WORLD WATER WEEK

in Stockholm,
August 16–22, 2009

On the Water Front

Selections from the 2009 World Water Week in Stockholm

Edited by Jan Lundqvist

www.worldwaterweek.org

Table of Contents

Photo: Digital Vision

Editor: Jan Lundqvist

ISBN: 978-91-975872-8-0

How to cite: Lundqvist, J. (ed.) 2010. On the Water Front: Selections from the 2009 World Water Week in Stockholm. Stockholm International Water Institute (SIWI), Stockholm.

Photo: Image Source

Preface

Since 1991, the World Water Week in Stockholm is an annual event and meeting place for people from various professions, cultures and parts of the world with a common concern and ambition. The ambience in well over 200 sessions during the week and also in the informal exchanges in corridors and other meeting places is characterised by dialogue and an urge to scrutinise, learn, reassess concepts and standpoints and capture the best and most appropriate knowledge with regards to water and development issues. The scope is broad and goes beyond an academic search for new knowledge and better understanding per se. A prime task is to promote the use of this knowledge for necessary change, for policy and concrete action at appropriate levels in different parts of the world. This task presumes a process where new insights and skills are tested and integrated into our ways of thinking and doing things.

Each year, the World Water Week features a theme. In 2009, the theme was "Responding to Global Changes: Accessing Water for the Common Good" with Special Focus on Transboundary Waters. As illustrated by the range of issues discussed in the articles in this volume, the World Water Week programme includes sessions that elaborate also on issues outside the scope of the theme.

Presentations and discussions during the World Water Week generate a remarkable level of energy and commitment. Based on the comments that we hear from participants, we are convinced that seeds are sown for improvements in water policy and management for the betterment of humankind and the life support system on which we all depend. This is a very stimulating response. However, 51 weeks will pass until the next opportunity arises in Stockholm to learn more and to inform each other about what has been achieved since last time. Together with other documentation from the World Water Week, On the Water Front provides an opportunity to recapture key features from the World Water Week throughout the year.

On the Water Front is a new publication. This volume contains a selection of articles that cover important scientific and policy issues. They are written by colleagues who made presentations at workshops, seminars and plenary sessions during the World Water Week, August 16 – 22, 2009. The full programme for World Water Week and documents from the deliberations in 2009 as well as from other years can be accessed and downloaded from www.siwi.org and www.worldwaterweek.org. With the analytical character and with appropriate illustrations and references, the texts in this publication are intended to play a role in the thinking and work of colleagues from research, governments, international, national and local organisations.

One important feature in the texts is an ambition to combine and merge new thinking, concepts and experiences with practice, in policy and in the field. The texts aim to illuminate the need for scientific findings in policy and in practice and vice versa; the need to formulate scientific enquiries and carry out scientific studies, which are relevant for policy and human endeavors.

The Scientific Programme Committee plays a central role in the identification of the authors together with staff at SIWI. The texts submitted have been peer reviewed by the members of the SPC and other colleagues who are familiar with the topics discussed in the articles in line with the procedures applied in Scientific Journals. The texts mirror the range of presentations that are made at the WWW.

Apart from highly positive responses and contributions from distinguished authors and the work by esteemed colleagues in SPC, many other people have contributed to this publication, in particular, Michael Moore, publication manager (until July 2010, thereafter project officer at the National Water Commission, Canberra, Australia), Britt-Louise Andersson, design manager, Johanna Sjödin, assistant publication manager. Thank you very much!

Executive Director

Director World Water Week

Chair, Scientific Programme Commitee

Members of the Scientific Programme Committee (2009/2010):

