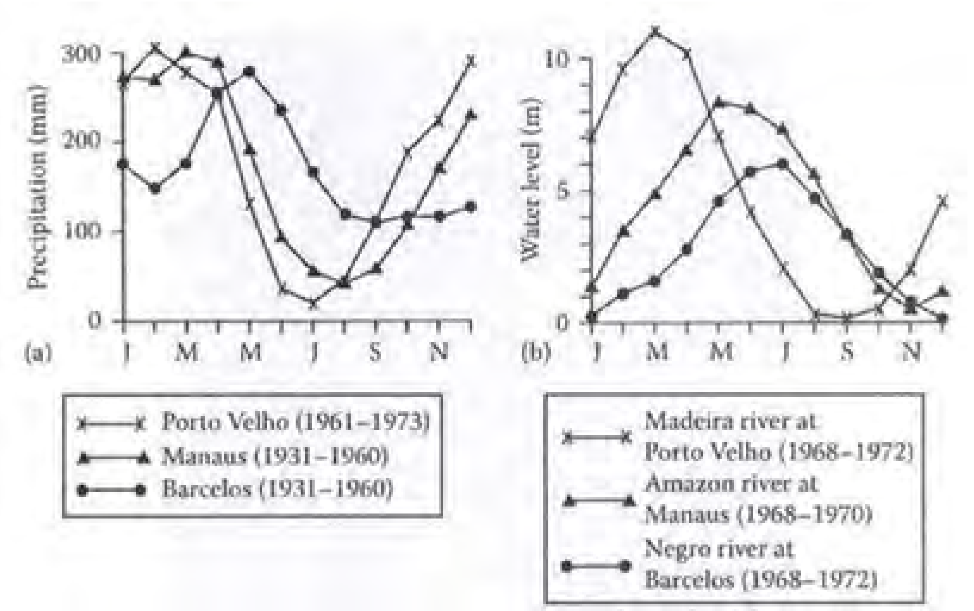


Figure 4.1 - Monthly rainfall(a) and water level fluctuations (b) in the Madeira River at Porto Velho, the Amazon River at Manaus, and the Rio Negro River at Barcelos, corresponding to southern, central, and northern parts of the Amazon basin.
Source: The Amazon: Limnology and Landscape Ecology of a Mighty Tropical River and Its Basim[4]

[4] JUNK, W. J. Ecology of the varzea, floodplain of Amazonian white rivers. In: SIOLI, H. (Ed.). **The Amazon**: Limnology and Landscape Ecology of a Mighty Tropical River and Its Basim. Dordrecht, the Netherlands: Dr. W. Junk Publishers, 1984

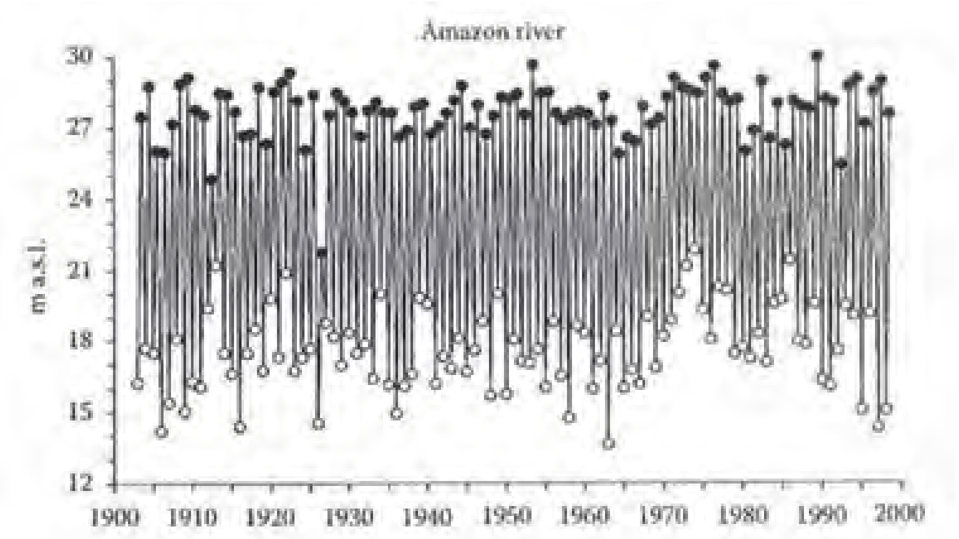


Figure 4.2 - Water level of the Amazon River near Manaus
Source: The Central Amazon Floodplain: Actual Use and Options for a Sustainable Management[5]

Table 1 - Annual mean river flow and drainage area of twelve major rivers of the world. Vol. at station is an average of long-term measurements (Stn ± std dev); river transport model (RTM- simulate river flow in km^3 $year^{-1}$); River mouth: estimated annual volume (vol); drainage area (DA - 10^3 km^2); Nyr is station record length in yr; long and lat are longitude and latitude (negative in the Western Hemisphere) for the station.

[5] JUNK, W. J. et al. (Eds). **The Central Amazon Floodplain**: Actual Use and Options for a Sustainable Management. Leiden, the Netherlands: Backhuys Publishers, 2000. 584 pp.

Table 1

No.	Name	Vol at station: Stn ± std dev	Vol at station: RTM	River mouth: Vol	River mouth: DA	Stn DA	Nyr	Lon(º)	Lat(º)	Station, Country
1	Amazon	5330 ± 426	5083	6642	5854	4619	49	-55.5	-2.0	Obidos, Brazil
2	Congo	1271 ± 130	1266	1308	3699	3475	81	15.3	-4.3	Kinhasa, Congo
3	Orinoco	984 ± 112	1141	1129	1039	836	66	-63.6	8.1	Pte Angostu, Venezuela
4	Mississipi	536 ± 130	458	610	3203	2896	71	-90.9	32.3	Vicksburg, MS, United States
5	Paraná	476 ± 96	589	568	2661	2346	89	-60.7	-32.7	Timbues, Argentina
6	Mekong	292 ± 33	271	525	774	545	7	105.8	15.1	Pakse, Laos
7	Ganges	382 ± 76	428	404	956	952	21	88.1	24.5	Farakka, India
8	St. Lawrence	226 ± 26	318	363	1267	774	64	-74.7	45.0	Cornwall, ON, Canada
9	Niger	33 ± 9	102	193	2240	1516	29	3.5	11.9	Gaya, Niger
10	Zambese	105 ± 44	404	117	1989	940	4	33.6	-16.1	Matundo-Cai, Moçambique
11	São Francisco	89 ± 28	127	90	615	623	56	-37.0	-10.0	Traipu, Brazil
12	Rhine	73 ± 14	86	75	165	180	6	6.1	51.8	Lobith, Netherlands

Source: Modified from Daí and Tremberth (2002)

Table I present the annual mean river flow rate and the drainage area the farther test downstream station and the river mouth flow for 12 major rivers of all continents. The Amazon River accounts for more than one third of the discharge. Sediment transportation and particulate carbon, phosphorus and nitrogen enrich the coastal zone at the Amazon mouth. Fig 5 shows the sediment discharge at the Amazon mouth. The total amount of sediment discharged for the Amazon is around 800 million/tons.year. Thus the water availability in the amazon watershed, besides its main role in the functioning of the regional ecosystems, is also directly, related to the hidrosocial cycle of fisherman and the "varzea" (floodplain) inhabitants. However this water availability is not reflected in potable water distribution: there is scarcity of potable water for the major part of the regional population (BECKER; STENNER, 2008).

3 THE ORIGIN OF BIODIVERSITY IN THE AMAZON BASIN

The geophysical functioning of the amazon basin is the fundamental forcing function that establishes the dynamic ecological mechanism of the region. The interaction of the climatological dynamics, the geomorphological set up and the biodiversity was discussed by Salati et al. 1984, Junk 2005. Accordingly to Salati et al. 1978, the hydrological cycle is a fundamental factor controlling the atmospheric humidity, the rainfall and the drainage. Primary sources of moisture are the Atlantic Ocean; east west winds bring water vapor to the amazon basin, which has a yearly rainfall of 2.300mm. The other source of moisture is the Amazonian forest itself which replenishes to the atmosphere by evapotranspiration about 30% of water vapor. Therefore, climate/hydrological factors, drainage and geomorphological factors, and geomorphology are the fundamental factors influencing the terrestrial and aquatic biodiversity. Several hypotheses were put forward by many authors, in order to explain the high biodiversity of the amazon watershed. These are (HAFFER, 2008):

I. Changes in the spatial distribution with the dynamics alterations promoted by tectonic movements, landscape modification temporary or permanent barriers (paleogeographic hypothesis);

II. River morphology dynamics acting as barriers (rivers hypothesis);

III. Changes in the vegetation cover associated with periods of high humidity or dryness (refuse hypothesis);

IV. Isolation of regions with mosaics of vegetation in areas of higher altitude in the amazon watershed periphery (Refuge hypothesis);

V. Changes in the density of the canopy due to climatic changes (hypothesis of the canopy);

VI. Speciation in environmental gradients (hypothesis of spatial heterogeneity);

VII. Competitive interaction between species and isolation in perypherical regions of Amazonia during cold and warm periods (hypothesis of intermediary disturbance).

The cyclic changes, the raising and retreat of large forest areas, the changing fluvial dynamics with time, and tectonic movements are considered as the main factors enhancing the terrestrial and aquatic biodiversity in the amazon watershed (SALO et al. 1986).

The present dynamics processes in the entire amazon basin deltas, the inundated areas of forest, the floodplain, promote “active centers of evolution” which have to be considered in the process of management, exploitation of the water resources and biodiversity available. The interactions climate hydrological-fluvial dynamics are spatial and temporal and are fundamental for the maintenance of the ecological and biological processes. Therefore fisheries and biomass exploration, expansion of agricultural activities, hydropower development should take into account this dynamic nature of the ecosystem and its spatial and temporal complexity.

4 THE BIOGEOCHEMICAL CYCLES

River systems, floodplains, inundated forests are significant components of the global cycles of phosphorus, carbon and nitrogen. A large scale loss of CO_2 to the atmosphere occurs in the carbon dynamics of inland waters. Nitrogen and phosphorus cycles are closely related to the biomass production, primary productivity and decomposition processes that occur during inundation and dry periods in the floodplain.

Advection, reactions and transition of carbon, phosphorus and nitrogen from living organisms and decomposing matter to river transportation downstream are part of the dynamic processes that occur in the amazon basin. As the water moves downstream its composition, and process rates are altered by seasonally and spatially inputs/outputs. The small creeks in the Amazonian forests collect organic matter permanently falling from, the trees; these non point sources enhances the detritus food chain as well as include a large mass of sources of carbon, nitrogen and phosphorus to the streams and tributaries (WALKER, 1995). Thus the large hydrographic network acts as a collector of nutrients to the main rivers and tributaries. The water moving downstream the rivers and tributaries is modified in its composition by biological processing and a large scale remineralization of organic matter occurs. In the floodplain the surface of aquatic and terrestrial plants are covered by a biofilm of bacteria, fungi, protozoa and detritus, accelerating the transference of energy between detritus, the microbial loop, invertebrates and fishes. In the floodplain lakes, further processing of carbon, nitrogen and phosphorus stimulates primary productivity, higher biomasses and their role as nursery grounds for fishes and shrimps. Diurnal cycles of the dissolved oxygen, carbon dioxide, phosphorus and nitrogen concentration occurs (TUNDISI et al. 1984). These cycles are tied up with biomass living and dead of macrophytes. Insects, phytoplankton, zooplankton and alenines.

5 THE FUNCTIONING OF THE AMAZON WATERSHED: DYNAMIC INTERACTIONS

Figures 5 and 6 provide a summary of the main fluvial and the forest dynamics of the amazon watershed, linkages and connectivity of the ecosystems. These figures shows the complexity of the processes, the interaction between the components of the system and the dynamic character of the basin. Water fluxes, biodiversity, biogeochemical cycles are interrelated in small units and large subcontinental scales.

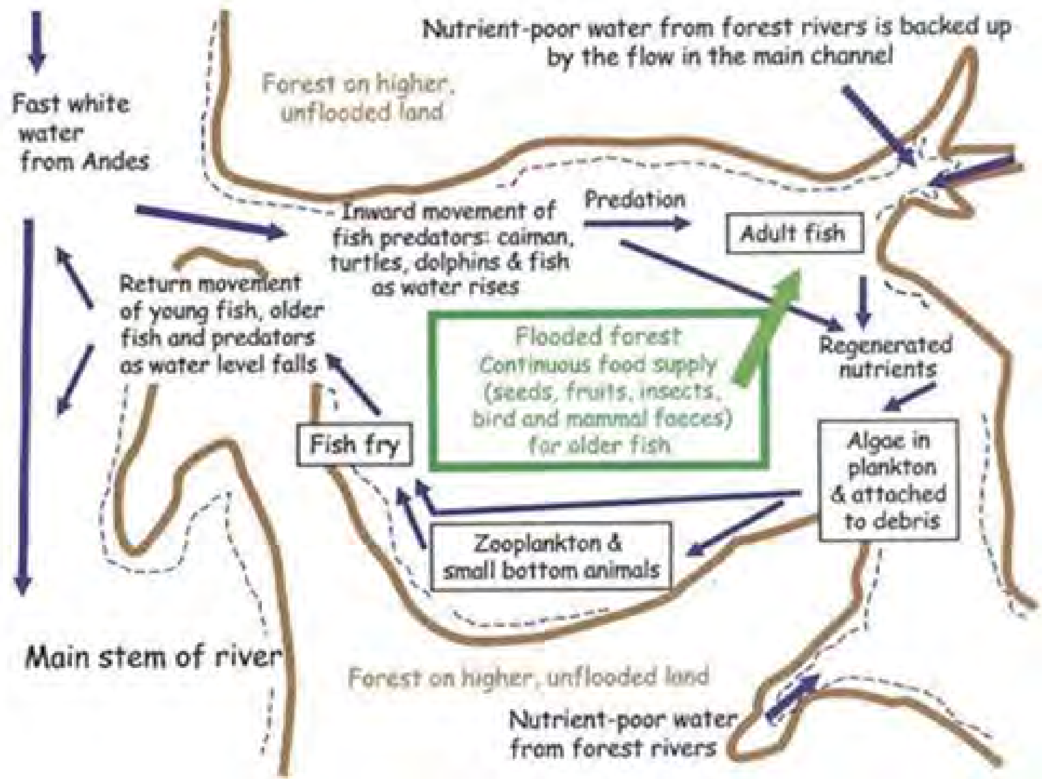


Figure 5 - Linkages in the Amazonian floodplain system. Based on E. J. Fitkau, 1970, Role of caimans in the nutrient regime of mouth-lakes in Amazon effluents (a hypothesis). Biotropica, 2, p. 138-142
Source: Moss (2012)

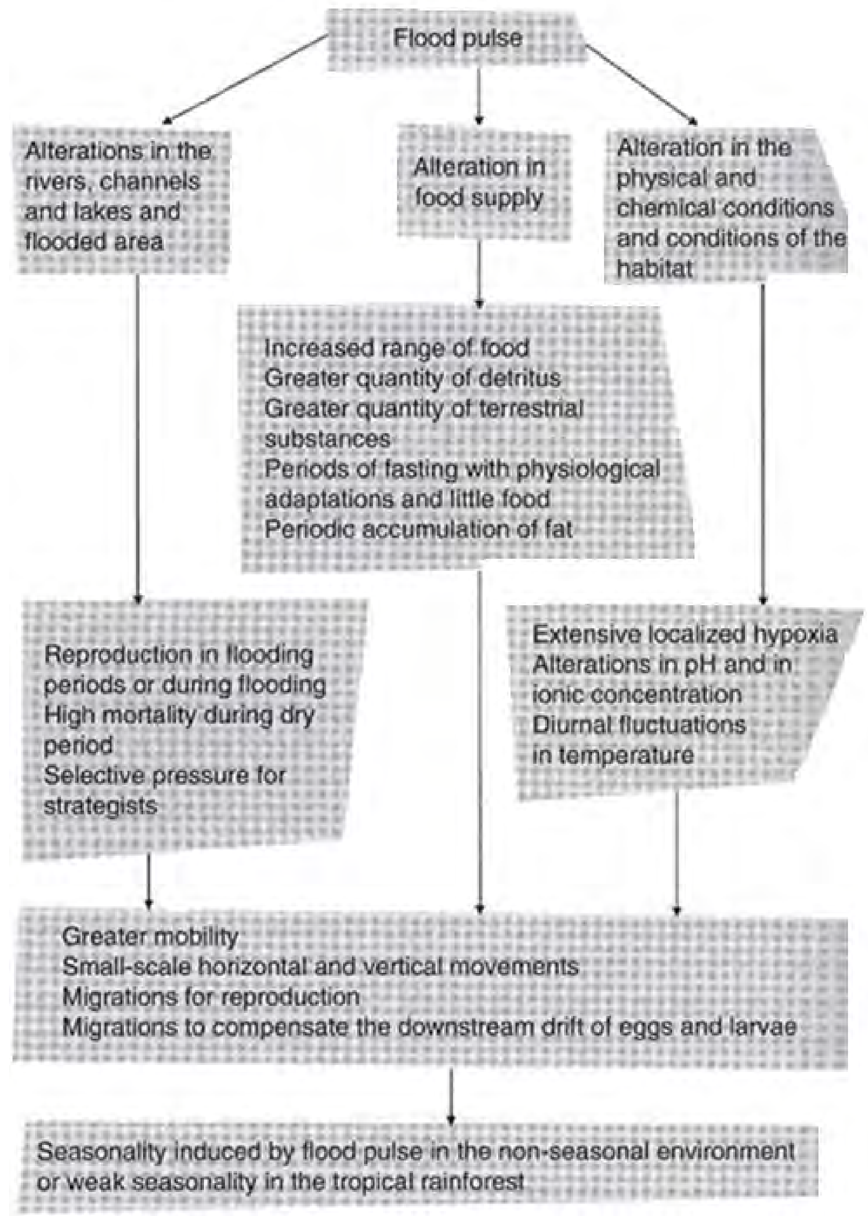


Figure 6 - Impacts of flood pulse on fish in the flood valleys of the Amazon
Source: Junk (2006)

6 ECOLOGICAL SERVICES IN THE AMAZON BASIN

An economic evaluation of the ecological services in the Amazon Basin is fundamental for the conservation policy, once the economic development with “business as usual” disrupts the functioning of the ecosystems affecting ecological biological and evolutive processes. As an “active center of evolution” the “value of existence” for the Amazon Basin is extremely important. It has no market value but there is a direct and indirect contribution to the human well being. In the last ten years there was an effort in the analysis that tries to evaluate the interrelationships between the economy and the ecosystem services in the Amazon Basin. The main concept supporting this evaluation is that financial flows in today’s economy disrupt sustainable activities in the Amazon Basin. The Amazon forest promotes environmental services in three categories: maintenance of biodiversity, water cycling, and carbon and phosphorus stocks. For example accordingly to several studies quoted in Marengo (2006) about 30% of the water in the atmosphere is due to the replenishment of the evapotranspiration of the forest. Therefore the economic value of ecosystem services can be the conceptual basis for the policy of ecosystem sustainability of the Amazon Basin. Since half of the dry weight of the threes is carbon, when the forest is cleared this carbon is released as CH_4, CO_2 to the atmosphere. The services promoted by the megadiversity of the Amazon Region are one of the central focuses of this economic evaluation. In the amazon territory in Brasil the possible existence of 1.8 million species of plants, animals and microorganism is estimated. Among the 17 countries with megadiversity in the Planet Earth, the biodiversity in the Brazilian Amazon is the first, considering plants, freshwater fishes, amphibians and insects. The Amazon Forest contains 50% of the worldwide biodiversity (Table 2).

Table 2 - Amazon Biodiversity compared with Brazil and the world

(continue)

Taxonomic Group	Amazonia	Brazil	World
Plants	30.000	43.020-49.520	263.800-279.400
Animals	?	103.780-136-990	1.279.300-1.359-400
Invertebrates	?	96.660-128.840	1.218.500-1.298.600
Arthropods	?	88.790-118.290	1.077.200-1.097.400
Chordate	?	7.120-7.150	60.800

SUMMARY

(continuation)

Taxonomic Group	Amazonia	Brazil	World
Fishes	1.300	3.420	28.460
Amphibians	163	687	5.504
Reptiles	240	633	8.163
Birds	> 1.000	1.696	9.900
Manuals	311	541	5.023
Total		168.640-212.650	1.697.600-1.798.500

Source: Becker and Stenner (2008)

The largest diversity of fishes in South America is concentrated in the Amazon basin. The number of fish species is higher than 1.500 this number is higher than the number found in all watersheds of the world. The demands of the market for products of the Amazon biodiversity are increasing fast. This means that there is a deep gap between the demands of the biodiversity services and the accumulated knowledge about biodiversity. The ecological services provided by the biodiversity include:

1. Health products – phytopharmacological products. Potential market U$ 20 billion/year;
2. Food products – products with physiological effects, complementary to diets;
3. Dermocosmetics product;
4. Food supply – large scale supply of protein, especially from fisheries with a high local/regional market and a national market in the countries sharing the amazon basin. Estimated value of these products: U$ 300million/year;
5. Bioenergy – oil products from forest plants.