- *Prof. Jan Lundqvist*, Stockholm International Water Institute (Chair)
- *Dr. Husamuddin Ahmadzai*, Swedish Environmental Protection Agency
- *Prof. Lotta Andersson*, Swedish Meteorological and Hydrological Institute
- *Prof. Paul P. Appasamy*, Karunya University, India
- *Dr. Akiça Bahri*, African Development Bank
- *Dr. Thomas Chiramba*, UNEP (co-opted member)
- *Prof. Mohamed Dahab*, Water Environment Federation and Nebraska University, USA
- *Prof. Malin Falkenmark*, Stockholm International Water Institute
- *Dr. Line Gordon*, Stockholm Resilience Centre, Sweden
- *Mr. Jack Moss*, World Business Council for Sustainable Development and AquaFed
- *Prof. Peter Rogers*, Harvard University, USA
- *Prof. Hubert Savenije*, Delft University of Technology, The Netherlands
- *Prof. Thor Axel Stenström*, Swedish Institute for Infectious Disease Control and World Health Organization
- *Prof. Xiaoliu Yang*, Peking University, China
- *Mr. Martin Walshe*, Department for International Development, UK
- *Mr. Anders Berntell*, Stockholm International Water Institute
- *Ms. Katarina Andrzejewska*, Stockholm International Water Institute (Secretary)
- *Mr. Michael Moore*, Stockholm International Water Institute (co-opted member)

Photo: Anja Christina Beier

Ms. Gunilla Carlsson
Minister of International Development Cooperation, Ministry for Foreign Affairs, Sweden

Foreword

World Water Week in Stockholm provides a unique platform and focal point for practitioners, researchers and policy-makers in the water and development sectors. As Minister for International Development Cooperation, I believe three issues are crucial.

First, equitable access to sustainable water services and sanitation is fundamental to reducing poverty and promoting economic growth and social development at local and national level. The link between water management, growth and poverty reduction is obvious. By increasing access to water and sanitation we can change the lives and health of poor women, men and children for the better.

Second, adaptation to climate change is a challenge for every country and of particular importance to developing countries as they are more dependent on and exposed to the vagaries of the weather. The hydrological cycle is an integral part of the climate system. Adaptation therefore naturally evolves around water. By integrating competing demands for water within and between sectors, the burdens and benefits can be shared. It is crucial to strengthen the capacity of people and institutions to deal with this challenge.

Third, water is inextricably interlinked with the promotion of gender equality and the empowerment of women and girls. To the majority of women and their families, better health and better life opportunities depend on safe and reliable water supplies. Women and girls often have the main responsibility for water provision and management at household level, for both consumption and production. Therefore they play a crucial role in all water activities and investments. We also know that a lack of access to water, toilets and adequate sanitation contributes to high educational drop-out rates for girls.

The availability of water resources varies over both time and space, and has always done so. The problem we now see with climate change is that these variations are becoming less predictable. The challenges and problems associated with water stand out as an area in which coherence and cooperation are needed: between different sectors, such as energy, agriculture and health, as well as between different nations sharing water boundaries. However, water issues do not just concern rivers or river basins that require political and technical solutions between bordering nations; they also affect coastal areas and oceans where there are no bordering nations. Dumping sewage from ships into the seas requires binding international anti-dumping laws. The pollution or depletion of our seas, requires solutions on land.

It is private individuals and households, villages and local authorities that have to deal with and adapt to the changes. Adaptation measures are therefore best implemented by those who are closest to the effects of climate change, by people at the local level. I believe that local authorities and organisations know their community best and should therefore be given primary responsibility both for identifying groups at risk and for supporting them in their efforts to build safe communities.

Sustainable development is dependent on long-term commitment and the building of trust between stakeholders. This can only be achieved through the full participation of all stakeholders at all levels. Poor people in rural areas have to be able to voice their views through democratic channels so as to achieve equitable and efficient development. Good governance, human rights and gender equality are fundamental principles for water and climate, as well as for society as a whole.

The common denominators are joint solutions and global agreements. We can only achieve success if we recognise our interdependency and agree to come together for our solutions. ■

Photo: Mats Lannerstad

Mr. Jan Eliasson
Chair, WaterAid Sweden
www.wateraid.se

Water as the catalyst for peace, security and prosperity

Precious water resources sustain life and are fundamental in processes towards peace and human progress. Conversely, poor stewardship leads to human suffering and conflict. In an era when climate change threatens to dry up entire regions, the social and economic stakes related to water are painfully clear. The lack of access to water causes millions of premature deaths, human misery and lost opportunities. It is a dire and unacceptable reality. The beauty of the vital task to solve the world's water and sanitation problems is that it is entirely doable. Individual as well as joint action to deal with water scarcity is necessary. It is essential to better understand how political decisions can promote, but also prevent, peace and security. Water justice is intimately linked to peace, development and human rights. Ignorance and unfounded pessimism are real problems. People from all walks of life need to react and to choose the path that will lead to mutual gain, peace, security and prosperity.
Key words: Political will, water justice, human rights, peace and development, enlightened self interest, win-win solutions, new media, early action.

Water is the lifeblood

Over the years in various roles, I have found many basic truths in regard to human well being and the prosperity – or lack of prosperity – in nations, regions and communities. A number of things seem consistently to be key factors from one region or situation to another.

Throughout all of this, one element is always present: water. We cannot deny, and we must not ignore, the simple fact that water is the lifeblood of human beings and societies. No other resource is as precious, and no other natural asset is as fundamental in our work to relieve suffering, improve living conditions, sustain public health, and provide economic opportunity for those in need.

This, of course, is common knowledge to those of us who have worked in these fields. We all know it because we have seen it. Even so, there is another dimension to water that may not be as well understood.

In my work with the United Nations, I was frequently involved in matters of strife between and within nations. I was often struck by the central role of water in serving as a catalyst for cooperation or conflict. I witnessed this phenomenon from many perspectives: as Sweden's ambassador to the UN, as president of the UN General Assembly, and – most poignantly – as the UN special envoy for the conflict in Darfur.

Now, in my role as chair of the recently formed WaterAid Sweden, I am gaining new insights into the role of water in conflict or peace. Our mission for WaterAid focuses on resource mobilisation and advocacy. We aim to make things happen by building cooperation among diverse interests and parties. So it is from this new perspective that I offer these observations.

Together

It is clear to me, and many others, that we have to establish a common understanding that we must all work together. This may seem obvious in some quarters, but it really does need emphasising. The word together is crucial here because it encompasses so many different groups, organisations and interests – not just a handful of prominent names in the field.

Nations, districts, regions, cities and small towns and villages – all of them have important stakes in water and sanitation for their people and their economies. Many of them have a special need to work together because they, in fact, share resources across transboundary water basins.

Then, of course, there are the many sectors involved in the water or sanitation issues and their related problems. These include actors from the NGO, academic, industrial, and civil society sectors as well as the United Nations. They all have to work together, and in concert with governmental organisations, to get things done.

This really demands some new thinking if we wish to be truly effective in addressing the world's urgent water and sanitation problems.

Crossing boundaries

We tend to work vertically in our professional lives and become specialists in our own specific areas of expertise. Generally, most of us do not tend to cross over into other areas that might be related in some ways to our work. Yet, we must learn to do just that – collaborate with other sectors, other experts, other government agencies – if we want to solve problems in the real world.

The challenges we face have many dimensions that are social, political, economic and scientific. To handle the big global issues such as climate change – which is water change – we need a new international "division of labour" that fosters cross-sector, cross-agency, and transnational collaboration. The problems are all interrelated, and the solutions demand cooperation.

One of the reasons for hopelessness and powerlessness in the world is that people, especially the disadvantaged, are overwhelmed by the size of the problems. That is why we must realise that there can be no real progress unless we combine forces and move against the major challenges.

There are important tasks now before us. They are urgent, and in the case of water, truly concrete in character. We know the causes and we understand what must be done to make sure that people have the clean water and sanitation they need to live healthy productive lives. We now have to answer the question 'how?'

Political will

It should also be recognised that many of the problems are in our minds and in the inertia of social and political systems. This is a key point: solving the world's water and sanitation problems is entirely doable. We have the resources and knowledge to meet the challenge. However, we must not allow ourselves or the world to fall into the dual traps of pessimism that might prevent us from tackling and solving these very solvable problems. What we need most right now is the political will to get the job done.

We need to build political will because the problems of water and sanitation are enmeshed with the volatile issues of peace, human rights, and development. I have seen it firsthand.

On a recent mediation mission to Darfur, I was flying over the Northern region in a helicopter with my co-negotiator when I saw something that I never thought I would witness with my own eyes. Through the wind and dust at ground level below us, I could see the sand overtaking and burying the grasslands. I was literally witnessing the process of desertification – climate change in action right there below us.

Our Canadian pilots told us that in the two years that they had been flying that route, they figured that the sand had gained eight to ten kilometres on the grass.