The value of direct use for non forestry resources in the Amazon is given in the following, Table 3:

Table 3 - Direct use values – non-wood resources – in the Amazon

Source	Methodology/calculation basis	Value
Motta (2002)	Data from 2000	R$ 0.34/ha.year
Andersen et al., (2002)	Data from 1995	R$ 0.85/ha.year
Wunder (1999)	Agriculture and stockbreeding census of 1995/1996	R$ 0.22/ha.year

Source: Cabral et al. (2012)

Table 4 shows the value for direct use-ecotourism in tropical regions including Amazonia for comparison.

Table 4 - Direct use values – ecotourism – in tropical regions

(continue)

Source	Methodology/ calculation basis	Value	Area
Motta (2002)	This is a potential estimation compared to Pantanal ecotourism, considering a future scenario when tourism potential in the Amazon would be similar to Pantanal	US$ 9.00/ha.year	The Amazon
Costanza (1997)	All types of tropical rainforests and all ecosystem services related to recreation are considered	US$ 112.00/ha.year	Tropical Rainforest
Tobias and Mendelsohn (1991, *apud* TORRAS, 2000)	Travel Cost values of Monteverde Cloud Forest, in Costa Rica	US$ 50.00/ha.year	Costa Rica
Ruitenbeek (1992, *apud* TORRAS, 2000)	Values resulted from an assessment of governmental data of Korup National Park, Cameroon	US$ 5.00/ha.year	Tropical Rainforest (Cameroon)
Edwards (1991, *apud* TORRAS, 2000)	This study considers values obtained by demand function analysis of vacation recreational activities cost in Galápagos Islands, Ecuador	US$ 55.00/ha.year	Galápagos Islands
Andersen (1997)	Ecotourism and fishing in the Amazon	US$ 1.55/ha.year	The Amazon

(continuation)

Source	Methodology/ calculation basis	Value	Area
Naidoo and Adamowicz (2001)	Values based on: number of birds in the forest reserve, presence of primary and secondary forest, travel duration and lodging cost	US$ 0.59 (reserve with 20 bird species) and US$ 1.32 (reserve with 80 bird species)	Tropical Rainforest (Uganda)

Source: Cabral et al. (2012)

Table 5 shows the indirect use values for tropical environments and Table VI shows the value of existence for the Amazon.

Table 5 - Indirect use values – hydrological cycle – for tropical rainforest environments (NPV= Net Present Value)

Source	Methodology/calculation basis	Value	Area
Andersen (1997)	Marginal Productivity, NPV 6%	US$ 67.60/ha.year	The Amazon
Fearnside (1997)	Marginal Productivity, NPV 5%	US$ 30.00/ha.year	The Amazon
Tolmasquim (2000)	Economic valuation, NPV 5%, 20 years	US$ 1.76/ha.year	Tropical rainforests
Fearnside (1997)	Marginal Productivity	US$ 19.00/ha.year	The Amazon
Andersen (1997)	Marginal Productivity, erosion control	US$ 3.00/ha.year	The Amazon

Source: Cabral et al. (2012)

Table 6 - Existence value for the Amazon

(continue)

Source	Methodology/calculation basis	Value
Pearce (1991)	Based on a Contingent Valuation applied in rich countries in the 1980s on the Willingness-To-Pay (WTP) for the Amazon conservation	US$ 8.90/ha.year
Fearnside (1997)	Based on Cartwright (1995), considering all forests extension (Otpion Value+ Existence Value)	US$ 20.00/ha.year

(continuation)

Source	Methodology/calculation basis	Value
Horton et al. (2003)	Specific contingent study for the maintenance of Conservation Units in the Amazon. Applied in Italy and in the United Kingdom in July/August of 1999	US$ 50/ha.year for the conservation of 5% of the forest and US$ 67/ha.year for the conservation of 20% of the forest US$ 36/ha.year for a conservation of 20% and US$ 50/ha.year for a conservation of 5%
Fearnside et al. (1997)	Option and Existence Values are added together. This estimation is based on deforestation rates of 1990	US$ 5.423/ha.year
Torras (2000)	The total deforestation cost for 1993 is US$1,175/ha.year, of which US$194/ha.year corresponds to existence value	US$ 194.00/ha.year

Source: Cabral et al. (2012)

As shown the calculated value of existence for the Amazon obtained by various methodologies, range from U$ 8.90/hect year to U$ 194.00 hect.year (TORRAS, 2000). Values provided by Fearnside et al (1997) considering option and existence are U$ 5.423 hect.year A contingent specific study for the maintenance of conservation areas in the Amazon provide values that range from U$ 50 hect/year (for conservation of 5% of the forest) to U$ 67 hect/year (for conservation of 20% of the forest).

These estimates of the ecological services include a wide range of uses of the services by the local communities. Structural changes in the region with large scale impacts can impair these services and interfere with the multiple uses of the water, the biodiversity and the overall potential economic values, of the natural capital.

The strategic evaluation of the territory; the tendencies to the technical economic re-structuration of the space and the fluxes (road, telecommunications, migration) are confronted with alternative projects promoted by the local regional society based on the sustainability and the value, exploitation and conservation of the natural capital. In the last 20 years the significance of the Amazon in the global, regional and national context, promoted a change of concepts with emphasis on the quality of the human life and the natural capital mainly the megadiversity and water.

New strategies have to be considered, and implemented capable to solve the conflict between economic development, nature conservancy, social inclusion and use of the natural resources.

These new strategies encompass the logic of accumulated genetic information and the economic value of the natural capital as a consequence of the high relevance of biodiversity and sustainability. The accumulated natural capital and the cultural processes merged into the logic of nature conservancy as the major global geopolitical issue problem.

7 MULTIPLE USES OF WATER IN AMAZONIA

7.1 THE HYDROSOCIAL CYCLE

The Amazon watershed contains 70% of the freshwater available in the Planet Earth and has a extensive network of 1.000 rivers and streams (OHLY; JUNK, 1999).

Among the several multiple uses of water, public supply for domestic use, food production through fisheries, navigation, transportation, and recreation are the relevant ones. The resident population in the Amazon is adapted to the specificity of the floodplain and the hydrological cycles with their changing water levels.

Techniques and ways of life associated with the water cycle include working, transportation, housing social relationships; the hydrological cycle along the rivers and floodplains, encompass all activities of human life (food, recreation, transportation, soil fertility) including cultural processes. However despite the abundance of water and the intense relationship with human life, there is a social exclusion: the lack of portable water for the regional population. Only 56% of the population is connected to the potable water distribution syste and 5% to the collecting network of domestic wastewater.

Large percentage of the rural population living in the "varzea" and the inhabitants of small villages consume water in a raw state without any treatment. Sanitary conditions are thus based (disposition of domestic wastewater and solid wates) increasing local pollution and the risk and vulnerability of the human population.

Water borne diseases among adults and children are thus common in the vast floodplain ecosystems. Among water borne diseases in the Amazon, malaria occurs in modified environments (540.000 infected in 2006) Localized contamination of toxic metals such as mercury occurs in areas of gold mining.

7.2 THE ROLE OF FISHERIES

Fisheries in the Amazon floodplain are one of the major inland fisheries (MCGRATH et al., 1999), of the world. The fish production in Amazonia is directly related with the biological production which depends upon the photosynthetic activity of terrestrial and aquatic plants. On the contrary of oceanic waters where the photosynthesis is due primarily to phytoplankton, the primary productivity in Amazonian waters and the floodplain lakes is much more complex depending upon aquatic macrophytes, terrestrial plants in inundated forests, and phytoplankton in floodplain lakes. The classification of waters in the rivers of the Amazon basin consists in three categories (SIOLI, 1984; BARTHEM; GOULDING, 2007): Whitewater Rivers, Clear Water Rivers and Black Water Rivers. Besides the chemical characteristics of these waters, there is a high correlation between these water types and the biological production and fisheries. The White Water Rivers have their headwaters in the Andes and they carry a large concentration of suspended sediments rich in nutrients. When in the floodplain lakes the suspended sediment settles, increasing transparency and enhancing primary production by phytoplankton and also stimulating the macrophyte growth. Main white water Rivers of the Amazon Basin are Amazonas, Napo, Maranon, Tigre, Juruá, Purus and Madeira. These rivers have a high fishery production and are also areas of nursery for several fish species of the amazonian aquatic ecosystems. Black Water Rivers have their colors as a product of decomposition of the wood of forest, branches leaves, and fruits. They are nutrient poor and their productivity depends upon the plant material (detritus, leaves, fruits) of the drowned forest (GOULDING et al., 1988).

Clear Water Rivers are poor in suspended material, poor in nutrients with their headwaters in the Brazilian and Guianas shields. Rivers, Tocantins, Xingu and Tapajós are the three most important clear water rivers. Sources of food and energy for the fishes are: phytoplankton algae, macrophytes, detritus, seeds, aquatic invertebrates, periphyton. The trophic network that sustains the fisheries is extremely complex and varied along the Amazon Basin. The extension and diversity of the amazonian hydrographic network of large rivers, tributaries, channels, lakes and meanders, wetlands, is favorable to the migrating species of fishes. The major part of the species that are for commercial use in the Amazon Basin are migrating, exploring a variety of habitats for feeding, reproduction and as a nursery ground (BARTHEM; GOULDING, 2007). The average estimate of biomass of fishes and shrimps in Whitewater Rivers is from 67-150 kg/ha. Estimates for Solimões River near Manaus are of a biomass of 1.600 kg/ha which is very high compared with other South American, Africa and South East Africa, rivers. In the Amazon floodplain estimates of biomass are 162 to 318 kg/hectare.

Figure 7 shows the area used by the main commercial species of fishes in the Amazon Basin.

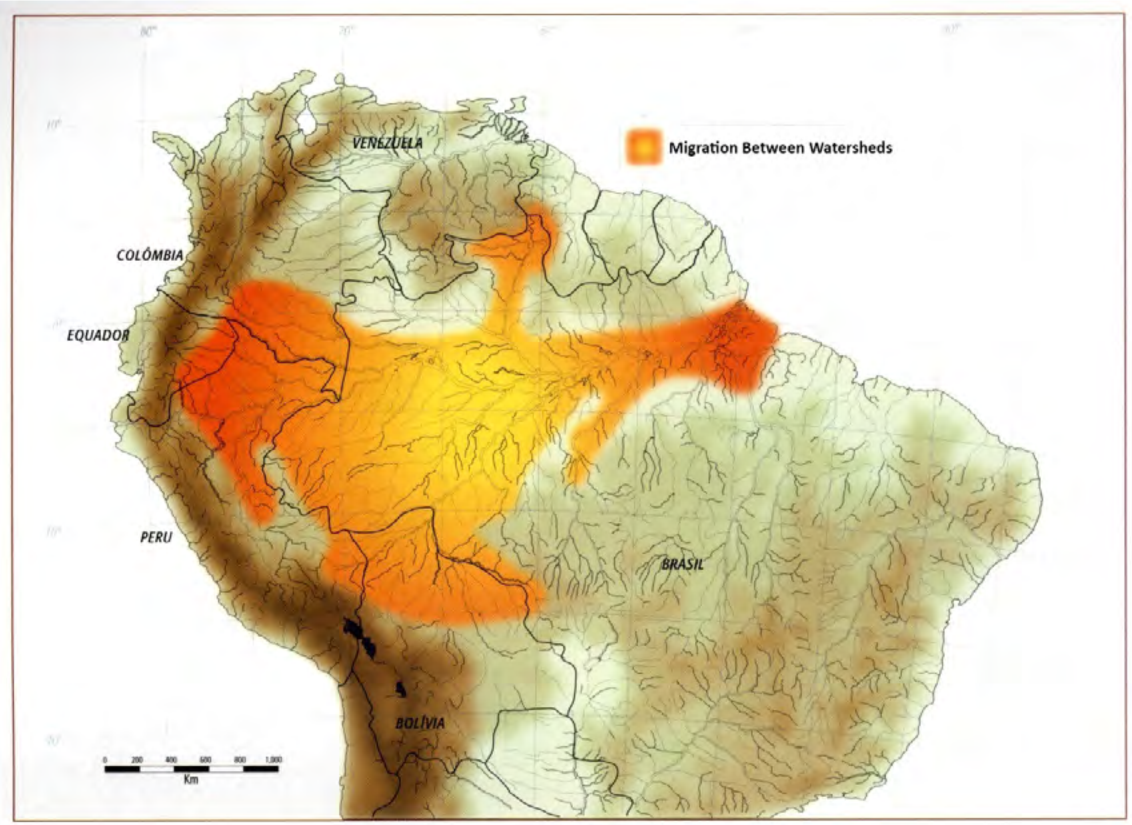


Figure 7 - Area used by the main commercial species of fishes in the Amazon Basin
Source: Barthem and Goulding (2007)

The fisheries regions in the Amazon Basin are associated with the areas of high biological production such as the floodplain or estuary of the Amazon. The Amazon River has the highest floodplain area, and it is the most important river for commercial fisheries. Black Water and Clear Water Rivers support also important commercial fisheries. The rivers connect the large floodplain with the estuary in a continuum exploited by fishermen and rural communities (Fig. 8). The Central Amazon, Estuary and Peruvian Amazon are the highest fisheries regions, with a total of approximately, 5 million inhabitants.

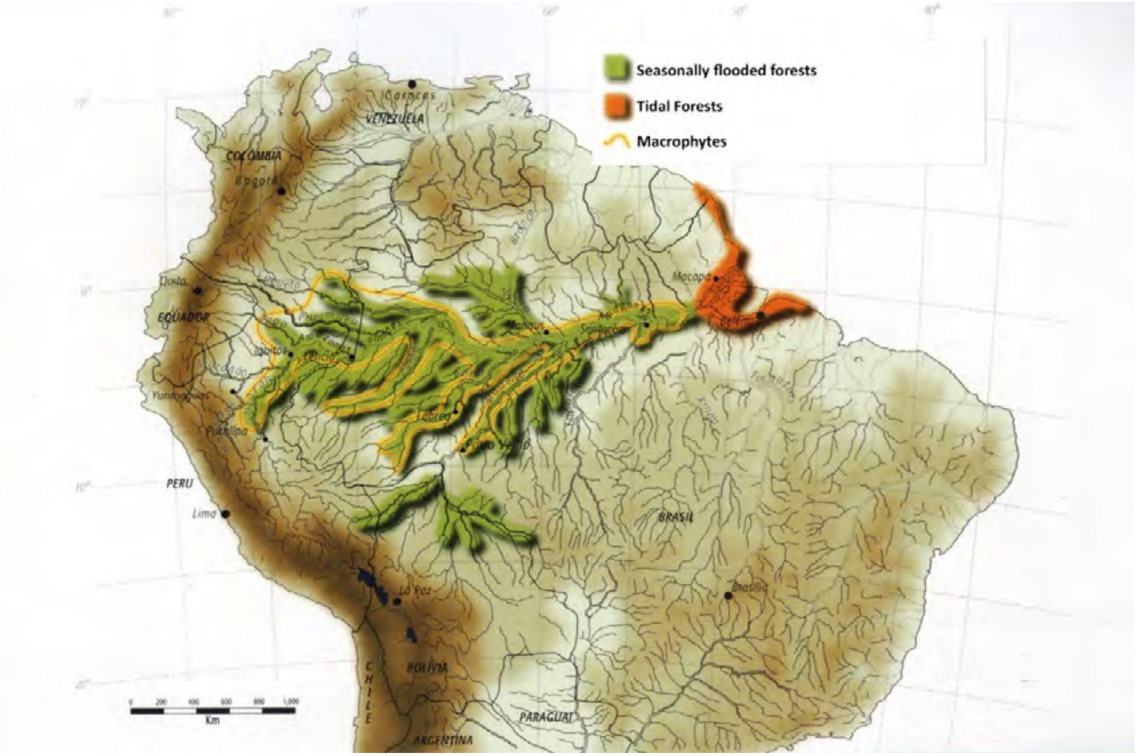


Figure 8 - Flooded forests and aquatic macrophytes in central Amazonia connected with the main fishery grounds
Source: Barthem and Goulding (2007)*

The maximum fish production of the 66 towns analyzed by Barthem & Goulding, 2007, was 173.000 tons with a population of 7 million inhabitants. This gives a per capita consumption approximately of 600 g/day. This is the main source of proteins for the human population in the Amazon. The major part of the fish captured is consumed locally. The increase in the pressure on the fisheries in the result of changes in fishing technology, combining with increasing regional and national demand for fish. The total economic production of fisheries in the Amazon Basin is estimated as U$ 250 million/year (BAYLY; PETRERE, 1989).

As an example of distribution of fisheries, the production of "Tucunaré" (*Cicchla occelaris*) is shown. (Fig. 9).

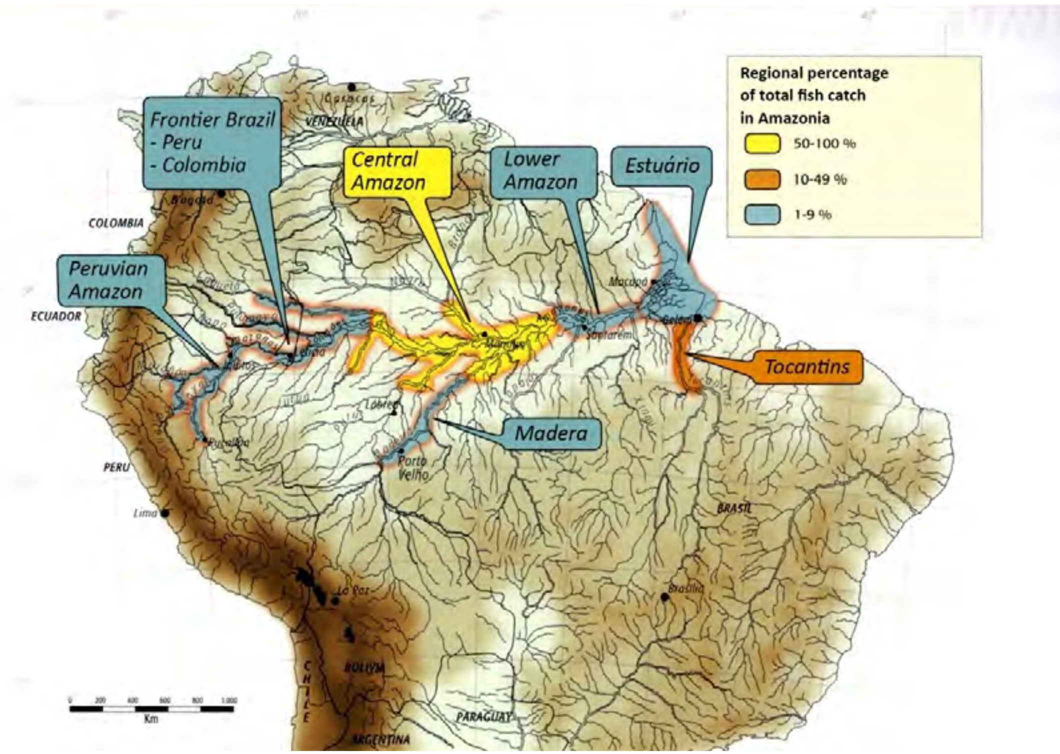


Figure 9 - Distribution of "Tucunaré" (*Cicchla occelaris*)
Source: Barthem; Goulding (2007)

7.3 RESERVOIR CONSTRUCTION IN THE AMAZON BASIN

The main hydrographic basins of the Southeast and South of Brazil were regulated by a great number (approximately 150) of large dams (dam height higher 15 meters) accumulating a great volume of the water. The hydroelectric potential of the South East and South hydrographic basins of Brazil is almost exhausted.

Amazon basin retains 70% of capacity of hydropower production in Brazil. Therefore among the competitive uses of water in the Amazon Basin the construction of hydroelectric reservoirs is a relevant one. Fig. 10 and 11 shows respectively the dams in operation and the planned reservoirs for the Amazon Basin.

Figure 10 - Reservoirs in operation in the Amazon
Source: Eletrobrás 2011

Figure 11 - Planned Reservoirs for the Amazon basin
Source: Several

The complex interactions between the flood regime, the aquatic and terrestrial systems were described in another section of this paper. Structure, functions of organisms and ecosystems and their temporal and spatial patterns are interrelated with the climatologic hydrologic and fluvial dynamics of the Amazon watershed main rivers and tributaries. Tundisi (2007) pointed out the following impacts of reservoir construction in the described complex interactions:

- Disruption of the flooding regime and the flood pulse;
- Deterioration of water quality of the reservoirs, downstream the reservoir due to decomposition of organic matters of the drowned vegetation;
- Disruption of the hydrosocial cycle and ecological services of aquatic ecosystems (loss of biodiversity, loss of fish stocks);
- Increase of potential development and expansion of waterborne diseases;
- Decrease of water availability for domestic use due to deterioration of water quality;
- Increasing costs of water treatment due to deterioration of water quality of reservoir;
- Economic impacts due to reduction of fisheries;
- Changes in all economic activities related with water availability and uses;
- Another process that is being currently studied refers to the emission of greenhouse gases from reservoirs. Besides the decomposition of accumulated organic matter of the drowned vegetation the contribution from the watersheds and the higher retention time play an important role in the emission of CH_4, CO_2 and N_2O by the reservoirs. (FEARNSIDE 2002; ROSA et al. 2003) (Fig. 12).

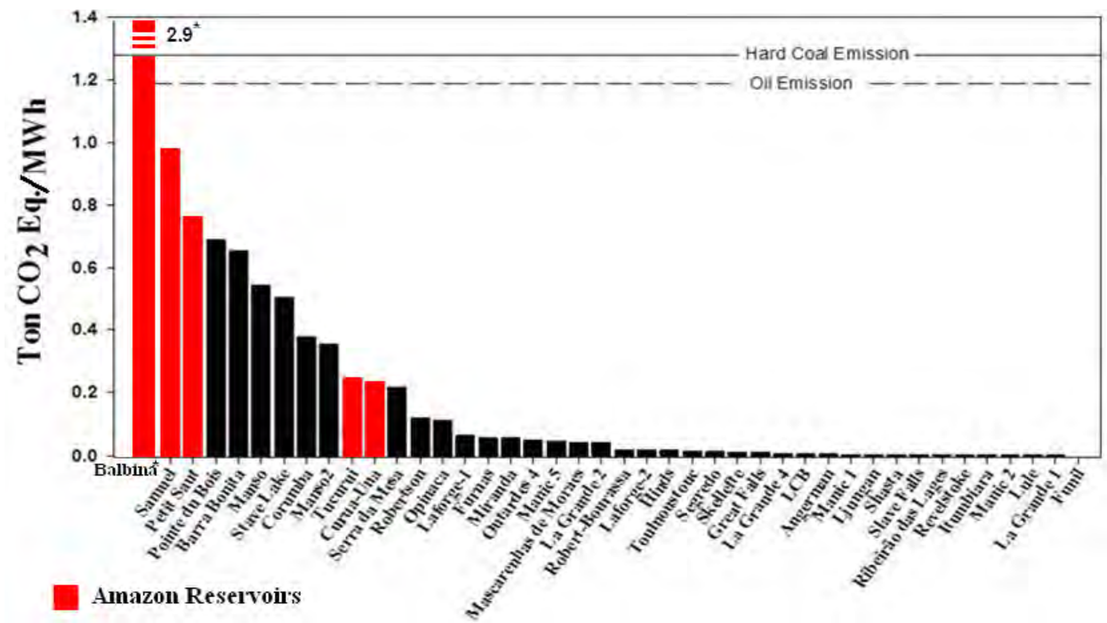


Figure 12 - GAS emissions by reservoirs
Source: Ometto et al. (2012) and Kemenes et al. (2007)

- The transport of sediment by the rivers is reduced by the reservoirs affecting channels morphometry and the spatial reorganization that is common in the Amazon Basin;
- The constructed reservoirs can be subjected to a extensive eutrophication process. With the deforestation in the watershed, the increase of non point and point sources of nutrients, the higher temperature and stratification of the reservoir accelerated eutrophication occurs (TUNDISI; MATSUMURA TUNDISI, 2008).

Despite all these interferences and impacts reservoir construction in the Amazon Basin, showed positive aspects such as access to energy, the revitalization of regions with a better infrastructure, (hospitals, schools, roads, housing, sanitation) (TOMALSQUIM, 2012) is also an advanced result of reservoirs construction, consolidation of water ways, enhancing of and recreation activities and aquaculture.

However these water uses and the harnessing of the hydropower of Amazonian rivers do not benefit only the local population. Due to the energy distribution in Brazil most of the energy produced in the amazon basin is used by the South, South East and North East population and industries;

Thus one of the most important economic uses of water in he amazon basin serves mainly other regions of Brazil and practically all other countries sharing The Amazon Basin in South America.

8 THE OVERALL IMPACTS ON THE WATER USES

The water quality and water availability in the amazon watershed can be impacted by the several projects for economic development such as:

I. Agricultural expansion with deforestation;
II. Fisheries overexploitation;
III. Introduction of exotic species;
IV. Mining activities;
V. Reservoir construction;
VI. Aquaculture;
VII. Expansion of urbanization;
VIII. Road construction.

The activities will interfere with the water user, biodiversity (terrestrial and aquatic) modify habitats and environments and produce an impact on the flooding process and spatial heterogeneity of the system.

8.1 AGRICULTURAL EXPANSION

The large scale agricultural development in the Amazon basin in order to increase food production (soya bean or meat production) has as a consequence a rapid deforestation, destroying the areas of forest that support the floodplains and aquatic macrophyte habitats. Without the habitats of inundated forests or macrophytes the water quality will be impaired and fisheries will be affected. The areas of macrophytes are nursery grounds for commercial species of fihes. The agricultural expansion homogenizes the environment removing its main ecological factor fundamental for the environmental sustainability and species diversity that is the spatial heterogeneity.

8.2 FISHERIES OVER EXPLOITATION

As a consequence of the increasing demand for fish from the large markets in the urban regions of the Amazon basin and the export of commercial fishes to South East of Brazil markets such as São Paulo metropolitan region, some species are over exploited. An example is the "tambaqui" (*Colosoma macropogum*). Other large catfish species are being over exploited, reducing fish stocks and interfering with the food supply to the local markets.

8.3 INTRODUCTION OF EXOTIC SPECIES

The promotion of aquaculture is considered to be as a indirect factor for a better fisheries management (BARTHEM; GOULDING, 2007). However aquaculture is being developed near large urban centers such as Manaus and Belem in Brazil or Iquitos in Peru. Exotic species of fishes and shrimps were introduced in these aquacultural activities. It is doubtful as pointed out by several specialists (PADOCH et al., 1999) if aquaculture could be an alternative way to increase fish production in Amazon basin. Many new initiatives focus to increase production of native fish fauna, through conservation practices and of the fisheries regulation.

8.4 MINING ACTIVITIES

The degradation of landscape, interference in the hydrological cycle and the deforestation caused by the mining activities such as gold mining have considerable impact in the natural system of the Amazon basin. Contamination of freshwater fish and humans with Mercury as a consequence of gold mining was described by many authors (TUNDISI; MATSUMURA-TUNDISI, 2012). Impacts on the water uses and availability as a consequences of degradation of natural water sources is a common characteristic of mining sites; local alteration of the water ecosystems and the hydrological cycle, loss of habitats and species are also common.

The "environmental transition" from a natural to an anthropic process is the cause of increasing several diseases such as malaria, dengue fever, and others.

8.5 IMPACTS OF RESERVOIR CONSTRUCTION

Major impacts of reservoir construction were discussed on section 5.3.

8.6 EXPANSION OF URBANIZATION

In the urban centers of Amazon basin such as Manaus or Belém the sanitation problems in the periurban regions are extremely serious causing several infections or parasitic diseases to a great number of people living in these areas. The vulnerability of these groups is aggravated by the precarious water supply, inexistent waste water treatment and insufficient infrastructure. In this periurban region there are frequent outbreaks of malaria or dengue fever as a consequence of the proximity of the native forest.

8.7 ROAD CONSTRUCTION

The Road construction in Amazon is another relevant impact on the sustainability of the natural ecosystem. Roads change the regional organization that was traditionally defined around and along the rivers. Roads advance from the South and Central Brazil simultaneously with the expansion of the agricultural frontier. A change in the distribution of the population and the degree of urbanization occurs: the human population now aggregates along the roads axis and not along the river axis. Therefore the sustainability of rural communities in the floodplain organizing in smaller managed units around lakes, wetlands, dry areas during low water is at risk.

8.8 HUMAN HEALTH CONSEQUENCES OF THE IMPACTS AND THE VULNERABILITY OF THE SUSTAINABILITY PROJECTS

All the human interventions in the Amazon basin have as a consequence an increase and expansion of several diseases, originally contained in the forest area, floodplains, but now expanding to the periphery of urban centers or towns along the roads. The mobility of some social groups such as miners, indigenous people, people moving to large development projects such as reservoirs in construction is one of the causes of these expansions.

Table 7 shows the structural changes in the Amazon with impacts and advances.

Table 7 - Structural changes in Amazon, impacts, advances, infrastructure

Structuralchange	Main negative impacts	Advances/Infrastructure
1 - Territory conectivity - net-wrk of transport telecomunication	* Migration / mobilityo workers * Deforestation * Disregand of ecological / social peculiarities	* Diversification of population * Social Mobility * Access to information * Urbanization
2 - Industrialization - Economic Structure	* Large Projects * Subsidies to large companies * Territorial change * Environmental impacts	* Urbanization * Industrialization * Increase in Mining activities * Increase in consumables production
3 - Urbalization - Structure of the human oc-cupation macrozoning	* Growth of uncontrolled urbanization * Growth of poor periurban regions * Increase of deforestation and termic hot spots	* Change of axis management Belem * Networks of information/circulation * Green markets * Locus of internal accumulation in Brazil * Political and environmental iniciatives
4 - Organization of civil society	* Social Environmental Conflicts	* Diversification os structure * Establishment of new/local societies * Political learning * Citizinships
5 - Socio Environmental networks	* Conflicts on land use * Environmental conclicts	* Establishments of a technical ecological vector * Indigenas land demarcation * External aliances * Multiplication of conservation unity * Capacity Building
5 - New Scale - Geopolitics of the social groups - resistence to free	* Conflicts	* Insertion of Amazon Region in Brazil

Source: Becker and Stenner (2008)

9 IMPACT OF CLIMATIC CHANGES ON THE WATER CYCLES, WATER AVAILABILITY AND WATER USES IN THE AMAZON BASIN

Models presenting scenarios for the future of the Amazon Basin in relation to climatic charges showed tendencies in the increase of extreme events such as rainfall as well as dry periods (MARENGO, 2006, MARENGO et al. 2010). Certain areas of the Amazon Basin, corresponding to 11% of the forest area from Tocantins to Guiana, have patterns of precipitation more close to the Cerrado (savannah type of vegetation of Central Brazil). This is consistent with future scenarios generated by the model “Hadley Centre” projecting for Amazonia a savannah type climate from 2050. The soils of this modified Amazon forest are dryer, the evapotranspiration is higher, and the loss of humidity and the dryness increase the vulnerability to forest fires, accelerating the process.

Accordingly to Marengo et al (2010) if the expansion of the agriculture frontier and the deforestation are maintained at the present levels, the forest cover will be changed from 5.3 million km^2 of the present (85% of the original area) to 3.2 million km^2 by 2050 (53% of the original cover).

The increase of temperature in the amazon basin can cause dryness in the atmosphere due the forest “savannization”. Some more drastic scenarios project an increase of approximately 8°C in the air temperature. The average results for all models tested indicate higher probability of reduction of rainfall is the east and northeast of the Amazon regions (Marengo et al 2010).

There are several consequences of these changes in the hydrological functioning of the Amazon watershed. These are:

i. Changes due to disruption of connectivity between the small creeks in the forest and wetlands, with effects on the productivity and biodiversity in these ecosystems;

ii. Changes in the water level fluctuations with loss of floodplain lakes and huge losses on fish stocks and fish diversity. The dry period and the “savannization” of Amazonia will produce an impact on the water replenishment in Amazonia due to the fact that approximately 30% of the water in the atmosphere is originated by the evapotranspiration of the forest (SALATI; NOBRE 1991; MARENGO, 2006);

iii. The fertility of the “varzea” (floodplain) will be affected as a consequence of the dry period. This implies in loss of local productivity is small structured units;

(continuation)

iv. Interference on the hidrosocial cycle as a consequence of smaller water level fluctuations and isolation of large areas;

v. The Amazon watershed is a source of moisture for the La Plata Basin and the "savannization" of this ecosystem implies in less rain for the La Plata Basin and large regions of Central South America (MARENGO, 2006). (Fig. 11).

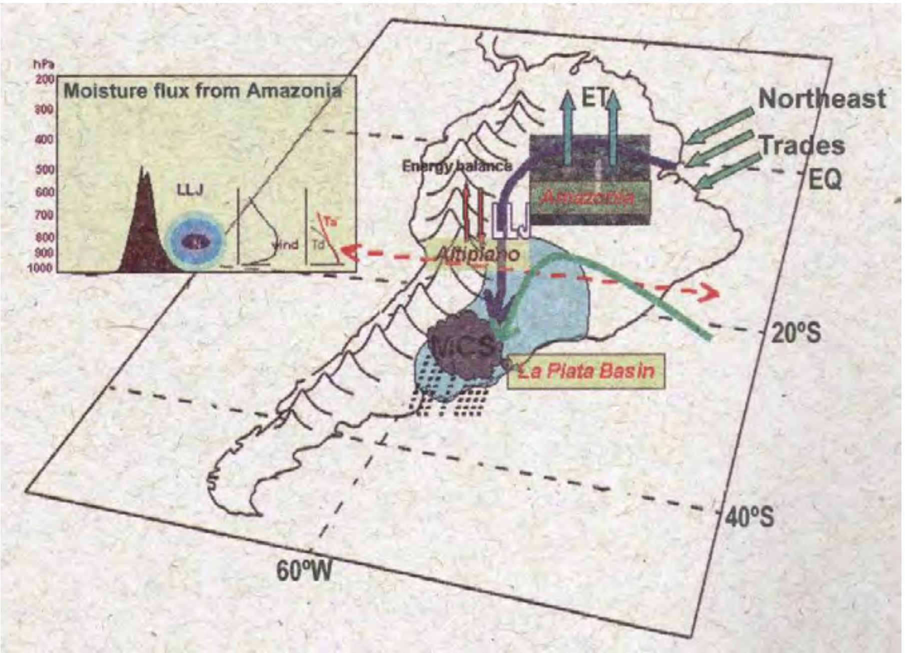


Figure 13 - Transference of moisture from the Amazon Basin to Central Brazil
Source: Marengo (2006)

Impact on the biogeochemical cycles, specially the carbon cycle which depends upon the capacity of photosynthesis of aquatic and terrestrial plants. The changes in this cycle will affect food chains, lakes, wetlands and can increase the emission of greenhouse gases.

vi. In small rural communities, availability of water can be impaired. Water sources for domestic supply will be difficult to access, due to recession of rivers and channels. This is evidence from the experience of the 2005 dry period. (MARENGO; 2006).

10 CONCLUSIONS, RECOMMENDATIONS AND PERSPECTIVES

As pointed out by Becker and Stenner (2008) the Amazonian territory offers vast possibilities for the future, based on its complexity and heterogeneity this heterogeneity, social, environmental, cultural, economic, anthropologic an ecological, is strength not a weakness and should be exploited in the planning and actions for future according to Jorgensen, Tundisi and Matsumura Tundisi 2012, the strategy. Since the model of environmental preservation is exhausted now it is necessary to develop the Amazon with integrated development that includes the diversity/the value of natural capital and the implementation of networks of cities, urban areas, interconnected with villages, small settlements based on production of forest, the forest economy and the environmental services, will be the basis of this development with a true South America agenda. Projects of water management by BID/OAS and USAID and other new projects, integrating and connecting production, transport, processing including the countries sharing the Amazon watershed wil be a fundamental development process in the region.

10.1 THE FOREST PRESERVATION

The information that the Amazon forest is a key component of the water cycle but also the Amazon basin transfers permanently moisture to the central region of Brazil and La Plata Basin is well established. Therefore the conservation of the Amazon forest is of high priority. The large scale ecosystem services on the water cycle provided by the Amazon forest, could be the basis for this preservation considering the continental impact of the deforestation and the need to secure food production in the Central and South East Brazil. The forest has a strong contribution to the convective precipitation that plays an important role in the region for water supply (MALHI et al. 2008).

As Martinelli et al. (2012) pointed out a balance has to be achieved between food production, biodiversity and ecosystem services specially taking into consideration the role of ecosystem services of aquatic ecosystems and the water cycle that drives the whole functioning of the natural systems in the Amazon. To preserve huge losses of forest and consequently of water, models for exploitation of forests combined with preservation units have to be considered. Many state interventions in the Amazon, failed to close the gap between modern and sustainable forms of exploitation of the natural resources and the needs of local populations. The use of the scientific and technological knowledge of the functioning of the natural ecosystem in the Amazon is fundamental for management practices.

10.2 THE MANAGEMENT OF FLOODPLAIN

The adjustment of technologies directed to the principle of diversity rather than the patronization and homogeneity should be the basis for the rational exploitation of the natural resources. As pointed out by Junk (2005) the complexity of the ecosystem in the floodplains requires different approaches. The preservation or restoration of a near natural flood regime is one of the key measures to preserve floodplains, fisheries and the hydrological cycle. Land and water uses in the floodplain vary greatly along the Amazon basin (Amazon River and tributaries), therefore adapted technologies for management is essential. Since the floodplain is a fragile ecosystem one possible mechanism to maintain it, is the effort of communities to assume control of local lakes and the floodplain in order to secure continued lake fisheries and small scale agriculture. Thus the "effective user-group participation" (sic MCGRATH et al., 1999) is fundamental for a local level management. Fishing is carried out in the lake system close to the community as well as agricultural practices in the floodplain during low water.

The lake reserves being used as management units are a way to preserve and manage other components of the floodplain ecosystems. The removal of some barriers to implement the community management model includes a revision of the brazilian fishery management legislation to promote a decentralized process based on a regional/ local watershed approach. The other barrier to be removed is the adequate use of scientific information in order to organize, systematize and improve the local knowledge. The biology of the main commercial species of fishes is not yet completely known and efforts should improve his information that could be extended to the local communities.

The conservation and sustainable development Project at Mamirauá Ecological Station initiated in 1990 is an example of the use of natural resources in a flooded forest located in the region between the Japurá, Solimões and Auti-Paraná Rivers. The total area of the reserve is 11.240 km^2. The Project aimed to stimulate the coexistence of human population, with the protection of local biodiversity and the exploitation of fisheries, logging, tourism and other activities, such us small scale agriculture.

Educational programs of the approximately 1.600 residents in the reserve, community participation in the design of yearly objectives for management and an overall long term management plan where achievements of this Project. The protection of the lakes as a resource for fisheries was implemented early in the beginning of the Mamirauá Project and the practice of using some lakes for sustainable production and other lakes for conservation is adopted today by almost all varzea communities along the Amazon River (AYRES et al., 1999).

10.3 RESERVOIR CONSTRUCTION

As shown in reservoir impacts a large scale harnessing of the hydroelectric potential of the Amazon basin is a major impact on the flooding regime and on biodiversity of aquatic ecosystems and associated terrestrial ecosystem in the inundated area and the floodplain. The large inundation area of the reservoirs in the Amazon basin proved to be a large ecological impact as demonstrated by the power plants of Tucuruí, Balbina, Samuel and Curuá-Uma. The disrupting of the hydro social cycle the loss of aquatic biodiversity and the extreme homogenization produced by the large reservoirs are long term impacts that affect permanently the Amazonian ecosystem and their functioning. Therefore an analysis on the possible reduction in the number of the dams is a imperative measure of strategic significance for the future of the whole region. Experience shows also that cascades of dams in the rivers will have deleterious effects in the floodplain, in the flooding regime and in the ecological connectivity and spatial heterogeneity of the system (TUNDISI, 2007). Therefore natural areas interrupting reservoir sequences in the same river should be a strategy to allow for the recovering of the river mechanisms preserving floodplains, lakes and hydrosocial cycle.

The reservoirs engineering should be changed when considering the Amazon basin organization and functioning. Reservoirs with a long retention time are deleterious to water quality upstream and downstream and increase the emission of green house gas such as methane and nitrous oxide (TUNDISI, 2007, 2008a-b). Therefore reservoirs with lower retention time (less than one month) are more appropriate with a reduced impact. The maintenance of a ecological flow downstream is a key operational objective and for that reservoir construction has to be re structured.

Finally as a strategic overall public policy for the future: some rivers relevant for fisheries and sustainability of the Amazon basin should be permanently preserved (see Fig. 8 and 9) in order to maintain the “core area” of the functioning of the water cycle and biodiversity in the Amazon basin, and preserve future economic development.

A vast range of diseases affects directly or indirectly the human population in the Amazon. In order to maintain sustainability, it is necessary a mobilizing project first to treat the “local infections” and then those caused by the human intervention.

REFERENCES

BARTHEM, R.C.; GOULDING, M. 2007. Um ecossistema inesperado. Amazônia revelada pela pesca. ACA SCM, p. 241.

BAYLY P. AND PETRERE M. 1989. Amazon Fisheries. Assessment methods, currents status, and management options. Canadian Special Publications on fisheries and aquatic sciences. Vol. 106 pp. 385-399.

BECKER K.B. E STENNER CLAUDIO. 2008. Um futuro para Amazônia. Oficina de Textos. Série inventando o futuro. pp. 1-150.

CABRAL W. C. J. et al 2012. Rio Puru: águas, território e sociedade na Amazônia Sul-Ocidental. Librimundi. 274 pp.

DAI A. AND TREMBERTH K.E. 2002. Estimates of freshwater discharge from continents: Latitudinal and seasonal variations. Journal of Hydrometeorology. American Metereological Society. vol 3, pp 660 – 683.

FEARNSIDE, P.M. 1997. Environmental Services as a Strategy Development in Rural Amazônia. Ecological Economics, v.20, p 53-70.

___ 2002. Greenhouse gas emissions from a hydroelectric reservoir (Brazil's Tucuruí Dam) and the energy policy implications. Water, Air and Soil Pollution, 133:69-96.

GOULDING M. 1988. Ecology and management of migratory food fishes of the Amazon Basin. Pp. 71-85. In: F. Almeida and Pringle C.M. (Editors) Tropical rainforests, diversity and conservation. California Academy of Sciences. San Francisco.

HAFFER J. 2008. Hypothesis to explain the origin of species in Amazonia. Brazilian Journal of Biology, IIE, São Carlos, SP, v. 68, n.4, p. 917-948.

JUNK W.J. 1984. Ecology of the varzea, floodplain of Amazonian white rivers. In: SIOLI H. The Amazon: Limnology and landscape ecology of mighty tropical river and its basin. Dr. W. Junk Publishers, p.763.