Because of that creeping desertification, scarcity of water was becoming a key factor in an extremely inflammable conflict. On the ground in this mountainous area of Northern Darfur, the implications on human lives were stark and disturbing. The region is marked by abject poverty and nearly total isolation due to the violence and fighting. Aid agencies simply could not reach large parts of the area.

In one desolate town, I saw a market with no real food available other than a few onions. There was not even any local fruit. The schools had no books. The children had gray skin.

The sound I remember most from this visit was that of a solitary woman chanting a single word over and over. I asked what the word meant. The answer: "Water, water, water".

There were two wells in the region, but both were worthless to the people. One had been poisoned by the militias and the other had simply dried up. To get what little water that might be available, the women and girls of the town had to walk ten kilometres over the desert in temperatures exceeding 45° C, only to return with water that was dirty and polluted.

The toll of lack of water or poor quality water

Thus, the children of the region were routinely dying of dysentery, diarrhoea or dehydration, just like 4000 children around the world every day. It was a horrific situation where the convergence of conflict and climate change was wreaking havoc on people and a way of life. Water – or rather the lack of water – was the primary medium for this devastation.

I had seen other such effects years earlier when I had accompanied Swedish Prime Minister Olof Palme on a UN peace mediation mission for the Iraq–Iran war.

After the war, the leadership of Iraq faced ethnic uprisings across the marshlands in the country's southern tier. To deal with the uprisings, the government set about drying up the marshlands to force the rebellious population to leave their ancestral homelands. Thus, a unique 5000 year old culture and way of life based on water simply disappeared from the world.

At the other side of the country, transboundary water issues took on critical importance across the Tigris and Euphrates River Basins. As a downstream riparian on those rivers, Iraq (and also Syria) openly worried about the impacts it would suffer from the dams planned at upriver locations outside the nation's boundaries. In a region not far from Iraq, we can currently witness the bitterness of Palestinians who have complained about the lack of direct access to water in their lands. We also hear their legitimate concerns that the water consumption patterns are so glaringly different between Israel and Palestine.

Water justice

All of these situations raise the issue of "water justice". We need to understand how political decisions can have profound impact on people, cultures and nations through the water they need and on which they depend for health and security. Ultimately, how we think about water justice can have direct implications on peace and conflict.

Those considerations should encourage us to strive always for fair solutions that provide real benefits and advantages for all stakeholders. When it comes to negotiating over water and sanitation, creating a "win–win" situation is more than just an ideal answer; it is the only way to achieve lasting water justice and progress for society and humans.

We know that across the world, humanitarian and political issues can make water a catalyst for peace or conflict. In the age of climate change these issues will be ever more at the forefront of human challenges. We also know that prosperity and economic opportunity are often issues, as well.

When I was working in New York as UN Ambassador, I attended a dinner where I sat next to an investment banker. Though I did not have much to invest myself, I politely asked him what he was investing in at the time. His answer: lake districts in British Columbia because California is drying up. Water has become both an economic issue and commodity in the age of climate change.

Even so, those of us who work in this sector truly have our work cut out for us in communicating the urgency and relevance of the issues we face. We need to find ways to break through to the many audiences in prosperous countries as well as in other parts of the world who simply do not understand or who overlook the gravity of the situation.

A glass of water – a dream for 800 million

I was in Washington, DC, recently, addressing an audience about the Millennium Development Goals, commonly known as the "MDGs". Not surprisingly, a majority of people in the room did not know what they are. To help them understand, I just held up a glass of water and said "this is a luxury, a dream for more than 800 million people in the world."

My simple comment was broadcast nationwide on C-Span, the American public affairs cable television channel. As a result, I got more direct responses to that little demonstration than anything I had done before or have done since. Americans from all walks of life emailed me with their thoughts, from nurses in Arkansas to chemical engineers in Iowa.

The lesson for us is that we need to be concrete and clear if we are to achieve true public awareness of the situation. It is the only way that we can build the necessary political will throughout the world.

Be aware of sanitisation of words

One of our first orders of business is to take away the orphan image of sanitation in relation to clean water. Even the word "sanitation" seems sanitised. Let us be direct: the issue is all about toilets. A global queue of 2.5 million people needs them – for their own sake and to make the world a better place for all.

We need to be clear and concrete about what this means in human terms. Because their communities do not have access to toilets, 28% of the children who die around the world are currently dying from diarrhoea, dysentery and dehydration caused by filthy water teeming with pathogens. This horrific toll is easily as big as that of tuberculosis, malaria and AIDS combined. Most horrific of all is the knowledge that it is entirely preventable.

Beyond communicating the urgency of the matter, we must also lead the world to understand the interrelationship between humanitarian needs and other issues.

Peace, sustainability and human rights

When I was president of the United Nations General Assembly, we worked to establish the connection between peace, economic development and human rights. We developed a simple, easily understood way of expressing that connection.

- There is no peace without development.
- There is no development without peace.
- There is no lasting peace or sustainable development without respect for human rights.

All three are related – development, peace and human rights. They are truly the pillars of prosperity and a life of dignity that every human

Photo: Håkan Tropp, SIWI

being deserves. If we fail to combine our efforts and strengths on all three we will not have stable progress where it is most needed in the world.

It is no surprise that water is a fundamental dynamic in each of these pillars. Indeed, the problems of meeting the MDGs in water and sanitation are also affecting our abilities to achieve the MDGs for reducing extreme poverty.

Consider the many facets of gender equality across parts of the developing world. In sub-Sahara Africa, for example, girls and women spend 15–20% of their time looking for water. The girls are not going to school because they do not have the time, and because there are no toilets for them in the schools. The women have less time for tending to their families or productive work and also suffer for lack of toilets and clean conditions. There is little if any progress in education, health, social conditions, or economic opportunity. Water is one of the common denominators.

Ultimately it all leads to the major questions of human rights, justice, and peace among the peoples and nations of our world. As we consider those questions, we must take into account the tremendous pressures converging on the planet's resources, water being the most prominent.

Choosing the road

Indeed, that is why we are convening in Stockholm at the World Water Week each year. We come together to consider what population growth, urbanisation and climate change will do to the world's precious water resources. More importantly, we ponder how humanity will react to these pressures.

How will we react? I believe that we have a choice between two paths.

One of those paths is the road to conflict. It will lead us to a never-ending global competition for resources, perhaps even open war, where the powerful nations continue extracting and consuming far too much while the weaker nations suffer deprivation and decline. Along this road, we may see more horrors such as the poisoned wells of Darfur and water deployed as a weapon to make people flee their ancestral homes. This is truly a nightmare path.

Then, of course, there is the other path open to us: the road to co-operation. On this path, we will combat water scarcity through collaboration and with the aim of mutual gain. It will lead us to develop "win–win" solutions to our water and sanitation challenges based on our interdependence and the understanding that water is the world's common resource, which requires common stewardship.

On this road, our enlightened self interest will motivate us to find new and innovative ways to preserve that resource and make sure that our partners have access to the water supplies and sanitation they need. Along the way we will confront climate change and shortages together, thus avoiding conflict and fostering peace and prosperity.

Smart policies and ethical choices

Obviously, one hopes that we will take the road to cooperation. But such idealism should not blind us to the temptations that could lead some to choose the road to conflict, even inadvertently. With looming shortages and climate change, those temptations could get even stronger.

We need to be both smart and ethical in our choices. In the realm of ethics, the issue of water and human rights has now taken centre stage.

To many people, there is no question that water should be considered a basic human right. But one aspect compounds the discussion: human rights are free. In a truly free society, there is no financial cost to exercise freedom of speech, religion, or right to life.

Should those same criteria apply to water? Do the present challenges call on us to think differently about water in order to conserve our resources and prevent waste? Does prudence require us to put a price on water to encourage preservation?

While we ponder those questions, we also need to consider the inequity between rich countries where water fees are a tiny fraction of our budget and the poor parts of the world where people often pay dearly, even in absolute terms, to get just enough water to eke out a bare existence. This question puts us at the intersection where the forces of the free market meet the ethics of water justice.

Water and human rights

Ultimately, no rational discussion can shy away from the fact that there is a direct link between water and human rights. That link is well established in the canon of international declarations.