JUNK W.J. AND WEBER G. E. 1996. Amazonian floodplain: a limnological perspective. Verh. Int. Verein limnology. Vol. 26 pp. 149-157.

JUNK W.J. 2000. The Central Amazon River Floodplain: Concepts for the Sustainable Use of its Resources. In: Junk, W.J., Ohly, J.J., Piedade, M.T.F. & Soares, M.G.M. The Central Amazon Floodplain: Actual Use and Options for a Sustainable Management. Leiden: Backhuys Publishers B.V., P. 75-94.

JUNK W. 2005. Flood pulses and the linkages between terrestrial, aquatic and wetland systems. Verh. Intern. Verein Limnol. V.29, p.11-38.

KEMENES, A.; FORSBERG, B.R.& MELACK, J.M. 2007. Methane release below a tropical hydroelectric dam. Geophysical Research Letters, 34:L1289, doi: 10.1029/2007GL029479.55.

MALHI Y. ROBERTS J.T. BETTS R.A. KILLEEM T.J. Liw and Nobre C.A. 2008. Climate change, deforestation and the fate of the Amazon. Science. 319 pp. 169-172.

MARENGO J.A. 2006. Mudanças climaticas globais e seus efeitos sobre a biodiversidade. Biodiversidade, 26, Brasília, MMA. 159pp.

MARENGO J. A. and Tomasella J. Nobre C. 2010. Mudanças climáticas e recursos hídricos pp. 201-215. In: Bicudo, C. E. M., Tundisi J. G., Scheuentsul M. (Editores) Águas do Brasil. Análises estratégicas. Academia Brasileira de Ciências, Inst. Botânica. 222pp.

MARTINELLI L. A. 2012. Ecosystem services and agricultural production in Latin America and the Caribbean. IDB. Technical note, pp 24.

MC GRATH D. CASTRO F. CAMARA E. AND FUTEMAC. 1999. Community Management of floodplain lakes and the sustainable development of Amazonian fisheres. Pp 59-82. In: Padock et al (Editors) Varzea: diversity, development and conservation of amazonias whitewater floodplains. New York Botanical Gardens Press. Advances in Economic Botany. 407 pp.

MOSS B. 2012. Liberation Ecology: the reconciliation of natural and human cultures. International Ecology Institute, Germany, 433 pp.

OHLY J.J. AND JUNK W.J. 1999. Multiple use of Amazonian floodplains: combining ecological conditions, requeriments for environmental protection and socioeconomic needs pp. 283-300. In: Padock C. et al (Editors). Varzea: Diversity, Development and conservations of Amazonias whitewater floodplains. New York Botanical Gardens. 407 pp.

ROOSEVELT A.C. Twelve thousand years of human environment interaction in the Amazon. 1999. Pp 371-392. In: Palock et al: Varzea: chiversity, development, and conservations of amazonias whitewater floodplain. New York Botanical Garden Press. Advances in Economic Botany. 407 pp.

ROSA, L.P; DOS SANTOS, M.A.: MATVIENKO, B.;SIKAR, E.; LOURENÇO, R.S.M. & MENEZES, C.F. 2003. Biogenic gás production from major Amazon reservoirs, Brazil. Hydrological Processes, 17(7):1443-1450.

SALATI E. MARQUES J. Mollion L.C.B. 1978. Origem e distribuição das chuvas na Amazônia. CENA. Piracicaba. 33 pp.

SALATI E. AND MARQUES J. 1984. Climatology of the Amazon region. Pp 85-126. In: Sioli H. (Editor). The Amazon: Limnology and Landscape ecology of a mighty tropical river and its basin. W. Junk. 763 pp.

SALATI E. & NOBRE C. A. 1991. Possible climatic impacts of tropical deforestation. Climatic change. Vol. 19. pp. 177-196.

SALO, J.; KALLIOLA, R.; HAKKINEN, J.; MAKONEN, Y.; NIEMELA, P.; PUHAKKA, M.; COLEY, P.D; 1986. River dynamics and the diversity of Amazon lowland forest. Nature, v. 322, p. 254-258.

SIOLI, H. (Ed). 1984. The Amazon: Limnology and Landscape Ecology of a Mighty Tropical River an its Basin. Dr. W. Junk Publishers, Haia, Países Baixos.

SIOLI, H. 1984. The amazon: Limnology and lands cape ecology of a mighty tropical river and its basin. Dr. W. Junk Publishers, P. 763.

TOMASLSGUIN M. 2012. Conference Brazilian Academy of Sciences. May 7 (2012).

TORRAS M. 2000. The total economic Value of amazonian deforestation. 1978 – 1993. Ecological Economics, v. 33, p. 283-297.

Tunsisi J.G. et al. 1984. Mixing patterns in Amazonian lakes. Hydrobiologia, W. Junk. Dordrecht. Vol. 108 pp. 3-15.

TUNDISI J. G. 2007. Exploração do potencial hidroelétrico da Amazônia. Pp. 109-117. In: Estudos Avançados, USP. Dossiê Energia, vol. 59, 382 pp.

TUNDISI, J. G. ; MATSUMURATUNDISI, T. ; TUNDISI, J. E. M. . Reservoirs and human well being: new challenges for evaluating impacts and benefits in the neotropics. Brazilian Journal of Biology (Impresso), v. 68, p. 1133-1135, 2008.

TUNDISI, J. G. ; MTASUMURATUNDISI, T. ; ABE, D. S. . The ecological dynamics of Barra Bonita (Tietê River, SP, Brazil) reservoir: implications for its biodiversity. Brazilian Journal of Biology (Impresso), v. 68, p. 1079-1098, 2008.

TUNDISI J.G.; MATSUMURA TUNDISI T. 2008. Biodiversity in the neotropics: ecological, economical and social values. Braz. Journal. Biol., v. 68, n. 4, p. 913-915.

TUNDISI J. G.; MATSUMURA TUNDISI T. 2008 Limnologia. Oficina de Textos. 632p.

TUNDISI J. G. AND MATSUMURA TUNDISI T. 2012. Limnology. CRC Press. Taylor & Francis. 831 pp.

WALKER, I. 1995. Amazon streams and small rivers. Em Tundisi, J. G., Bicudo e T. M. Tundisi (Ed), Limnology in Brazil. Academia Brasileira de Ciências / Sociedade Brasileira de Limnologia, Rio de Janeiro: 167-193.

ECOHYDROLOGY FOR REDUCTION OF CYANOBACTERIAL BLOOMS IN RESERVOIRS: FROM IDENTIFICATION OF THREATS TO DEVELOPMENT OF SOLUTIONS

Katarzyna Izydorczyk[1]
Wojciech Frątczak[2]
Maciej Zalewski[3]

[1] II PAS European Regional Centre for Ecohydrology under the auspices of UNESCO. Pilica River Catchment, Poland.
[2] II PAS European Regional Centre for Ecohydrology under the auspices of UNESCO. Pilica River Catchment, Poland.
[3] II PAS European Regional Centre for Ecohydrology under the auspices of UNESCO. Pilica River Catchment, Poland.

ABSTRACT

The ecosystem regulation concept, i.e. the key *ecohydrology* thesis constitutes the fundamental element of water resources management to limit eutrophication processes, and ultimately reduce intensity of cyanobacterial blooms in reservoirs. Due to the complexity of hydrological, biological, sociological and economic processes, which involve dynamics and use of water resources in a catchment, a system approach to manage the reservoir in the context of the catchment as a whole is necessary. A water reservoir recultivation strategy based on the ecohydrology concept should include four elements: (1.) identification of threats, (2.) analysis of cause-effect relationships, (3.) development of ecohydrological methods and tools, and (4.) development of system solutions leading to the sustainable development and good ecological status. The objective of paper included a synthesis of analyses of factors that determine intensity of cyanobacterial blooms in the Sulejow Reservoir (Poland), which is of fundamental importance to developing tools to regulate the main processes in the catchment and implement measures to recultivate the reservoir.

1 ECOHYDROLOGY - A PROBLEM-SOLVING SCIENCE

Improving access to safe drinking water is one of the important challenges laid out in the United Nations Millennium Development Goals. In many countries, potential hazards to consumer health are caused by the effects of secondary pollution created by the appearance of toxic cyanobacterial blooms (CODD, 2000; MANKIEWICZ et al., 2003; FALCONER, 1999, 2005). The most frequently found cyanobacterial toxins in freshwater are the microcystins, toxins produced by *Microcystis* and other cyanobacterial genera. They are possible carcinogens, have tumour-promoting properties, and have been associated with primary liver cancer (CARMICHAEL, 1992; FUJIKI et al., 1996). Cyanobacterial blooms, therefore, may limit ecosystem services, for example, availability of drinking water, due to increased costs for purification (JURCZAK et al., 2005; MEREL et al. 2010; ZAMYADI et al., 2012; DELGADO et al., 2012). Reservoirs are ecosystems especially susceptible to eutrophication and the occurrence of toxic cyanobacterial blooms due to the high proportion of catchment surface to reservoir area.

The intensity of cyanobacterial blooming depends on two-way regulatory processes: *bottom–up* and *top-down.* In classic ecology, the *bottom-up* approach assumes that succession of phytoplankton is regulated mainly by nutrient availability. Tilman (1982) established this approach with *the mechanistic resource competition theory* by indicating that it is not only the total concentration but the ratios of nutrients that determine the taxonomic outcome of species competition. According to the *top-down* approach, on the other hand, ecosystem structure is determined by a cascading effect, which transmits pressure down the trophic levels from predators to primary producers – phytoplankton (HRBACEK et al., 1961; CARPENTER et al., 1985). According to this concept, which becomes a basis for *biomanipulation*, the pressure of predators and planktivorous fish on zooplankton indirectly decreases phytoplankton abundance and contributes to water quality improvements.

In a reservoir, the role of hydrological processes has been recognised as a key factor determining the nature of zooplankton - phytoplankton interaction (ZALEWSKI et al., 1990). Several authors confirm that hydrodynamics and biological processes are strongly superimposed on each other so that it is not possible to explain the second without taking into account the effect of the first (e.g., STRASKRABA et al., 1993; TUNDISI; STRASKRABA 1999).

Increasing evidence on the importance of hydrological conditions in regulating biotic dynamics provides the background of the *ecohydrology* concept (ZALEWSKI et al., 1997; ZALEWSKI, 2000). Ecohydrology is a transdisciplinary science developed within the framework of the International Hydrological Programme of UNESCO (IHP V–VII) as a subdiscipline of hydrology, focused on biological aspects of the hydrological cycle (ZALEWSKI et al., 1997, 2000; ZALEWSKI, 2006, 2010, 2011). The novelty of this approach is to extend conservation and restoration measures by regulating water-biota interaction to enhance the ecological potential of the global environment (carrying capacity) composed of water resources, biodiversity, ecosystem services for society, and resilience to various forms of impacts and to climatic changes (ZALEWSKI, 2011). The fundamental application of ecohydrology is that in terms of evolution terrestrial and aquatic organisms have adapted to quantitative and qualitative water dynamics in a catchment; thus, biocenotic processes are shaped by hydrology and, *vice versa*, biocenotic structure and interactions shape hydrological processes (ZALEWSKI, 2011).

Following the recommendation of the International Council of Scientific Unions (ICSU, 1991) on the applicability of science in the 21st century, ecohydrology has become a transdisciplinary, problem-solving science (ZALEWSKI, 2011). Ecohydrology provides not only a scientific understanding of the hydrology/biota interplay, but also a systemic framework on how to use ecosystem processes as a new tool for Integrated Water Resources Management (IWRM), complementary to already applied hydrotechnical solutions. A methodology for ecohydrology implementation for IWRM includes the following four steps: (a) monitoring of threats; (b) assessment of cause–effect relationships; (c) development of ecohydrological methods, and (d) development of system solutions (ZALEWSKI, 2002; WAGNER et al., 2009).

The Pilica River Global Reference Site for UNESCO IHP Ecohydrology was the first step toward implementation of ecohydrology in solving existing problems under the auspices of the UNESCO IHP. The key management issue addressed was ecological and health hazards resulting from eutrophication of the river-reservoir system and toxic cyanobacterial blooms. Summaries of activities in the Pilica River Demosite were presented by Wagner et al. (2009). In this paper, aspects of cyanobacterial monitoring, identification of the hierarchy of factors influencing the intensity of cyanobacterial blooms, and development of ecohydrological biotechnology methods for their reduction are discussed.

2 DEVELOPMENT OF AN EARLY WARNING SYSTEM FOR CYANOBACTERIAL PRESENCE IN RESERVOIRS AND WATER INTAKES

Due to human health risks from cyanobacterial toxins, adequate bloom monitoring is necessary. Traditionally, and as recommended by WHO (2008), cyanobacterial monitoring is based on chlorophyll *a* concentrations and/or cyanobacterial cell counts. Unfortunately, measurement of chlorophyll *a* does not provide enough information because it does not allow selective detection of cyanobacteria from other groups of phytoplankton. Phycocyanin, a blue photosynthetic pigment, is an acknowledged marker of cyanobacteria (LEE et al., 1994, 1995; AHN et al., 2002). Positive correlation between phycocyanin fluorescence and cyanobacterial biomass blooms of *Microcystis aeruginosa* was demonstrated by several authors (IZYDORCZYK et al., 2005; 2009; BRIENT et al., 2008; CHANG et al., 2012). Therefore, measurement of phycocyanin can be regarded as an indicator for the concentration of cyanobacterial cells in water, similar to the established indicator of the number of cyanobacterial cells.

Since cyanobacterial blooms are characterized by highly dynamic changes, which vary seasonally as well as over short time periods (several hours) due to local weather, it is necessary to use modern analytical techniques that enable quick and easy detection of cyanobacteria. Application of fluorometric methods using traditional fluorimeters and/or equipment such as the Algae Online Analyser (bbe-Moldaenke), or a FluoroProbe (bbe-Moldaenke), provides capability. Measurement of phycocyanin fluorescence can enable monitoring of vertical and horizontal distribution of cyanobacterial cells in a reservoir, which may then be used for forecasting potential risk from the generation and translocation of cyanobacterial blooms, especially in bathing areas.

When a reservoir is a drinking water source, it is particularly important to determine if cyanobacteria are present. Izydorczyk et al. (2005, 2009) showed that measurement of phycocyanin fluorescence is an effective early warning system for cyanobacteria in source water, and can provide rapid information applicable to water treatment. The effectiveness of an early warning system improves as the monitoring frequency increases; therefore, optimization of water treatment processes should be based on continuous monitoring of cyanobacteria in raw water. That is why the advantages of fluorometric methods include their potential for adjusting sampling frequency, as well as the fact that all measurements can be performed on-line, providing rapid results without time-consuming manual pre-treatment of water samples. Additionally, Izydorczyk et al. (2009) determined threshold values for an Alert Level Framework, based on Algae Online Analyser (bbe-Moldaenke) measurements of Sulejow Reservoir water. The calculated threshold values were determined specifically for their abstraction point, but the principles can be applied to other locations. It should be noted that on-line fluorometric measurement of phycocyanin does not exclude the use of microscopic identification and counting because these two methods should be considered complementary.

One limitation of the fluorescence method is the absence of a direct estimation of toxin concentrations. Another is the inability to distinguish between toxigenic and non-toxigenic strains of cyanobacteria. Analysis of cyanobacterial toxins includes screening methods like ELISA and PPIA (protein phosphatase inhibition assay) and analytical methods like HPLC (high performance liquid chromatography) (MERILUOTO; CODD, 2005). Measurement of molecular markers of the microcystin biosynthesis (*mcy*) gene cluster, however, provides the only method for identification of toxigenic cyanobacterial strains (KURMAYER et al., 2002; HISBERGUES et al., 2003; DITTMAN; BÖRNER, 2005). Detection of *mcy* genes at the beginning of summer can indicate the potential toxicity of environmental samples and the possibility of microcystin production in the next period of monitoring (e.g. MANKIEWICZ-BOCZEK et al., 2006, 2011a, b; GAGAŁA et al., 2012).

In order to predict the intensity of cyanobacterial blooms, it is important not only to monitor threats, in this case the intensity of cyanobacterial blooms and cyanobacterial toxin concentrations and their variation in time and space, but also to monitor their drivers. In the case of cyanobacterial blooms it is essential to analyse hydrological parameters (e.g., water retention time, the dynamics of water flow), physico-chemical aspects (e.g., temperature, availability nutrients) and biological factors (e.g., structure and dynamics of zooplankton). In the case of a reservoir that is characterized by a dynamic and variable inflow of suspended matter and nutrients from the basin, it is necessary to monitor the processes in the whole catchment.

3 IDENTIFICATION OF THE HIERARCHY OF FACTORS INFLUENCING TOXIC CYANOBACTERIAL BLOOM OCCURRENCE

3.1 PHYSICAL PARAMETERS (TEMPERATURE AND WATER TURBULENCE) AS DRIVERS OF PHYTOPLANKTON SUCCESSION

Understanding the spatiotemporal patterns of toxic cyanobacterial bloom appearance and identifying the hierarchy of factors influencing blooms are fundamental to development of strategies for their prevention. Analysis of the seasonal changes in factors influencing the intensity of cyanobacterial blooms in the Sulejow Reservoir showed that different factors played a crucial role in different time periods (ZALEWSKI et al., 2000; TARCZYŃSKA et al., 2001; IZYDORCZYK, 2003; IZYDORCZYK et al., 2008a, 2008b).

Temperature is a major driving force in phytoplankton succession. Cyanobacteria have generally higher temperature optima for growth than other phytoplankton. Maximum growth rates are attained by most cyanobacteria at temperatures at, or above, 25°C (ROBARTS; ZOHARY, 1987; PAERL; HUISMAN, 2008). This can explain why in temperate and boreal water bodies most cyanobacteria bloom during summer. As a consequence of global climate changes, future warming of temperate aquatic systems could lead to toxic *Microcystis* dominating phytoplankton populations for longer time periods than they do at present (PAERL; HUISMAN, 2008). Additionally, the rise of water temperature may promote growth of toxic, rather than non-toxic, populations of cyanobacteria, leading to blooms with a higher microcystin content (DAVIS et al., 2009; JOUNG et al. 2011).

Water retention time may play an important role in determining biomass and species composition of a phytoplankton community (STRASKRABA et al., 1993). Short water retention times cause an increase of water turbulence, which stimulates the growth of species that prefer a mixed water column, e.g., diatoms. Increase of water retention times during warm, windless days causes stability of the water column, which usually leads to formation of cyanobacterial blooms (NEGRO et al., 2000; ROMO et al., 2012). This cyanobacterial preference for a stable water column results from buoyancy regulation, which can be a substantial advantage in competition with other phytoplankton organisms (MUR et al., 1999). Promotion of cyanobacterial bloom development by extended water retention time was noted in Sulejow Reservoir. An increase in water retention time from 10 to 100 days resulted in a six-fold increase of cyanobacterial biomass (TARCZYNSKA et al., 2001), whereas shortening water retention time to below 30 days seems to be a limiting factor for cyanobacterial development (IZYDORCZYK, 2003).

Hydrodynamic conditions in a reservoir depend on water retention time and the morphometry of the reservoir. The diversified shape of Sulejow Reservoir determines the horizontal diversity in flow velocity, which can affect the spatial diversity of the phytoplankton community (Fig. 1a, 1c). During spring, the low temperature of the water is the main factor influencing phytoplankton composition. Diatoms, especially the colonial pennate forms, are strong potential candidates for domination of phytoplankton composition during the spring period due to their photosynthetic behaviour, cell size, ratio of surface area to volume, and an ability to maintain overwintering vegetative populations in suspension in ice-free lakes (REYNOLDS, 1980). In the spring, the phytoplankton community in the entire reservoir was dominated by diatoms. The heterogeneous hydrodynamic conditions did not cause horizontal variability in the phytoplankton community. Nevertheless, during the summer, the composition of the phytoplankton community differed in the two analyzed station sites. In the lacustrine part (station I), characterized by lower flow velocity, the cyanobacteria (mainly *Microcystis aeruginosa*) dominated. Temperature has been considered to be the most important factor contributing to cyanobacterial dominance; however, in the upper, riverine part (station II), despite having the same temperature, the phytoplankton community was dominated by diatoms. Higher flow velocity caused increased water turbulence and prolonged suspension of non-motile diatoms, which reach their maximum biomass in Sulejow Reservoir.

Intensive mixing of a water column prevents the appearance of cyanobacterial blooms (REYNOLDS, 1984; LINDENSCHMIDT; CHORUS, 1997). Therefore, enhancing turbulence within a reservoir may reduce both formation and accumulation of cyanobacterial blooms. Mixing of the water column can be enhanced by (1) decreasing water retention time (e.g., adjusting reservoir volume to climatic conditions in newly constructed reservoirs): (2) increasing flow velocity (e.g., by constructing barriers elongating the path of water flow within the same water retention time in an existing reservoir); and (3) maximizing turbulence created by the wind (e.g., orienting a newly constructed reservoir to maximize mixing by the wind) (WAGNER et al., 2004).