In the Declaration of Human Rights of December 1948, Article 1 states simply that "All human beings are born free and equal in dignity and rights", and Article 3 states even more simply that everyone has the right to life. Those are clear and unambiguous statements with direct implications for access to clean water and sanitation. Yet, in the time it took to read them here, nearly 300 children around the world died from water-related illness.

Article 25 makes the relationship even more concrete by stating that everyone has the right to a standard of living adequate for the health and well-being of himself and his family. There can be no doubt that water is essential to this right.

At the Vienna conference of 1993, economic and social rights were put on a par with political and civic rights. The message here is that there is a direct connection between basic human rights and the more nuanced political and economic rights. Water and sanitation are relevant across the entire spectrum.

So how do we now move forward? What we can do, apart from adopting a solid analysis of the situation?

I believe that our first task is to encourage practical innovations like those of Dr. Bindeshwar Pathak, the 2009 Stockholm Water Prize laureate. Dr. Pathak has shown the world how to go about solving an enormous problem with a solution matched to the culture and customs of his nation. We would do well to follow his example with similar solutions attuned to the needs of the people they are designed to help.

Potential of new media

We should also take seriously the role of information, communication and advocacy. In a media-oriented world we need to use all of the resources at hand to engage people around the world, especially the younger generation who intuitively grasp the power and potential of the new media. We need to gather government and civil society around the issues through the new media as well. This will help us build a global framework for action.

Next, we must give water and sanitation a higher priority on the global agenda. With all respect to my friends in Africa and Asia, these problems must first rise on the local agendas in the places where the problems are acute. We must truly think globally but act locally.

That, of course, places more responsibility on the donor community to direct aid toward these places where the problems are most serious. In an age of finite resources, that requires us to give water and sanitation a higher percentage of our overall development budgets. Japan is currently leading the way here, with 14% of its overall aid budget directed toward water and sanitation. My own country should, in my view, double its percentage from 3 to 6%.

How to accomplish all this?

…cuts in our comfort zone

To accomplish all this, we may have to move out from our own comfort zones and sometimes act out of character. We can no longer afford to wait politely while the world bides its time getting to these problems. The urgency of the situation requires us to speed things up, raise our voices and, if necessary, become harsher in our calls for action.

…early action

We also need to change our traditional frame of reference. Presently, the world is still analysing the situation and thinking about what should be done. I now believe that we have all the information we need. We now have to move from fact-finding and early warning … to fact facing and early action. Simply put; the time for talk is over. We need to face the facts and act … right now.

…and leadership

Lastly, we need to exercise leadership and demand leadership. It is time for us to introduce an era of responsibility in our work on water and sanitation. The means we need to think of the world's water as a resource that belongs to everyone, a concept that we could call hydrosolidarity.

It's now time to unite around the cause of water as an essential requirement of life and human dignity. ■

Dr. Bindeshwar Pathak
Founder, Sulabh Sanitation and Social Reform Movement and 2009 Stockholm Water Prize Laureate
sulabhinfo@gmail.com

Sustainable toilet technologies bring dignity to women and reduce disease risks

In India, the sanitation scenario, till the late sixties was dismal. In rural areas no house had a toilet. In cities there were no community toilets and bucket toilets were cleaned by 'human scavengers' or 'untouchables'. In 1970, I decided to start a silent revolution for the removal of untouchability through their liberation. I invented, innovated and developed two technologies: one for individual houses – Sulabh Shauchalaya – and the other for public places. The biogas digester connected to a public toilet recycles human excreta to biogas which can be put to various uses. The effluent discharged is treated through Sulabh Effluent Treatment technology by which it becomes colourless, odourless and pathogen-free and can be discharged into rivers/water bodies without polluting them. These on-site, sustainable technologies help to reduce global warming, economise water-use and produce bio-fertiliser. The Millennium Development Goal on sanitation can be achieved by use of these technologies.

Keywords: toilets, human scavengers, untouchability, on-site technologies, liberation

Background

In 1970, I started the Sulabh Sanitation and Social Reform Movement to solve three basic problems that India was facing – defecation in the open, manual cleaning of bucket toilets by people called human scavengers and public places without toilet or urinal facilities.

Lack of safe water and facilities for the disposal of human excreta are two key factors behind the huge burden of infectious diseases like diarrhoea, dysentery, cholera, typhoid, hepatitis and worm-infections, particularly in the developing countries.