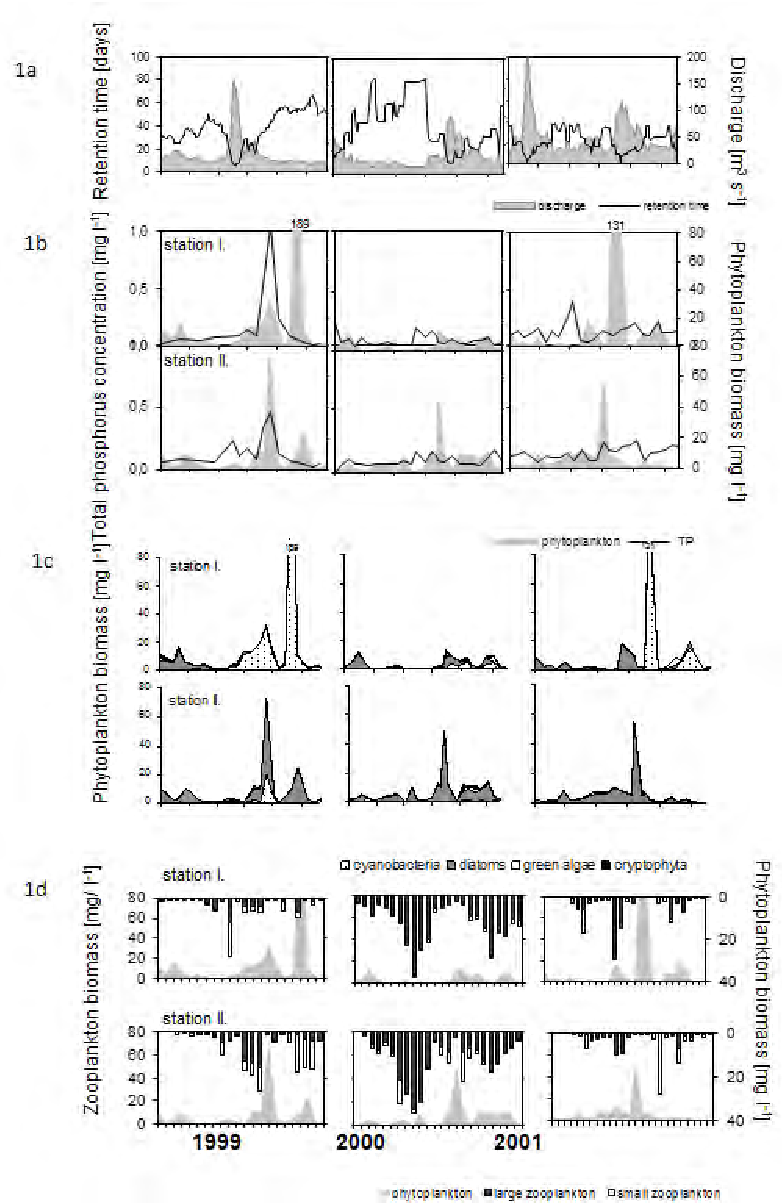


Figure 1 - Seasonal dynamics of water retention time and discharge (1a), total phosphorus concentration (1b), phytoplankton (1c) and zooplankton (1d) composition for Sulejow Reservoir between 1999 and 2001
Source: modified from Izydorczyk (2003)

3.2 DYNAMICS OF PHOSPHORUS AVAILABILITY IN RESERVOIRS AND CONSEQUENCES FOR CYANOBACTERIA

Long-term analysis showed that availability of phosphorus is a crucial factor in determining the intensity of cyanobacterial blooms in Sulejow Reservoir (Fig. 6). Many authors confirm that high nutrient levels lead to increased intensity of cyanobacterial blooms (HUSZAR; CARACO 1998; DOWNING et al., 2001; GIANI et al., 2005,). Additionally, inflow of phosphorus results in an increase of microcystin concentrations (CHORUS, 2001; GIANI et al., 2005; IZYDORCZYK, 2008a, b). However, Chorus (2001) found no direct impact of total phosphorus on microcystin concentrations and suggested that the correlations observed could be explained by the impact of total phosphorus on the size of the population producing microcystins.

Through-flow reservoirs (like Sulejow Reservoir) have a continuous inflow of nutrients that is not constant between or within years (Fig. 1b.). Nutrient concentrations in the reservoir differed significantly from the pattern of water discharge, which, in turn, influenced the intensity of cyanobacterial blooming. Research by Wagner and Zalewski (2000) demonstrated that the highest concentrations and loads of phosphorus reach the reservoir *via* the main tributaries during short periods of highest river flows. Hydrochemical composition of inflowing waters, although determined by several factors, differs significantly from the pattern of water discharge. The highest concentrations usually happen during rising water stages of medium floods and at very initial stages of flash floods (WAGNER; ZALEWSKI, 2000). Consequently, the external loads at these times also increase, and high concentrations of nutrients are afterwards observed in the reservoir. According to the *bottom-up* concept, this may stimulate phytoplankton growth and increase intensity of cyanobacterial blooms (Fig. 1a, 1b). Phosphorus was transformed into phytoplankton biomass, which increased significantly after the water retention time of the reservoir stabilized. In 1999, high phosphorus concentration, connected with long water retention time, high temperature and decreased zooplankton pressure, stimulated formation of a particularly large cyanobacterial bloom. Nevertheless, during spring 2001, despite increased nutrient concentrations after a spring flood, phytoplankton biomass remained low because of strong zooplankton grazing pressure (Fig. 1d). Floods in July 2000 and August 2001, which had lower amplitudes and long duration times, did not lead to an increase of phosphorus concentration. Short water retention times (15-30 days) connected with high volume water discharges caused dilution of phosphorus loads and prevented phytoplankton growth (IZYDORCZYK, 2003).

Additionally, suspended organic matter delivered to through-flow reservoirs settles out along the reservoir's basin due to lowered water flow velocity (STRAŠKRABA; TUNDISI 1999), and is a potential internal source of nutrients. Phosphorus recycled from sediments often provides significant input to phosphate pools in water, which supports formation of algal blooms (JENSEN; ANDERSEN, 1992; RYDIN, 2000). Physical and chemical processes, depending on sediment chemical characteristics and their changes (pH, redox potential, organic matter, Al and Fe, inorganic P equilibrium), are responsible for phosphorus retention in sediments and release to the water column (PSENNER et al., 1988; GOLTERMANN, 1995). However, microbial activity, especially hydrolysis catalysed by one microbial enzymes, alkaline phosphatase, appears to be crucial for phosphorus transformation in sediments. Phosphatase is released mainly by bacteria in response to lack of soluble phosphates in water; therefore, it is considered as greatly important in phosphorus cycling in water and soil environments (JANSSON et al., 1988; CHRÓST; SIUDA, 2006). Trojanowska and Izydorczyk (2010) showed that high spring alkaline phosphatase activity in sediments might be a significant factor for cyanobacterial bloom formation in summer, which was also hypothesized by Zhou et al. (2002, 2008). Analysis of Sulejow Reservoir sediments showed higher organic matter content and total phosphorus concentration in spring than in summer due to deposition of phosphorus delivered by floods. In spring, an increase in total bacterial number, as well as alkaline phosphatase activity in sediments, was observed, resulting in release of nutrients to the water column and support to cyanobacterial bloom development during the summer (TROJANOWSKA; IZYDORCZYK, 2010).

3.3 QUANTIFICATION OF NUTRIENTS SOURCES ON THE CATCHMENT SCALE

In accordance with the first principle of ecohydrology, processes occurring in a reservoir, especially water balance and nutrient flows, should be considered in the context of a whole catchment basin. The Sulejow Reservoir catchment area is approximately 4 900 km^2, of which approximately 240 km^2 is the direct reservoir catchment. Based on data for the period 2005-2009 provided by the Regional Inspectorate for Environmental Protection in Lodz and Institute of Meteorology and Water Management, it is estimated that the reservoir receives 1,336.0 tonnes of nitrogen and 56.7 tonnes of phosphorus from the main inflows during a year. This confirms the hypothesis that reduction of nutrient inflow from the catchment is a key element in the process of reservoir rehabilitation.

Estimation of nutrient inputs by various point and diffuse sources is the first step toregulating processes for sustainable water use and ecosystem protection. The GIS-oriented model MONERIS (MOdeling Nutrient Emissions in

RIver Systems, IGB German) is one modeling tool that can be applied to identification of sources and pathways of nutrient emissions, as well as to analysis of the transport and retention of nutrients in river systems. The basic inputs into the model are discharge data , water quality data for the investigated river basin, and a Geographical Information System that integrates digital maps with statistical information for different administrative levels. MONERIS allows estimation of seven pathways for nutrient emission into surface waters, one point source from municipal and industrial waste water treatment plants which are directly discharged into the river, and six pathways from different flow components: *via* atmospheric deposition, groundwater, tile drainage, paved urban areas, erosion, and surface runoff (only dissolved nutrients) (VENOHR et al., 2009).

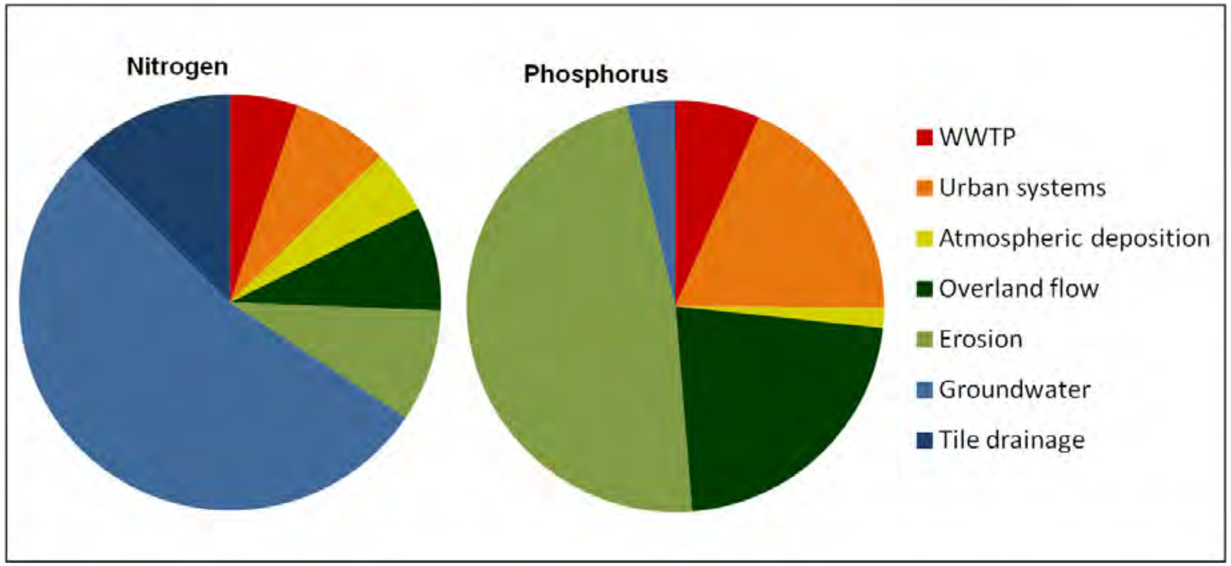


Figure 2 - Percentage contribution of various nitrogen and phosphorus emission pathways into Sulejow Reservoir from the Pilica basin
Source: modified from Kowalkowski (2012)

The MONERIS model results showed that only about 7% of the nitrogen and phosphorus loads were from point sources in the Pilica River Basin and >90% were from diffuse sources (Fig.2) (KOWALKOWSKI, 2012). If we assume that about 8% of nitrogen and 20% of phosphorus loads were from urban sources, agriculture could be one of the most important factors responsible for water pollution, resulting from the high (61.3%) share of agricultural land in the Pilica catchment, including 40.7% of arable land and 11.2% meadows and pastures. Many studies showed that agricultural activities are the main source of elevated nitrate concentrations in soils (HOWARTH, 2004; PASTUSZAK; IGRAS, 2012). Nitrogen and phosphorus, as essential elements for plants, are used as natural and artificial fertilizers to increase yield. However, losses of nutrients from agricultural land occur when intensive use of fertilizers is not balanced by the requirements of, and consumption by, plants. Nitrogen, particularly, is a very mobile element due to its high solubility as well as its presence in gaseous and ionic forms. Nitrogen losses from agricultural land include: (1) ammonia volatilization from the soil and from manure storage to the atmosphere; (2) leaching of mobile nitrate from soil and its transfer through groundwater, overland drainage waters, and water in drainage ditches to surface water; and (3) surface runoff to surface waters. In the Pilica basin, 65% of nitrogen emission into river basins was *via* groundwater and tile drainage (Fig.2a). Unlike nitrogen, the movement of phosphorus in soil or water is one of the slowest biochemical cycles. Phosphorus occurs in soils in organic and inorganic forms and may be dissolved in water, or embedded in minerals and organic material. Phosphorus losses to groundwater and surface waters may occur through leaching or surface runoff with soil particles. Phosphorus losses due to leaching are insignificant, whereas sediment-bound phosphorus includes phosphorus associated with soil particles and organic material eroded during flow events and constitute about 51% of the P transported from the Pilica basin (Fig. 2b).

4 DEVELOPMENT OF ECOHYDROLOGICAL BIOTECHNOLOGIES TO ACHIEVE GOOD ECOLOGICAL STATUS OF RIVER BASINS

Results of monitoring supported establishment of a hierarchy of factors influencing toxic cyanobacterial blooms, and also helped identify key processes that could be regulated in a reservoir and it's basin. The next step is development of new methods and new solutions based on ecohydrological principles for regulation of these processes: for example, by enhancement of the effectiveness of naturally occurring processes, as in the case of highly effective enhanced ecotone zones, or by use of hydrology to regulate ecosystem trophic structure using hydrobiomanipulation.

4.1 HYDROBIOMANIPULATION - A TOOL FOR MODIFICATION OF TROPHIC STRUCTURE IN RESERVOIRS

Long-term analysis of trophic interaction in Sulejow Reservoir showed that the strength of *top-down* interactions increases during periods of stable hydrology and biotic interactions may modulate the phytoplankton community (IZYDORCZYK, 2003; WOJTAL et al., 2008). Large-bodied zooplankton may be the last link in bloom control, provided that the food-web structure permits them to dominate (ELSER, 1999). This is especially so in the early stages of blooms, when the density of algae is low (DAWIDOWICZ et al., 1988). Additionally, filter feeders coexisting with cyanobacteria are more resistant to their toxins than organisms that were never exposed to them (HIETALA et al., 1995; DE MOTT, 1999, KURMAYER; JÜTNERR, 1999). This suggests the possibility of development of a gradual adaptive evolution in grazing zooplankton as a response to toxins. On the other hand, Izydorczyk et al. (2008b) supposed that exposure to *Daphnia* and/or chemical signals released by predators at higher population densities may have resulted in an increased microcystin content of cyanobacterial cells. Nevertheless, this possible influence on microcystin concentrations in the reservoir was less than that of cyanobacterial biomass, which was strongly correlated with temperature and phosphorus availability.

Since most YOY (young of the year) fish are planktivorous, they are potentially important regulators of zooplankton communities (NASELLI-FLORES; BARONE 1997; WAGNER et al., 2004; DIONISIO; PIRES et al., 2005). Reduction of the abundance of juvenile planktivorous fish as a principal consumer of *Daphnia* may be achieved by increasing predatory fish pressure or controlling fish spawning success. The recruitment success of fish, which use the littoral zone as habitat for reproduction, depends on water level fluctuations in a reservoir during spawning periods (PLOSKEY 1986, ZALEWSKI et al., 1990; NASELLI-FLORES; BARONE, 1997). This is why water level control in a reservoir can be an effective tool for modifying ecosystem trophic structure. Initiation of the *top down* effect by hydrological process rather than regulation of predatory fish stocking is a key component of hydrobiomanipulation (ZALEWSKI et al., 2013). This idea resulted from work by Zalewski et al. (1990), which showed that during a year characterized by unstable and low water levels during the spawning period in Sulejow Reservoir, low fish spawning success resulted in high zooplankton biomass, which in turn grazed more efficiently on the phytoplankton and prevented cyanobacteria from blooming . Results of Zalewski et al. (1990) were confirmed by research conducted 20 years later (IZYDORCZYK, 2003). In 2000, during the spawning period, a decrease of about 0.17 m in the water level (conservation work on reservoir dam) caused a strong reduction in the reproductive success of fish. As a result, in spite of a long water retention time and high levels of nutrient loading, phytoplankton biomass was reduced as a consequence of high grazing pressure by *Daphnia* (Fig. 1b, 1d). In 2001, the opposite situation was observed. An increase in water level of about 0.86 m created optimal conditions for fish reproduction. High predation pressure shifted the zooplankton community towards small and inefficient grazers (Fig. 1b, 1d).

Hydrobiomanipulation was tested in Sulejow Reservoir in 2006-2007. It was started by increasing and maintaining high water levels before and during spawning time. Increased water level caused flooding of the ecotone zone along the shoreline, which enabled perch to use inundated terrestrial vegetation as spawning substrates. Water level reduction was started immediately after spawning, and resulted in eggs drying out on subtrates and reduction of recruitment success. In 2006, as a result of a decreased water level of about 40 cm, high grazing activity of zooplankton may have reduced the phytoplankton population and delayed cyanobacterial bloom formation until mid July. Despite optimal physico-chemical conditions stimulating cyanobacterial growth, a 50% reduction of the toxic cyanobacterial bloom was achieved. The mean observed cyanobacterial biomass reached 7.6 mg dm^{-3}, whereas prognostic cyanobacterial biomass, which was estimated using a regression model based on long-term data, was 15.7 mg dm^{-3} (Fig.3). Water level regulation to control fish recruitment and reduce the impact on filter-feeding zooplankton led to a decreased cyanobacterial biomass characteristic of a phosphorus concentration half of that observed (about 130 µg dm^{-3}).

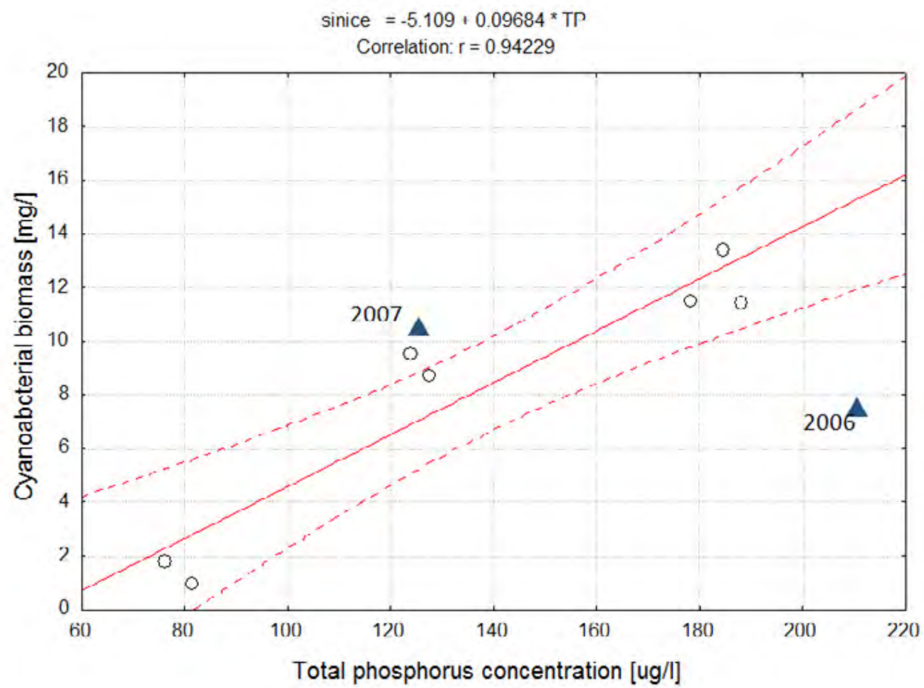


Figure 3 - Comparison of measured data (triangles) and predictive regression model values based on long-term data of the relationship between TP concentration and cyanobacterial biomass (circles: data from 1997-2005)
Source: Zalewski et al. (2013)

Hydrobiomanipulation may be an important method of using *top-down effect* in a reservoir to reduce eutrophication symptoms. Moderating a dam's operational procedure may become a cost-efficient tool to modify ecosystem trophic structure, complementary to biomanipulation. Nevertheless, the effectiveness of hydrobiomanipulation, just as is the case with biomanipulation, has a threshold: total phosphorus concentration in the reservoir should not exceed 100 µg dm^{-3} (JEPPESEN, 1990; HANSSON et al., 1998) to be effective. This is why external reservoir phosphorus loading should be diminished by complex activities in the basin before hydrobiomanipulation is attempted.

4.2 ENHANCED BUFFER ZONES AS AN ECOHYDROLOGICAL BIOTECHNOLOGY FOR REDUCTION OF DIFFUSE SOURCES

Agricultural diffuse (non-point) source pollution of water bodies and the coastal zone is an important environmental problem throughout the world, e.g., in North America (UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 2002), and Europe (EUROPEAN ENVIRONMENTAL AGENCY, 2005). Increases in agricultural yield in some counties, such as the USA, may become increasingly dependent on fertilizer and pesticide inputs, whereas countries such as Brazil and China have used rapid expansion of agricultural land to improve agricultural production (STRINGFELLOW; JAIN, 2010). Crop production, ploughing fields to the edge of rivers and lakes, intensive use of fertilizers, and increasing the number of animals per hectare have all contributed to the increase in the nutrient load transported from a landscape to freshwater. The riparian, land/water buffer zone (ecotones) is a widely recommended and promoted tool for reducing agricultural impacts on freshwater ecosystems caused by nutrients coming from the landscape (NRC, 2002). Linear bands of permanent vegetation adjacent to an aquatic ecosystem allow maintenance or improvement of water quality by trapping and removing various non-point source pollutants from both overland and shallow subsurface flows. It may be a strip of riparian vegetation including herbs, grasses, shrubs or trees separating arable land from watercourses or reservoirs. Buffer zones efficiently reduce nitrogen and phosphorus concentrations from diffuse pollution through biogeochemical processes that occur in them (LOWRANCE et al., 1984; PINAY; DECAMPS 1988; SCHIEMER; ZALEWSKI, 1991, see review by DOSKKEY et al., 2010). The removal of nitrogen in riparian buffer zones is commonly attributed to: (1) uptake and storage in vegetation, (2) microbial immobilization and storage in the soil as organic nitrogen and (3) microbial conversion to gaseous forms of nitrogen, i.e., denitrification. Phosphorus retention in ecotones is controlled by a range of physical, geochemical and biological processes, including (1) sediment deposition, (2) adsorption to iron and aluminium oxides in acidic soils or precipitation of calcium phosphates in alkaline soils, and (3) plant uptake (HOFFMANN et al., 2009).