In earlier civilizations, like the Greek, Roman and Indus, toilets, baths and other facilities were provided; but with the advent of new civilizations everybody around the world started going outside and defecating in the open. By the 20th century, Europe, America and Australia had solved the problem of sanitation through the provision of septic tanks and sewerage systems. Because these technologies were not affordable in terms of both construction and maintenance costs, and they required enormous quantities of water to work properly, the sanitation problem remained in Asia, Africa and Latin America. In these continents, 2.6 billion people do not have access to safe and hygienic toilets.

In India, the sanitation scenario, until the late 1960s, was dismal and in rural areas almost no house had a toilet. Everybody in the village used to defecate in the open. Given the lack of toilets, women suffered the most; they had to defecate before sunrise or after sunset. Sometimes they faced criminal assaults or suffered snake bites while defecating in the evenings. Girls generally did not go to school as no schools in the rural areas had toilets. In the villages, many children used to die because of diarrhoea and dehydration. My own sister's son died of diarrhoea.

In urban areas, only few towns had sewerage system facilities. Fifteen per cent of the urban population used septic tanks. A large number used to defecate in parks, lanes and on both sides of the railway tracks. The remainder of the population used bucket toilets cleaned by human scavengers who carried human excreta as head-loads.

If scavengers had not cleaned the bucket toilets, there would have been epidemics of cholera, diarrhoea, dysentery, etc. and people


Photo: Sulabh International Social Service Organisation

Figure 1. A woman scavenger cleaning a bucket toilet manually, a sub-human practice

would have died in large numbers. But society kept them at the lowest ladder of the social structure of the caste system and gave them the stigma of being "untouchable". They were ostracised and had to live on the outskirts of the city/town lest they touched anyone by mistake. Women would not give them food hand to hand, but dropped it into their palms. If they were thirsty, water was poured from a safe distance into their cupped palms. Even the traders would accept their money only after cleaning the coins. There was no question of their going to school, entering temples or their children playing with children of other communities. They played amongst themselves or with pigs.

There are two types of prisons; one is the physical prison run by the government, from which a prisoner can be released after days, months or years, except for heinous crimes. However, in India, before independence, there was a social prison without walls called the caste system, where a person born an untouchable would die as an untouchable.

Another critical problem was that there were no community toilets and urinal facilities in public places near railway stations, bus stands, marketplaces and religious and tourist places. It was very difficult for the people to manage when they felt the call of nature; they had to go to a nearby pond or bush or any dirty place just to defecate. Because of this lack of public conveniences, people, especially foreigners, were discouraged from visiting India.

In the days when you could not count on a public toilet facility, an English woman was planning a trip to India. She registered to stay in a small guesthouse owned by the local schoolmaster. She was concerned as to whether the guesthouse had a WC (water closet). She wrote to the schoolmaster inquiring about the availability of a WC. The schoolmaster, not being fluent in English, asked the local priest if he knew the meaning of WC. Together they pondered possible meanings of the letters and concluded that the lady wanted to know if there was a "Wayside Chapel" near the house. A bathroom never entered their minds. So the schoolmaster wrote the following reply:

Dear Madam,
I take great pleasure in informing you that the WC is located 9 miles from the house. It is located in the middle of a grove of pine trees, surrounded by lovely grounds. It is capable of holding 229 people and is open on Sundays and Thursdays. As there are many people expected in the summer months, I suggest you arrive early. There is, however, plenty of standing room. This is an unfortunate situation especially if you are in the habit of going regularly. It may be of some interest to you that my daughter was married in the WC, since she met her husband there.

It was a wonderful event. There were 10 people in every seat. It was wonderful to see the expressions on their faces. My wife, sadly, has been ill and unable to go recently. It has been almost a year since she went last, which pains her greatly. You will be pleased to know that many people bring their lunch and make a day of it.

Others prefer to wait until the last minute and arrive just in time! I would recommend that your ladyship plan to go on a Thursday, as there is an organ accompaniment. The acoustics are excellent and even the most delicate sounds can be heard everywhere. The newest addition is a bell which rings every time a person enters. We are holding a bazaar to provide plush seats for all since many feel it is long needed. I look forward to escorting you there myself and seating you in a place where you can be seen by all.
With deepest regards,
The Schoolmaster.