Maintenance and/or restoration of degraded buffer zones, as well as establishment of new ones, is one of the most effective management strategies for non-point source pollution control. According to the third principle of ecohydrology, by shaping plant structure of buffer zones to increase efficiency in nutrient removal, the regulation of water quality may be achieved. Buffer zones should address habitat-related preferences of specific types of vegetation, and their tolerance to varied hydrological conditions. It is also recommended that native species should be used to enhance landscape values and terrestrial biodiversity. Using different types of vegetation increases the effectiveness of buffer zones (TILMAN, 1996). Native grass or herbaceous strips with deep rooted trees and shrubs along a stream can more effectively improve water quality than single plant species. Another important feature to be taken into account in the selection of species is the amount of nutrients, which can be taken up and accumulated in plant tissues. This varies depending on the plant species from 0.2 to 50 kg P ha^{-1} $year^{-1}$ and from 10 to 350 kg N ha^{-1} $year^{-1}$ (MANDER et al., 1997; HEFTING et al., 2005). In Central Europe, reeds and willows may be an efficient tool to block re-circulation of nutrients. Mowing and harvesting reeds (*Phragmites*) contributes to annual removal rates of up to 40 kg P ha and 225 kg N ha^{-1} $year^{-1}$ from an ecosystem, whereas cutting and harvesting 100 kgper year of wet mass of the youngest branches of willow removes 173.4 g P (KIEDRZYŃSKA et al., 2008).

However, due to limited space in shoreline zones or high initial loads, the efficiency of buffer zone biofiltration is not sufficient. That is why, ecohydrology postulates enhancing the absorbing capacity of buffer zones by regulation and intensification of naturally occurring processes like denitrification and phosphorus sorption. Enhanced buffer zones were designed on the basis of identification and quantification of threats and were constructed in the catchment of Sulejow Reservoir as demo sites of the LIFE+ EKOROB project: Ecotones for reduction of diffuse pollutions (Fig. 4: EKOROB 2011; IZYDORCZYK et al., *in preparation*).

One of the demo sites is surrounded by agricultural land. Nitrate concentrations (~ 100 mg NO_3 l^{-1}) in groundwater classified it as polluted, according to the Nitrates Directive (>50 mg NO_3 l^{-1}). The solution tested in the area was a denitrification wall as an additional element in the buffer zone (Fig. 3). Although it is an artificial structure, such a wall is invisible in the landscape and intensifies the naturally occurring process of denitrification - a key microbial nitrogen phase circulating in the biosphere. A denitrification barrier is constructed by digging a trench perpendicular to groundwater flow and mixing a slowly degrading source of organic carbon (most commonly used in the form of tree bark, wood chips and leaf compost) with soil (SCHIPPER et al., 2010). Degradation of added organic material stimulates growth of denitrifying bacteria and thus conversion of nitrate and nitrites dissolved in groundwater to nitrogen gas. The study by Bednarek et al. (2010) into the efficiency of denitrification barriers in Polish climatic conditions was conducted at a pig farm, where an unprotected storage area of manure was the source of pollution. The efficiency of the denitrification barrier was significant as shown by the high reduction level of nitrate (95%), ammonium ions (77%) and total nitrogen

(87%) in the groundwater flowing through the constructed wall. The solution seems to be an effective route toward achieving good ecological status of ecosystems and improved water quality, given the low construction costs, small labour input, high operating efficiency and lack of interference with the landscape.

Additionally, following the ecohydrological postulate of harmonizing societal needs with enhanced ecosystem potential (ZALEWSKI, 2011; ECOSUMMIT – COLUMBUS DECLARATION, 2012), among the actions proposed for restoring mosaic ecotone zones was construction of recreational infrastructures, such as jetties for bathing and boating. Lack of infrastructure contributes to degradation of vegetation buffer zones.

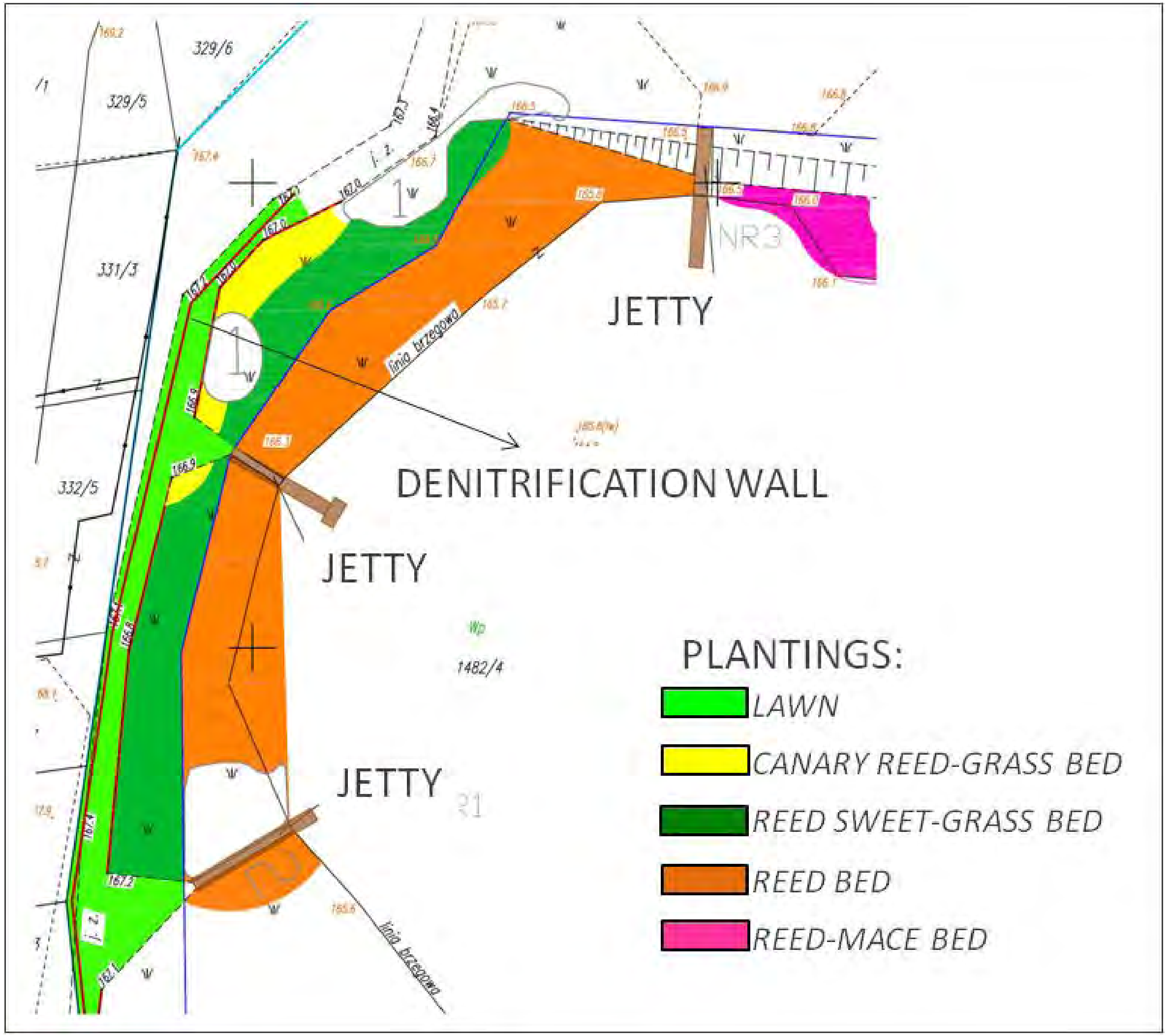


Figure 4 - Conceptual project to enhance buffer zones in the Sulejow Reservoir catchment. This is the Barkowice Bay Demo site of the LIFE+ EKOROB project (EKOROB, 2011)

5 CONCLUSION

Precise quantification of water budgets, nutrients, pollutants, and ecosystem performance as well as socioeconomic processes can provide the background for development of systemic transdisciplinary solutions (ZALEWSKI, 2011). Individual ecohydrological methods can be synergistically linked as part of system solutions complementary to already applied hydrotechnical solutions for water resources management, contributing to enhancement of the overall resilience of a catchment, and improving a catchment's ability to provide ecosystem services.

6 ACKNOWLEDGEMENTS

The research was supported by the European Commission projects (TOXIC and LIFE+EKOROB) and the Polish Committee of Scientific Research (project 2 PO4F 044 27). The author is grateful to Professor Maciej Zalewski for very constructive and valuable comments that substantially improved the manuscript.

REFERENCES

Ahn, Ch-Y., Chung, A-S., Oh, H-M. 2002. Rainfall, phycocyanin and N:P ratios related to cyanobacterial blooms in a Korean large reservoir. Hydrobiology. 474 (1-3): 117-124.

Bednarek, A., Stolarska, M., Ubraniak, M., Zalewski, M. 2010. Applying of denitrification wall for ground water protection. Ecohydrology and Hydrobiology 10: 355-362

Brient, L., Lengronne, M., Bertrand, E., Rolland, D., Sipel, A., Steinmann, D., Baudin, I., Legeas, M., Le Rouzic, B., Bormans, M. 2008. A phycocyanin probe as a tool for monitoring cyanobacteria in freshwater bodies. Journal of Environmental Monitoring 10, 248-255.

Carmichael, W.W., 1992. Cyanobacteria secondary metabolites - the cyanotoxins. Journal of Applied Bacteriology 72: 445-459.

Carpenter, S.R., Kitchell, J.F., Hodgson, J.R. 1985. Cascading trophic interactions and lake productivity. BioScience 35: 634-639.

Chang, D-W., Hobson, P., Burch, M., Lin, T.F. 2012. Measurement of cyanobacteria using in-vivo fluoroscopy - effect of cyanobacterial species, pigments, and colonies. Water Research 46: 5037-5048

Chorus, I. (ed.) 2001. Cyanotoxins occurrence, causes, consequences. Springer-Verlag Berlin and Heidelberg, 330 pp.

Chróst, R.J., Siuda, W. 2006. Microbial production, utilization, and enzymatic degradation of organic master in the upper trophogenic layer in the pelagial zone of lakes along a eutrophication gradient. Limnology and Oceanography 51: 749-762.

Codd, G.A. 2000. Cyanobacterial toxins, the perception of water quality, and the prioritisation of eutrophication control. Ecological Engineering 16: 51-60.

Davis, T.W., Berry, D.L., Boyer, G.L., Gobler, C.J. 2009. The effects of temperature and nutrients on the growth and dynamics of toxic and non-toxic strains of *Microcystis* during cyanobacteria blooms. Harmful Algae 8: 715–725.

Dawidowicz, P., Gliwicz, M.Z., Gulati R.D. 1988. Can *Daphnia* prevent a blue-green algal bloom in hypertrophic lakes? A laboratory test. Limnologica (Berlin) 19: 21-26.

De Mott, W.R. 1999. Foraging strategies and growth inhibition in five daphnids feeding on mixtures of a toxic cyanobacterium and green alga. Freshwater Biology 42: 263--274.

Delgado, L.F., Charles, P., Glucina, K., Morlay, C. 2012. The removal of endocrine disrupting compounds, pharmaceutically activated compounds and cyanobacterial toxins during drinking water preparation using activated carbon - A review. Science of the Total Environment 435-436: 509-525.

Dionisio Pires, L.M., Bontes, B.M., Samchyshyna, L., Jong, J., Van Donk, E., Ibelings, B.W. 2007. Grazing on microcystin-producing and microcystin-free phytoplankters by different filter-feeders: implication for lake restoration. Aquatic Sciences 69: 534-543.

Dittmann, E., Börner, T. 2005. Genetic contributions to the risk assessment of microcystin in the environment. Toxicology and Applied Pharmacology 203: 192-200.

Doskkey, M, Vidon, P., Gurwick, N.P., Allan, C.J., Duval, T.P., Lowrance, R. 2010. The role of riparian vegetation in protecting and improving chemical water quality in streams. Journal of the American Water Resources Association 46: 261-277.

Downing, J.A., Watson, S.B., McCauley, E. 2001. Predicting cyanobacteria dominance in lakes. Canadian Journal of Fisheries and Aquatic Sciences 58: 1905–1908.

Ecosummit – Columbus Declaration 2012. http://www.ecosummit2012.org/columbus-declaration.html

EKOROB. 2011. The Parliament Magazine, The Green Week Issue 238: p. 84.

Elser, J.J. 1999. The pathway to nouxious cyanobacteria blooms in lakes: the food web as the final turn. Freshwater Biology 42: 537-543.

European Environmental Agency 2005. Source apportionment of nitrogen and phosphorus inputs into the aquatic environment. EEA Report No 7. 48 pp.

Falconer, I.R. 1999. An overview of problems caused by toxic blue-green algae (Cyanobacteria) in drinking and recreational water. Environmental Toxicology and Water Quality 14, p. 5-12.

Falconer, I.R. 2005. Cyanobacterial toxins of drinking water supplies: cylindrospermopsins and microcystins. Boca Raton, CRC Press. 296 pp.

Fujiki, H., Sueoka, E., Suganuma, M. 1996. Carcinogenesis of microcystins. [In:] Watanabe, M.F., Harada, K., Carmichael, W.W., Fujiki, H. (eds) Toxic Microcystis. CRS Press. p. 203-233.

Gagała, I., Izydorczyk, K., Jurczak, T., Mankiewicz-Boczek, J. 2012. The key parameters and early warning methods to identify presence of toxigenic blooms dominated by *Microcystis aeruginosa* in the Jeziorsko Reservoir (Central Poland). Fresenius Environmental Bulletin 21: 295-303.

Giani, A., Bird, D.F., Prairie, Y.T., Lawrence, J.F. 2005. Empirical study of cyanobacterial toxicity along a trophic gradient of lakes. Canadian Journal of Fisheries and Aquatic Sciences 62: 2100–2109.

Golterman, H. L. 1995. The role of the ironhydroxide phosphate-sulphide system in the phosphate exchange between sediments and overlying water. Hydrobiologia 297: 43-54.

Hansson, L.A., Annadotter, H., Bergman, E., Hamrin, S.F., Jeppesen, E., Kairesalo, T., Luokkanen, E., Nilsson, P.A., Sondergaard, M., Strand, J. 1998. Biomanipulation as an application of food-chain theory: constraints, synthesis, and recommendations for temperate lakes. Ecosystems 1: 558-574.

Hefting, M.M, Clement, J.C., Bienkowski, P., Dowrick, D., Guenat, C., Butturini, A., Topa, S., Pinay G., Verhoeven, J.T.A. 2005. The role of vegetation and litter in the nitrogen dynamics of riparian buffer zones in Europe. Ecological Engineering 24: 465-482.

Hietala, J., Rainikainen, M., Walls, M. 1995. Variation in life history responses of *Daphnia* to toxic *Microcystis aeruginosa*. Journal of Plankton Research 17: 2307–2318.

Hisbergues, M., Christiansen, G., Rouhiainen, L., Sivonen, K., Borner T. 2003. PCR-based identification of microcysin-producing genotypes of different cyanobacterial genera. Archives of Microbiology 180: 402-410.

Hoffmann, C.C., Kjaegaard, C.K., Uusi-Kamppa, J., Hansen, H.Ch.B., Kronovang, B. 2009. Phosphorus retention in riparian buffers: review of their efficiency. Journal of Environmental Quality 38: 1942-1955.

Howarth, R.W. 2004. Human acceleration of the nitrogen cycle: drivers, consequences and step towards solution. Water Sciences and Technology 49: 7-13

Hrbacek, J., Dvorakova, V., Korinek, V., Prochazkova, L. 1961. Demonstration of the effect of the fish stock on the species composition of zooplankton and the intensity of metabolism of the whole plankton association. Verhandlungen der internationale Vereingung für theoretische und angewandte Limnologie 24: 574-579.

Huszar, V.L.deM., Caraco, N.F. 1998. The relationship between phytoplankton composition and physical – chemical variables: a comparison of taxonomic and morphological – functional descriptors in six temperature lakes. Freshwater Biology 40: 679--696.

ICSU (International Council of Scientific Unions) 1991. International Conference on an Agenda of Science for Environment and Development into the 21st Century (ASCEND 21), Vienna. Cambridge University Press.

Izydorczyk K. Carpentier C., Mrowczynski J., Wagenvoort A, Jurczak T., Tarczynska M. 2009. Establishment of an Alert Level Framework for cyanobacteria in drinking water resources by using the Algae Online Analyser for monitoring cyanobacterial chlorophyll a. Water Research 43: 989-996

Izydorczyk, I. 2003, Influence of abiotic and biotic factors on spatiotemporal sucession of phytoplankton in the Sulejow Reservoir [Wplyw czynnikow abiotycznych i biotycznych na sukcesje czasoprzestrzenna zespolu fitoplanktonu Sulejowskiego Zbiornika Zaporowego]. Ph.D. Thesis (in Polish). Department of Applied Ecology University of Lodz, Poland.

Izydorczyk, I., Frątczak, W., Cichowicz, E., Drobniewska, A., Michalska-Hejduk, D., Zalewski, M. Biogeochemical barriers for enhancement of reservoir riparian ecotones toward reduction of diffuse pollution by phosphorus and nitrogen (*in preparation*)

Izydorczyk, K., Jurczak, T., Wojtal-Frankiewicz, A., Skowron, A., Mankiewicz-Boczek, J., Tarczynska, M. 2008a. Influence of abiotic and biotic factors on microcystin content in *Microcystis aeruginosa* cells in a eutrophic temperate reservoir. Journal of Plankton Research 30: 393-400.

Izydorczyk, K., Skowron, A., Wojtal, A., Jurczak, T. 2008b. The stream inlet to a shallow bay of a drinking water reservoir a 'Hot-Spot' for *Microcystis* bloom initiation. International Review of Hydrobiology 93: 257-268.

Izydorczyk, K., Tarczynska, M., Jurczak, T., Mrowczynski, J., Zalewski, M. 2005. Measurement of phycocyanin fluorescence as an online early warning system for cyanobacteria in reservoir intake water. Environmental Toxicology 20: 425-430.

Jansson, M., Olson, H., Petterson, K. 1988. Phosphatase origin, characteristics and function in lakes. Hydrobiologia 170: 157-175.

Jensen, H.S., Andersen F. 1992. Importance of temperature, nitrate, and pH for phosphate release from aerobic sediments of four shallow, eutrophic lakes. Limnology and Oceanography 37: 577-589.

Jeppesen, E., Jensen, J.P., Kristensen, P., Sondergaard, M., Mortensen, E., Sortkjær, O., Olrik, K. 1990. Fish manipulation as a lake restoration tools in shallow, eutrophic temperate lakes 2: threshold levels, longterm stability and conclusions. Hydrobiologia 200/201: 219-227.

Joung, S.H., Oh, H.M., Ko, S.R., Ahn, C.Y. 2011. Correlations between environmental factors and toxic and non-toxic *Microcystis* dynamics during bloom in Daechung Reservoir, Korea. Harmful Algae 10: 188-193.

Jurczak, T., Tarczynska, M., Izydorczyk, K., Mankiewicz, J., Zalewski, M., Meriluoto, J. 2005. Elimination of microcystins by water treatment process – examples from Sulejow Reservoir, Poland. Water Research 39: 2394-2406.

Kiedrzynska, E., Wagner, I., Zalewski, M. 2008. Quantification of phosphorus retention efficiency by floodplain vegetation and a management strategy for a eutrophic reservoir restoration. Ecological Engineering 33: 15-25.

Kowalkowski T. 2012. Nitrogen and phosphorus emission into Pilica Basin – modelling studies (MONERIS). EKOROB Report.

Kurmayer, R. Jütnerr, F. 1999. Strategies for the co-existence of zooplankton with the toxic cyanobacterium *Planktothrix rubescens* in Lake Zurich. Journal of Plankton Research 21: 659-683.

Kurmayer, R., Dittmann, E., Fastner, J., Chorus, I. 2002. Diversity of microcystin genes within a population of the toxic cyanobacterium *Microcystis* spp. in Lake Wannsee (Berlin, Germany). Microbiol Ecology 43: 107-118.

Lee, T, Tsuzuki, M, Takeuchi, T, Yokoyama, K, Karube, I. 1994. In vivo fluorometric method for early detection of cyanobacterial waterblooms. Journal of Applied Phycology 6: 489-495.

Lee, T, Tsuzuki, M, Takeuchi, T, Yokoyama, K, Karube, I. 1995. Quantitative determination of cyanobacteria in mixed phytoplankton assemblages by an in vivo fluorimetric method. Analytica Chimica Acta 302: 81-87.

Lindenschmidt, K.E., Chorus I. 1997 The effect of aeration on stratification and phytoplankton populations in Lake Tegel, Berlin. Archiv für Hydrobiologie 139: 317-346.

Lowrance, R., Todd, R. L., Fail, Jr.J., Hendrickson, Jr.O., Leonard, R., Asmussen, L. 1984. Riparian forests as nutrient filters in agricultural watersheds. BioScience 34: 374-377.

Mander, Ü., Kuusemets, V., Lohmus, K., Mauring, T. 1997. Efficiency and dimensioning of riparian buffer zones in agricultural catchments. Ecological Engineering 8: 299-324.

Mankiewicz, J., Tarczynska, M., Walter, Z. Zalewski, M. 2003. Natural toxins from cyanobacteria. Acta Biologica Cracoviensia. Series Botanica 45: 9-20.

Mankiewicz-Boczek, J., Gagała, I., Kokociński, M., Jurczak, T., Stefaniak, K. 2011a. Perennial toxigenic *Planktothrix agardhii* bloom in selected lakes of Western Poland. Environmental Toxicology 26: 10-20.

Mankiewicz-Boczek, J., Izydorczyk, K., Romanowska-Duda, Z., Jurczak, T., Stefaniak, K., Kokociński, M. 2006. Detection and monitoring toxigenicity of cyanobacteria by application of molecular methods. Environmental Toxicology 21: 380-387.

Mankiewicz-Boczek, J., Palus, J., Gągała, I., Izydorczyk, K., Jurczak, T., Dziubałtowska, E., Stępnik, M., Arkusz, J., Komorowska, M., Skowron, A., Zalewski, M. 2011b. Effects of microcystins-containing cyanobacteria from a temperate ecosystem on human lymphocytes culture and their potential for adverse human health effects. Harmful Algae 10: 356-365.

Merel, S., Clément, M., Thomas, O. 2010. State of the art on cyanotoxins in water and their behaviour towards chlorine (Review). Toxicon 55: 677-691

Meriluoto, J. Codd, G.A. (eds) 2005. TOXIC. Cyanobacterial monitoring and cyanotoxin analysis. Abo, Abo Akademi University Press, 149 pp

Mur, L.R., Skulberg, O.M., Utkilen, H. 1999. Cyanobacteria in the environment. [In:] Chorus I., Bartram J. (eds) Toxic cyanobacteria in water. A guide to their public health consequences, monitoring and management. London: EandFN Spon on Behalf of the World Health Organization, p. 156-178.

Naselli-Flores, L., Barone, R. 1997. Importance of water-level fluctuation on population dynamics of cladocerans in a hypertrophic reservoir (Lake Arancio, south-west Sicily, Italy). Hydrobiologia 360: 223-232.

Negro, A.I, De Hoyos, C., Vega, J.C. 2000. Phytoplankton structure and dynamics in Lake Sanabria and Valparaiso reservoir (NW Spain). Hydrobiologia 424: 25-37.

NRC (National Research Council) 2002. Riparian Areas: functions and strategies for management. National Academy Press, Washington, D.C. 428 pp.

Paerl, H., Huisman, J. 2008. Blooms like it hot. Science 320: 57-58.

Pastuszak, M, Igras, J. (eds.) 2012. Temporal and spatial differences in emission of nitrogen and phosphorus from Polish territory to the Baltic Sea. MIR, IUNG, INS, 448 pp.

Pinay, G., Decamps, H. 1988. The role of riparian woods in regulating nitrogen fluxes between alluvial aquifer and surface water: a conceptual model. Regulated Rivers: Research & Management 2: 507-516.

Ploskey, G.R. 1986. Effects of water level changes on reservoir ecosystems with implications for fisheries management. [In:] Hall, G.E., Van Den Avyle M.J. (eds), Reservoir fisheries management: Strategies for the 80s. Reservoir Committee, Southern Division American Fisheries Society, Bethesda, Maryland: 86-97.

Psenner, R., Bostrom, B., Dinka, M., Petterson, K., Pucska, R., Sager, M. 1988. Fractionation of phosphorus in suspended matter and sediment. Archiv für Hydrobiologie–Beiheft Ergebnisse der Limnologie 30: 83-112.

Reynolds, C.S. 1980. Phytoplankton assemblages and their periodicity in stratifying lake systems. Holarctic Ecology 3: 141-159.

Reynolds, C.S. 1984. The ecology of freshwater phytoplankton. Cambridge University Press, Cambridge: 384 pp.

Robarts, R.D., Zohary, T. 1987: Temperature effects on photosynthetic capacity, respiration, and growth rates of bloom-forming cyanobacteria. – New Zealand Journal of Marine and Freshwater Research 21: 391–399.

Romo, S., Soria, J., Fernández, F., Ouahid, Y., Barón-Solá, Á. 2012. Water residence time and the dynamics of toxic cyanobacteria. Freshwater Biology Doi:10.1111/j.1365-2427.2012.02734.x

Rydin, E. 2000. Potentially mobile phosphorus in lake Erken sediment. Water Research 34: 2037-2042.

Schiemer, F., Zalewski, M. 1991. The Importance of Riparian Ecotones for Diversity and Productivity of Riverine Fish Communities. Netherlands Journal of Zoology 42: 323-335.

Schipper, L.A., Robertson, W.D., Gold, A.J., Jaynes, D.B., Cameron, S.C. 2010. Denitrifying bioreactors - an approach for reducing nitrate loads to receiving waters (review). Ecological Engineering 36: 1532–1543

Straskraba, M, Tundisi, J.G., Duncan A. 1993. State-of-the art of reservoir limnology and water quality management. [In:] Straskraba, M., Tundisi, J.G., Duncan, A. (eds) Comparative reservoir limnology and water quality management. p.188-213.

Straškraba, M., Tundisi, J.G. 1999. Reservoir water quality management. Guidelines of lake management 9. International Lake Enviroment Committee. 229 pp.

Stringfellow, W.T., Jain R. 2010. Engineering the global ecosystem. Clean Technologies and Environmental Policy 12: 197-203.

Tarczyńska, M., Romanowska-Duda, Z., Jurczak, T., Zalewski, M. 2001. Toxic cyanobacterial blooms in drinking water reservoir – causes, consequences and management strategy. Water Science and Technology. Water Supply 1: 237-246.

Tilman, D. 1982. Resource competition and community structure. Princeton Monographs in Population Biology 17. Princeton University Press, Princeton, NJ. 296 pp.

Tilman, D. 1996. Biodiversity: population vs ecosystem stability. Ecology 77: 530-563.

Trojanowska A., Izydorczyk K. 2010. Phosphorus fractions transformation in sediments before and after cyanobacterial bloom: implications for reduction of eutrophication symptoms in dam reservoir. Water, Air, and Soil Pollution 211: 287-298.

Tundisi, J.G. Straskraba, M. (eds) 1999. Theoretical Reservoir Ecology and its Applications. Brazilina Academy of Sciences, International Institute of Ecology, Backhuys Publishers. 585 pp.

United States Environmental Protection Agency 2002. National water quality inventory: 2002 report to Congress. USEPA, Office of Water Regulations and Standards, Washington, DC

Venohr, M., Hirt, U., Hofmann, J., Optiz, D., Gericke, A., Wetzig, A, Ortelbach, K., Natho, S., Newmann, F., Hurdler, J. 2009. The model System MONERIS - Manual. IGB, Berlin, Germany. 105 pp.

Wagner, A., Hulsmann, S., Dorner, H., Janssen, M., Kahl, U., Mehner, T., Benndorf, J. 2004. Initiation of the mid-summer decline of *Daphnia* as related to predation, non-consumptive mortality and recruitment: a balance. Arch Hydrobiol. 160, 1-23.

Wagner, I., Izydorczyk, K., Kiedrzynska, E., Mankiewicz-Boczek, J., Jurczak, T., Zalewski, M. 2009. Ecohydrological approach for protection and enhancement of ecosystem services for societies at the Pilica catchment demonstration project. Ecohydrology and Hydrobiology 9: 13-39.

Wagner, I., Zalewski, M. 2000. Effect of hydrological patterns of tributaries on biotic processes in lowland reservoir – consequences for restoration. Ecological Engineering 16: 79-90.

Wagner-Łotkowska, I., Izydorczyk, K., Jurczak, T., Traczyńska, M. 2004. Ecohydrological methods of algal bloom control. [In:] Zalewski, M., Wagner-Lotkowska I., Robarts, R.D. [eds] Integrated Watershed Management - Ecohydrology and Phytotechnology - Manual. UNESCO, p 188-193.

WHO (World Health Organization) 2008. Guidelines for Drinking Water Quality, Incorporating First Addendum (third ed.), Recommendations vol.1, 1407–1408.

Wojtal, A., Bogusz, D., Menshutkin, V., Izydorczyk, K., Frankiewicz, P., Wagner-Lotkowska, I., Zalewski, M. 2008. A study of *Daphnia-Leptodora*-juvenile Percids interactions using a mathematical model in the biomanipulated Sulejow Reservoir. Annales de Limnologie - International Journal of Limnology 44: 7-23.

Zalewski, M. 2000. Ecohydrology – the scientific background to use ecosystem properties as management tools towards sustainability of water resources. Ecological Engineering 16: 1-8.

Zalewski, M. 2006. Ecohydrology – an interdisciplinary tool for integrated protection and management of water bodies. Archiv für Hydrobiologie , Supplement 158: 613-622.

Zalewski, M. 2010. Ecohydrology for compensation of Global Change. Brazilian Journal of Biology vol. 70 no. 3 (suppl.), 689-695.

Zalewski, M. 2011. Ecohydrology for implementation of the EU water framework directive. Proceedings of the Institution of Civil Engineering Water Management 164: 375-385.

Zalewski, M., Brewinska-Zaras, B., Frankiewicz, P., Kalinowski, S. 1990. The potential for biomanipulation using fry communities in a lowland reservoir: concordance between water quality and optimal recruitment. Hydrobiologia 200/201: 549-556.

Zalewski, M., Izydorczyk, K., Ratajski, S., Frątczak, W., Skowron, A., Wojtal-Frankiewicz, A. 2013. Hydrobiomanipulation – regulation of trophic cascade by hydrological regime. Ecohydrology and Hydrobiology *(in press)*.

Zalewski, M., Janauer G.A., Jolankai, G. 1997. Conceptual background. [In:] Zalewski, M., Janauer, G.A., Jolankai G. (eds) Ecohydrology: A new paradigm for the sustainable use of aquatic resources. International Hydrobiological Programme UNESCO, Paris, Technical Document in Hydrology 7.

Zalewski, M., Wagner-Lotkowska I., Tarczynska, M. 2000. Ecohydrological approaches to the elimination of toxic algal blooms in the a lowland reservoir. Verhandlungen der internationale Vereingung für theoretische und angewandte Limnologie 27: 3176-3183.

Zamyadi, A., MacLeod, S.L., Fan, Y., McQuaid, N., Dorner, S., Sauvé, S., Prévost, M. 2012. Toxic cyanobacterial breakthrough and accumulation in a drinking water plant: A monitoring and treatment challenge. Water Research. 46: 1511-1523.

Zhou, Y., Li, J.Q., Zhang, M., 2002. Temporal and spatial variations in kinetics of alkaline phosphates in sediments of a shallow Chinese eutrophic lake (Lake Donghu). Water Research 36: 2084-2090.

Zhou, Y., Song, C., Cao, X., Li, J., Chen, G., Xia, Z., Jiang, P. 2008. Phosphorus fractions and alkaline phosphatase activity in sediments of a large eutrophic Chinase lake (Lake Taihu). Hydrobiologia 599: 119-125.

THE ECOSYSTEM APPROACH TO WATER MANAGEMENT: THE SUSTAINABILITY OPTION FOR SIDS IN THE CONTEXT OF CLIMATE CHANGE

Sunita Facknath[1]

Professor. Faculty of Agriculture, University of Mauritius, Reduit, Mauritius. E-mail: sunif@uom.ac.mu.

ABSTRACT

An ecosystem is a dynamic system composed of all the living (plants, animals, humans, micro-organisms) components, as well as non-living (soil, land, water, air, climate) components that continuously interact with each other. Water plays a very important role in ecosystem structure, composition and functioning, and is the life-blood of ecosystem functioning. Hence, water security is at the core of sustainable ecosystem management. An 'Ecosystem Approach' recognizes and ensures the sustainability of ecosystem services and goods, and advances on the Integrated Water Resources Management approach. The unique characteristics of Small Islands Developing States (SIDS) make sustainable development of SIDS an important challenge, with major constraints to efficient and effective water resources management. Some of these include traditional land tenure and land ownership systems, inadequate land-use policies, ill-maintained water supply systems, high losses due to non-revenue water, insufficient water storage facilities, insufficient human and financial capacity, inadequate water-related policies, poor implementation and enforcement of water-related legislation. UNEP (2012) proposes six main steps in the IWRM Planning Cycle for SIDS, and further recommends the integration of the Twelve Ecosystems Approach (EA) Principles and Climate Change into the SIDS IWRM Approach. The integrated ecosystem based approach to water management requires a strategy that will merge ecosystem science and socioeconomic principles, initiate institutional change and coordination, and ensure stakeholder participation and collaborative decision making. Ecosystem Management is an essential part of the 'tool kit' for tackling climate change and making progress towards long-term sustainability of water resources in the SIDS.

1 INTRODUCTION

Globally, 50% of all the accessible freshwater is already being used by people for various purposes, and this may increase to 75% by 2025. Of this total use, almost 70% is used for agricultural purposes globally, while 10% goes for domestic use, and the rest 20% for industry. Water equivalent for production of 1 head of cattle has been estimated to be 4,000/ m^3, 6 m^3 /kg for fresh poultry, and 1.5 and 1.0 m^3 /kg for cereals and pulses, respectively. Dietary changes in developing countries are increasing the demand for meat and dairy products (which are water-intensive foods), and this is further increasing agricultural water demand.

2 ECOSYSTEMS, ECOSYSTEM SERVICES AND GOODS

An ecosystem is a dynamic system composed of all the living (plants, animals, humans, micro-organisms) components, as well as non-living (soil, land, water, air, climate) components that continuously interact with each other. In a healthy ecosystem, the interactions are balanced and in equilibrium. Ecosystems can be **natural** (wild) or **managed** by humans. While natural ecosystems sustain themselves through inherent intricate and resilient mechanisms, managed ecosystems are sustained through human intervention. Together, the natural and managed ecosystems provide food for all life on our planet, e.g. capture fisheries, forest products (natural systems), crop and animal agriculture, aquaculture, and agroforestry (managed systems). The direct and indirect benefits that humans derive from natural and managed ecosystems, such as provisioning (including food), cultural, regulatory and supporting services, are referred to as **Ecosystem Services**. **Ecosystem Goods** pertain to goods produced by ecosystems, such as food (meat, fish, vegetables etc.), water, fuels, fibre, and timber.

3 ECOSYSTEM AND WATER

Water plays a very important role in ecosystem structure, composition and functioning. The quantity and quality of water in an area usually determines the type of habitat, vegetation and biodiversity of the region, that is, water shapes the ecosystem. Water also influences the extent of resilience of an ecosystem to external pressures, including climate change, through its effects on the critical processes and functions of the ecosystem. Other aspects of the ecosystem such as precipitation, temperature, the topography, soil type, in turn affect water flows and water availability. The term **Environmental Flows** is used to describe the quantity, quality and timing of water flows that are necessary to sustain Ecosystem Services, and the human livelihoods and well-being that depend on them. Environmental Flows have important implications for:

- Protection against flood risk, floodplains, forest cover, and riparian ecosystems;
- Water purification mediated by forest and other vegetation cover;
- Water recharge and water storage;
- Water regulation by forests;
- Carbon sequestration by aquatic vegetation;
- Replenishment of nutrients by aquatic vegetation;
- Coastline protection by mangroves and coral reefs from storm surges;
- Provision of spawning, nursery and feeding grounds by mangroves;
- Provision of food and economic resources.

4 ECOSYSTEMS, WATER & SUSTAINABLE DEVELOPMENT

Ecosystems need water for functioning, and water plays a crucial role in the delivery of many ecosystem services. In fact, water is the life blood of ecosystem functioning, and hence, water security is at the core of sustainable ecosystem management. Sustainable development is not possible without healthy and functioning ecosystems. Activities that result in ecosystem degradation can be significant constraints to sustainable development. In important food-producing regions, water resources limitations have already started endangering water & food security - groundwater levels are declining rapidly in several major breadbaskets and rice bowl regions such as the North China Plains, the Indian Punjab and the Western USA. Presently 70% of total global withdrawals of water go to meet food production needs, with figures going upto 90% in many areas (CA, 2007). With such high water needs, it is inevitable that water will be the main limiting factor for increased food production. This is particularly critical given that, on one hand, parts of South Asia and sub-Saharan Africa, already suffering from widespread malnutrition and food insecurity, and on the other hand the global population is predicted to increase to almost 9 billion people by 2050. Experts have estimated that food production must increase by 50% - 100% by 2030 in order to meet the needs of this growing population. This will cause a 100% increase in water demand for agriculture alone. Water is already a major constraint to agriculture, particularly in the poorest areas of the world where access to water, and its timely availability, is a problem. Based on current agronomic practices, Boelee (2011) has estimated that the current 1.6 billion people who live in areas of physical water scarcity could easily grow to 2 billion soon, unless there is a fundamental shift in our outlook towards water. Increasing urbanisation, changing dietary patterns, and other social and cultural transformations are further expected to increase water demand. Given that, in many areas, water availability has reached the absolute limit and even surpassed it in some places (CA, 2007), makes water an immense challenge to food security for the very near future. Decreased water availability, coupled with reduced water quality, and degradation of other natural resources are additional causes of food insecurity.

Reduction in tree cover and soil compaction due to expansion of agriculture into forest and woodland areas, is causing higher runoff. Increasing demand for aquaculture products like fish and shrimp is endangering the health of aquatic ecosystems in some countries. Agroecosystem degradation further adds to this equation, posing a major risk to the livelihoods and well-being of poor communities that depend on water and other ecosystem goods and services (IWMI; IRC; GWP, 2006), and illustrates the strong links between ecosystems, water and food. Worse still, most agroecosystems have lost their capacity to recover from stress.

In view of the presently feasible technologies available, the only option is to increase water productivity (the 'more crop per drop' concept) in all agroecosystems through the use of improved crop varieties and animal breeds that have greater water use efficiency, are more drought tolerant, develop and promote soil moisture and water conservation methods, encourage rainwater harvesting, etc. Water governance and management should also lay more emphasis on water capture and storage in order to increase water availability and accessibility. Appropriate policy and legislative framework must be put in place for effective water management at ecosystem level. Robust research is needed to fill present knowledge-gaps, coupled with capacity building, particularly in developing countries, in order to assess, and eventually realise, the potential of an **Integrated Water Resource Management (IWRM)** strategy pitched at multiple-ecosystem scales. It is imperative that the right balance of water is provided to natural ecosystems on one hand and to food production on the other, in order to ensure the sustainability of both. A healthy ecosystem is resilient and is able to adapt and adjust to changes without loss in productivity. In fact, understanding and managing water resources across multiple interlinked ecosystems is the key to sustainable integrated water resource management within an ecosystem approach.

Decline in ecosystem services are leading to problems such as soil nutrient depletion, loss of biodiversity, soil erosion, increased vulnerability to disease and pests, and loss of buffering and storage capacity to deal with rainfall variability. All this is already affecting agricultural productivity adversely, and climate change will accelerate and further exacerbate the situation. By 2050, humankind may be facing food shortages to the tune of 5-25% of demand. These problems have the greatest impact on the poorest people - those who are directly dependent on natural resources for food and livelihoods. Without full valuation of the less-tangible benefits from ecosystems, their exploitation will remain unsustainable and degradation remains inevitable leading to the potential collapse of important ecosystem functions and services. There is need to develop an economic model that accurately reflects benefits to people from the environment and the costs associated with ecosystem degradation. Valuing ecosystem services is an important tool when considering the costs and benefits of different options for achieving water and food security. When making decisions on water allocation, the whole range of ecosystem services, their benefits (values) and costs (social, financial, water) have to be taken into account (TEEB, 2010). Ecosystem management can help retain the balance between economic growth, societal development and ecosystem health to ensure long-term sustainability (the very principles of Sustainable Development).

5 THE ECOSYSTEM SERVICES APPROACH TO WATER RESOURCES

An **'Ecosystem Approach'** recognizes and ensures the sustainability of ecosystem services and goods. Implementation of the Ecosystem Approach advances on the IWRM approach. According to the Convention on Biological Diversity (CBD), the Ecosystem Approach is *a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way.* It is also an important element of the Local Agenda 21 approach as well as of the implementation of the Ramsar Convention and the CBD.

The Ecosystem Approach focuses on the **multifunctionality of the landscape**, instead of focusing solely on production, and can improve system resilience and reduce vulnerability of food production to climate change. In an Ecosystem Approach, the focus of water is widened to include and integrate multiple uses of water within a given system. It adopts the catchment or groundwater system perspective, taking the entire catchment/groundwater system into account, along with its land use, land cover, impacts of use from, and on, other ecosystems, water sources (rainwater, surface water and groundwater) and sinks (enhancing infiltration and percolation with trees), biodiversity (flora and fauna) in the region, the soil type, temperature, humidity, wind, climate and climatic changes, and the interactions among all these factors.

It is imperative the sustainability of the ecosystems be, a priori, estimated through an in-depth study of the past, present, and future water resources in the area, the water demand, the impacts of water removal from the area, and effect on human livelihood. Consumptive water use should be set at levels that do not undermine ecosystem resilience and productivity. Furthermore, It is critically important that a certain volume of water is reserved for the maintenance of freshwater ecosystem functions and the services they provide to people (**Environmental Water Requirements** - EWR). Such environmental flows should be seen as '**Environmental Water Demand**'— similar to agricultural, industrial or domestic water demand – and similarly catered for.

Present global economic models & national accounts do not give sufficient consideration to ecosystem services. This, leads to the overuse/ misuse of natural resources. Protection of the ecosystem, and its services and goods, necessitates a major change in mindset and attitudes based on a deeper understanding of ecosystem structures and functioning, for instance, in the area of food production, the emphasis must shift from 'water for food' to 'water for multifunctional agroecosystems'', and consider the whole ecosystem base of provisioning, regulatory, cultural, and supporting services (BOELEE et al., 2011).

6 SMALL ISLANDS DEVELOPING STATES (SIDS)

Small Island Developing States are small coastal countries with a set of features and characteristics that are very similar to each other but very different from the rest of the world. The combination of their small sizes exacerbated by the fact that they are often made up of a number of smaller islands, growing populations, small domestic markets with very little or no competition, increasing urbanisation, overdevelopment on coastal land, limited resource base (which does not make for economies of scale), geographical isolation, high costs of all production inputs and hence high cost of primary production, high energy costs, heavy dependence on imports, economies based usually on a few agricultural exports and tourism, high volatility of economic growth; limited opportunities for the private sector with heavy dependence on the public sector for employment, limited access to funding and over-dependence on donor funding for capital projects, heavy dependence on international trade without the means of influencing the terms of this trade, extreme susceptibility to global economic changes, fragile natural environments with high vulnerability to weather and climate variability and climate change, and problems associated with sea level rise and saline water intrusion, small watersheds and threatened supplies of freshwater, all make sustainable development an important challenge. Unsustainable development threatens the very livelihood of the island people and their cultures, as also the biological resources on which the SIDS depend.

This has resulted in their being recognised as a special case in the context of Agenda 21 (Chapter 17 G) at the 1992 United Nations Conference on Environment and Development (UNCED), also known as the Earth Summit, held in Rio de Janeiro, Brazil. The SIDS are grouped under one of three regional bodies based on their geographical locations, namely, the Caribbean (CARICOM), the Pacific and the Atlantic (PIF), and the Indian Ocean (IOC).

While the natural beauty of most SIDS makes tourism a logical choice as an economic driver of growth, the fragility of their environments makes it imperative to strike an appropriate balance between economic growth and development on one hand, and preservation of the pristine natural environment of the islands, on the other. For instance, it is well known that tourism is a major consumer of freshwater. Managing this often limited resource sustainably in the face of various competing demands, while satisfying environmental goals, is a key challenge for all SIDS.

7 MAJOR CONSTRAINTS TO EFFICIENT AND EFFECTIVE WATER RESOURCES MANAGEMENT IN THE SIDS

1. Many SIDS continue to have age-old, traditional land tenure and land ownership systems, with the associated rights of land and water usage and access, which often lead to poor and/or unsustainable land use and management practices. Coupled with inadequate land-use policies, or difficulties in implementation and enforcement of land and water-related regulations, this has major impacts on the water resources. Their resolution, usually through extensive dialogue and negotiations, is often a long-drawn out, time consuming process, and does not always result in a satisfactory conclusion due to the complexities involved, vested interests, conflicting interests of various parties involved, etc.;
2. Outdated, ill-maintained water supply systems, resulting in significant losses in water and thereby income to Government;
3. Inadequate water storage facilities for a growing population;
4. Insufficient funds/investments in the water sector to enable major infrastructural works;
5. There is a traditional, deep-rooted, general belief that water is a social service that must be provided by the Government, and is not an economic good that must be paid for;

6. Water-related policies and programmes are fragmented and responsibilities for their implementation are spread over several Ministries and institutions, resulting in duplications and overlaps, and inefficient and/or ineffective use of existing water resources, as well as of available human, technical and financial capacities;

7. Lack or inadequate coordination between the various institutions/organisations responsible for water management;

8. High degree of centralization, which makes it difficult to effectively operationalise and/or facilitate sustainable water management at grassroot levels;

9. Where water-related legislations exist, implementation and enforcement is usually poor, due to insufficient human, technical and financial resources for the same. This makes it difficult to apply economic instruments, such as incentives or penalties;

10. Lack or inadequate research and data collection - due to a number of factors ranging from clear allocation of institutional mandates for data collection and analysis, to lack of human, technical and financial capacities. This results in decisions not being evidence-based.

The IWRM approach in SIDS can only be undertaken as a holistic, realistic and realizable process that moves the water sector towards a centrally coordinated, but locally managed programme for the integrated and sustainable management of water, land and related resources. Furthermore, any water management approach in the SIDS has to take the special characteristics of the island into account, in particular the fact that the entire island is usually one large, multiple, interconnected-ecosystem landscape. Any intervention in one area can have major impacts on the entire hydrological system, with far-reaching consequences. It is advisable not to be too prescriptive or ambitious; the water management strategy must be adaptive and interactive, and streamlined into national development goals, with multiple areas of intervention (community, watershed and nation-wide). Moreover, the focus should be on incremental progress, backed by evidence-based tangible deliverables. Hence, unlike in other countries, in the SIDS the water management approach adopted must not only reflect the unique geological, bio-geographical, socio-economic and cultural attributes of the country, but also develop a management strategy that will encompass the entire island watershed stretching from the ridge to the reef, using the principles of an Ecosystem Approach. Unlike in several countries, SIDS in the Caribbean, the Pacific, Indian and Atlantic Oceans did not prepare IWRM plans prior to undertaking major reforms in the water sector to move towards an integrated approach. Although they are adopting IWRM, it is not done through the usual formal, stepwise and rigid planning process starting with water policy, governance and legislative reforms. Instead, practical steps have been taken with the aim of achieving coordinated, prioritised interventions, which will ultimately lead to sound and realistic IWRM.

7.1 ECOLOGICAL SYSTEMS+HYDROLOGICAL SYSTEMS + SOCIOCULTURAL SYSTEMS=SUSTAINABLE ECOHYDROLOGY

Box 1. The Twelve Ecosystems Approach (EA) Principles

Principle 1: The objectives of management of land, water and living resources are a matter of societal choices.
Principle 2: Management should be decentralized to the lowest appropriate level.
Principle 3: Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.
Principle 4: Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context.
Principle 5: Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.
Principle 6: Ecosystem must be managed within the limits of their functioning.
Principle 7: The ecosystem approach should be undertaken at the appropriate spatial and temporal scales.
Principle 8: Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term.
Principle 9: Management must recognize the change is inevitable.
Principle 10: The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity.
Principle 11: The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices.
Principle 12: The ecosystem approach should involve all relevant sectors of society and scientific disciplines.

UNEP (2012) proposes the following six main steps in the IWRM Planning Cycle for SIDS: **Diagnosing; Visioning; Strategising; Planning; Implementing; and Monitoring, Evaluating and Documenting.** Given the importance of an all-inclusive IWRM strategy where stakeholders at all levels (Community, watershed and national) have important roles to play, and given the vulnerability of SIDS to climate change, UNEP recommends the addition of two further cross-cutting components - **Awareness and Sensitisation,** and **Climate Change Considerations**, which are an integral part of all the six steps listed above. The activities in each of the six steps, along with the integrated of Awareness and Climate Change Considerations are given in Table 1.

Table 1 - Integration of the Twelve Ecosystems Approach (EA) Principles and Climate Change into the SIDS IWRM Approach

(continue)

Steps in IWRM for SIDS	EA Principles Applicable (from Box 1)	Awareness Activities	Integrating Climate Change into IWRM for SIDS
Phase 1: Diagnosing Information is collected and analysed on the current situation and the problems encountered			
Identifying the Entry Point	7, 8	Sensitisation of all key stakeholders, including the general public, about the intention to launch an IWRM programme	
Stakeholder Analysis	1, 12	Memos, flyers to agencies who own information critical for situation analysis	Stakeholders to be analysed should include Hydrological and Meteorological Agencies, and local weather stations; Discussions should take on board the agencies responsible for generating climate data and information, implementing climate change convention and/or have access to climate information and models.
Situation Analysis	4, 6, 7, 10, 11	Electronic circulation of Summary Report of findings of situation analysis; Summary Information Report uploaded on to website of the Lead and other relevant agencies.	Should take into account climate information and impact analysis, all available climate data sets; Should identify known climatic conditions affecting geographical scope and issues in the “entry point”; Conduct a participatory vulnerability to current climate variability and extreme events and of areas where risks would increase due to climate change.

(continuation)

Steps in IWRM for SIDS	EA Principles Applicable (from Box 1)	Awareness Activities	Integrating Climate Change into IWRM for SIDS
Phase 2: Visioning Stakeholders identify the core problem, and its causes and effects, and then develop a future vision for water resources management to mitigate this problem		Circulation of Workshop Report to management of Lead and other relevant agencies; Community presentation; Short statement on Vision uploaded onto Lead Agency's website	
Problem Tree Analysis	4, 5, 6, 7, 8, 10		Should consider the causes and effects of climate variability and climate change on the root problem; Should consider the issues influencing the vulnerability of the root problem.
Objective Tree Analysis			Should consider incorporating relevant issues of climate change vulnerability and adaptation into the objective(s).
Phase 3: Strategising Stakeholders begin to develop different scenarios to achieve the vision.		Workshop Report; Presentations to relevant stakeholders; Media communication to general public	
• Action Plan and Budget • Responsibility Matrix • Scheduling • Monitoring targets and indicators	1 – 12		Should use cost-benefit analysis, multi-criteria analysis, cost-effectiveness analysis and expert judgment in order to prioritise and select adaptation options; The roles of various stakeholders in implementing adaptation strategies, and their training and capacity development needs to be able to take up this responsibility, should be included in the strategy plans.

(continuation)

Steps in IWRM for SIDS	EA Principles Applicable (from Box 1)	Awareness Activities	Integrating Climate Change into IWRM for SIDS
Phase 4: Planning Planning will normally take place for a sub-set of the entire strategy. The Plan will include a budget, schedule, roles and responsibilities, targets, and indicators to be used for monitoring and evaluation.		Workshop Report; Presentations and Consultations with Lead Agency and implementing agencies; Summary Plan uploaded on website of Lead and other relevant agencies; Community Consultations; Media communication to general public	Should include the anticipatory or 'precautionary' approach as the basis for IWRM strategies.
Scenario Development	1 – 10		Applicable, available and accessible. climate change scenarios should be reviewed; Key adaptation measures to be used in each scenario should be identified; Selection of scenarios and related methodologies and measures to deal with adaptation to climate change should consider any possible side effects of their implementation; Adaptation measures articulated in Country's National Communications; Vulnerability Assessment Reports and National Adaptation Plans should be reviewed and updated.
Phase 5: Implementation	12	Regular Reports (Programmatic and Financial); Summary of Technical Reports uploaded on website of Lead and other agencies	

(continuation)

Steps in IWRM for SIDS	EA Principles Applicable (from Box 1)	Awareness Activities	Integrating Climate Change into IWRM for SIDS
Phase 6: M&E and Documentation	11	Regular M&E Reports; Reports on Lead and other agencies' websites; Summarised media reports for the general public	Results of the implementation of adaptation measures proposed in the plan should be measured against indicators; Indicators should include: - Impact: the extent to which the intervention reduces climate vulnerability and/ or enhances adaptive capacity (through bringing about changes in adaptation processes: policy making/ planning, capacity building/awareness raising, information management, etc.) - Sustainability: the ability of stakeholders to continue the adaptation processes beyond the intervention's lifetime, thereby sustaining development benefits.

Source: Modified from UNEP (2012)

8 WATER AND FOOD SECURITY

IWRM practiced within an Ecosystem Approach can contribute to long-term food security by providing water for agroecosystems as well as for non-agricultural ecosystems. Healthy ecosystems are more resilient, diverse and productive, and can support a wider range of ecosystem services, including water management functions that are vital for food security, and other services. The Ecosystem Approach requires the following:

- Valuation of ecosystem services from agroecosystems and non-agricultural ecosystems, so that these can be used to implement incentives, trade-offs and disincentives (e.g. the polluter pays principles);
- Management of agriculture as a continuum of agroecosystems that not only produces food, but also delivers a whole range of other ecosystem services necessary for long-term food security, in larger and diverse, more productive systems, e.g. integrated crop-animal-fish farming;

- Management for multifunctional agroecosystems in order to support the widest range of ecosystem services, and sustain efficiency in terms of regulatory and supporting services, e.g. through applying the principle "water for agroecosystems and agroecosystems for water";
- Application of interactive and adaptive IWRM to ensure water for food as well as water for nature/ environmental flows. This needs the necessary backstopping of capable, empowered and efficient institutions supported by appropriate policy and legislation;
- Collaboration between key sectors local, watershed, national and international scales in order to provide the necessary support from authorities and experts at in order to benefit optimally from the multiple ecosystem services available.

9 CLIMATE CHANGE

SIDS are among the states that contribute the least to global climate change and sea level rise and yet are among those that would suffer the most from the adverse effects of these phenomena. SIDS are particularly vulnerable to global climate change/variability, and water is the first sector to be affected by a changing climate. Climate change leads to an intensification of the hydrological cycle, which leads to serious impacts on the frequency and intensity of extreme weather events. Increased evaporation resulting from the higher temperatures, erratic rainfall patterns, and prolonged droughts are a few manifestations of climate change that directly impact on the availability and quality of water.

Some of the major threats to SIDS from climate change include the following:

I. Sea level rise is threatening the very survival of low-lying islets such as the Maldives and Agalega;

II. Saltwater intrusion into freshwater aquifers, reducing water availability and water quality;

III. The population tends to be concentrated in coastal zone, & any rise in sea levels will have dramatic effects on living and economic conditions through flooding of low-lying areas, salinisation of coastal ecosystems, salinisation of soil, loss of beaches, which will affect tourism. Reduction in tourism will affect foreign exchange earnings while costs of protecting beaches (e.g. through the use of gabion or other technologies) will increase;

IV. Loss of high-tide mark will result in loss of Exclusive Economic Zone (EEZ) rights over extensive areas of the ocean;

V. Destruction of economic structures and human settlements;

VI. Adverse effects on coral reefs and marine industries;

VII. Increase in intensity of cyclones and other natural disasters;

VIII. The predicted increase in temperature, increase in magnitude and frequency of droughts and floods is expected to increase the spatial and temporal variability in agricultural production with an overall decrease in food production;

IX. Climate change related events may result in killing some tree species, making others more susceptible to insect infestation, increasing the likelihood of fires, etc. all of which can result in large-scale die off of forest stands. This can have significant repercussions on the ecohydrology of the area;

X. Impacts on the hydrological cycle include changes in precipitation, streamflows, atmospheric water content, soil moisture, and ocean salinity;

XI. Impacts on the various ecosystems and thereby on water and food security have not been studied in sufficient depth, and are highly uncertain, although most forecasting scenarios indicate damage to ecosystems and reduced ecosystem services, decreased resilience and increased vulnerability to further changes, which may result in irreversible losses of various ecosystem services, including regulation of water flows. Current water management practices may not be robust enough to cope with climate change impacts on water supply reliability, flood risk, health, agriculture, energy and aquatic ecosystems.

10 MEETING THE CHALLENGE OF CLIMATE CHANGE

SIDS strategies to meet the challenge of climate change and protect and conserve freshwater resources must include the following:

I. A comprehensive assessment of current water demand and projections of future demand needs must be made;

II. A sustained research programme must be established to assess available fresh water resources;

III. More emphasis must be placed on the impacts of development projects, including tourism infrastructure, on the vulnerability of coastal freshwater resources;

IV. Water losses due to faulty and defective supply infrastructure must be reduced;

V. Appropriate financial and human resources must be channeled to national and regional meteorological institutions that are responsible for collecting and analysing climate data;

VI. Climate change adaptation and mitigation must be mainstreamed into national strategy and action plans, e.g. water management plans, land management and tree cover in catchment areas, increased water and aquifer storage, early warning systems, small-scale, community-based storage and water harvesting structures, and more efficient water use processes (agricultural, industrial, domestic, and environmental);

VII. The present way of managing water resources must be changed in order to ensure water for ecosystems, and ecosystems for water, i.e. the Ecosystem Approach must be adopted;

VIII. Steps must be taken to maintain healthy ecosystems in order to ensure water availability and the continuance of other ecosystem services.

11 STRATEGY ISSUES

1. Understanding, accepting, and implementing the Ecosystem Approach for water management.
2. Developing a new organizational mindset, coupled with appropriate institutional changes.
3. Assessing and developing knowledge systems at ecological level rather than sectoral or political levels.
4. Collecting/ researching site-specific, evidence-based knowledge about ecosystem services, about the interactions between key ecosystem services and human well-being, about the drivers for key ecosystem services, the economic value of the services, and the costs and benefits of changes in their delivery.
5. Turning knowledge to action by developing effective intervention strategies for mitigating the negative impacts of ecological change on ecosystem services, determine priorities for action, build local capacity, and implement.
6. Ensuring equitable access and use of ecosystem services by all stakeholders.
7. Monitoring and evaluating regularly to refine intervention strategies, using the overall delivery of ecosystem services as a measuring stick rather than the impacts on specific drivers.

12 ACTIONS

12.1 TECHNICAL ISSUES

- Better management of soil moisture, e.g. strategic placement of specific trees in agroecological landscapes to increase water infiltration and percolation, thereby improving overall water productivity while providing fuel, fodder, fruit and timber;
- Control of soil erosion;
- Enhancement of aquifers and increased water storage capacity;
- Development and adoption of drought and pest resistant crop cultivars and animal breeds;
- Development of efficient collection of runoff;
- Creation of vegetation corridors and the establishment of water points and resting areas to optimise smaller herds and prevent overgrazing in one area;
- Making multiple uses of water: livestock-aquaculture, rice-fish culture, aquaculture in irrigation reservoirs, wastewater-fed aquaculture;
- Integrating crop- tree- livestock systems in dry ecosystems;
- Integrating fisheries/aquaculture-livestock/crop systems in wet ecosystems;
- Promoting diversity in natural and agricultural landscapes, e.g. planting hedgerows, buffer strips, multipurpose trees and corridors of natural vegetation interconnecting parcels of agricultural land, to increase adaptive capacity to buffer against fluctuations in water availability and to enhance resilience, reduce runoff and erosion, and help protect watercourses and field crops;
- Reusing agricultural wastes, to increase the amount of food produced without increasing the amount of land and water resources required;
- Preventing and minimising pollution of freshwater ecosystems.

12.2 SOCIAL ISSUES

- Engaging local communities for sustainable use and management of water, e.g. small-scale, community-based water harvesting and storage.

12.3 POLICY ISSUES

- Combining water and land management in catchments and river basins;
- Combining water and land management in catchments and river basins;
- Making an economic valuation of ecosystem goods and services and develop incentive measures to support sustainable use of freshwater ecosystems and remove perverse incentive measures.

12.4 CAPACITY ISSUES

- Developing institutions for integrated water resources management; enable coordination for IWRM and the multipurpose use of water;
- Establishing funding mechanisms, e.g. trust funds for the conservation of freshwater ecosystems.

12.5 CONCLUSIONS AND RECOMMENDATIONS

- The ecosystem approach to water management can serve to improve human well-being, ensure sustainable development of the sector, and support the transition to a Green Economy (low-carbon, resource-efficient and equitable);
- Ensuring food security, managing water resources and protecting ecosystems must be considered as a single policy rather than as separate, and sometimes competing, choices;
- The integrated ecosystem based approach to water management requires a strategy that will merge ecosystem science and socioeconomic principles, initiate institutional change and coordination, and ensure stakeholder participation and collaborative decision making;
- Ecosystem Management is an essential part of the 'tool kit' for tackling climate change and making progress towards long-term sustainability of water (and other) resources in the SIDS.

REFERENCES

Bates BC, Kundzewicz ZW, Wu S, Palutikof JP (eds) 2008. Climate change and water. Technical Paper of the Intergovernmental Panel on Climate Change. Geneva: IPCC Secretariat.

Boelee E (ed) 2011. Ecosystems for water and food security. UNEP, Nairobi; IWMI, Colombo. 194 pp.

Boelee E, Chiramba T & Khaka E (eds) 2011. An ecosystem services approach to water and food security. UNEP, Nairobi; IWMI, Colombo. 35 pp.

CA, 2007. (Comprehensive Assessment of Water Management in Agriculture). 2007. Water for food, water for life: a comprehensive assessment of water management in agriculture. London: Earthscan; Colombo: International Water Management Institute (IWMI).

FAO. 2009b. Coping with a changing climate: considerations for adaptation and mitigation in agriculture. Rome: Food and Agriculture Organization of the United Nations.

IWMI, IRC, GWP. 2006. Taking a multiple-use approach to meeting the water needs of poor communities brings multiple benefits. IWMI Water Policy Briefing 18.

MA (Millennium Ecosystem Assessment) 2005. Ecosystems and human well-being. Washington DC: World Resources Institute.

TEEB, 2010. The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Earthscan, October 2010.

UNEP (United Nations Environment Programme). 2009. Ecosystem management programme. A new approach to sustainability. Nairobi: United Nations Environment Program.

UNEP, 2012. Integrated Water Resources Management Planning Approach for Small Island Developing State. UNEP. 130 pp.

SUMMARY

ISBN: 978-85-7717-187-3