No wonder the woman never visited India!!!

Another problem was that Indians were not used to paying for the use of toilets. The British Government passed an Act in 1878 to maintain public toilets on a "pay and use" basis, but it did not work. Toilets built by local bodies were not maintained properly, hence, were considered as a veritable hell on earth. Nobody liked to go inside the public toilets and tried to avoid even passing by those areas because of the terrible stink. Therefore, the absence of public toilets in public places was a great problem in India.

The human scavengers were treated as untouchables and they were hated, humiliated and insulted by the people for whom they used to work. In the Indian society, before the Independence of India in 1947, a person born into the "untouchable" caste died as an "untouchable". There was no chance of any change in the caste structure.

Mahatma Gandhi was the first person whose attention was drawn towards the plight of scavengers. He wanted scavengers to be released from their sub-human occupation of manually cleaning up human excreta and wished to restore their human rights and dignity, to bring them on a par with others in society.

I wanted to be a teacher of sociology at a university, but somehow I could not become one. I did sundry jobs and finally I joined the Gandhi Birth Centenary Celebration Committee in Bihar in 1968. There I got the idea of fulfilling the dream of Mahatma Gandhi. It was difficult for me to solve the above sanitation problem which India was facing as I belonged to an orthodox Brahmin family. Once I touched an untouchable lady named Dome. My grandmother made me swallow cow dung, cow urine and Ganges water to purify myself.

I decided I would solve the problem some way or another; unlike so many others in the world who are experts in collection of information, but are unable to deal with its dangers. So to prepare myself to shed my own prejudices against untouchables, I went and lived in a colony of scavengers for three months. There I encountered two incidents.

In sociology it was taught that if one wanted to work for a community one must build a rapport with the people of that community so that one can come to know about them. It was this lesson which prompted me to live in a scavengers' colony with the help of a scavenger. I lived in the colony of scavengers for three months and came to know about their origin, culture, values, mores, etc. When I came to live in the scavengers' colony named after Mr. Jagjivan Ram, a freedom fighter and former Deputy Prime Minister of India, I was not quite sure whether to continue in the profession, as my father was very upset because Brahmins and toilets did not go together. At that time, I was also married and my father-in-law was extremely angry and berated me in a language which I am loathe to repeat. The people of the Brahmin community also ridiculed and humiliated me occasionally. The situation was totally unfavourable and nobody appreciated my initiative to change the lives of the untouchable scavengers.

One particular morning while living in Bettiah in the scavengers' colony, I noticed that a newly married girl was being forced by her in-laws' family to clean the bucket toilets and she was crying bitterly as she was most unwilling to do so. On hearing her cries, I went and intervened, trying to persuade the family members not to force her, if she was unwilling to go and clean toilets. They heard me, but did not agree, counter-questioning me about what she would do from the morrow if she did not do the work of scavenging and earn some money. Even if she sold vegetables, who would buy them from her, she being an untouchable? Finally, despite my protests, they sent her to clean the bucket toilets.

After a few days, as I was going to the market with a colleague of mine from that colony, we saw a bull attacking a boy of 10–12 years who was wearing a red shirt. When people rushed to save him, somebody from the back shouted that he belonged to the "untouchable" scavengers' colony, whereupon everybody left him. We took him to the hospital, but the boy died. After this incident, I took a vow to fulfil one of the dreams of Mahatma Gandhi – to get the scavengers released from their sub-human and health hazardous occupation of manually cleaning and carrying human excreta.

While living in the colony I studied carefully the books written by Mr. Rajendra Lal Das and the book "Excreta Disposal for Rural Areas and Small Communities" published by the World Health Organization in 1958. The following sentence from the WHO book left a deep mark in my memory:

"Suffice it to say here that out of the heterogeneous mass of latrine designs produced all over the world, the sanitary pit privy emerges as the most practical and universally applicable type."

This book was about disposal of human waste in rural areas, but the problem of scavenging was mainly an urban one because most scavengers used to work in urban areas. Here I applied my mind and thought that if the soil conditions in rural and urban areas were the same, then there was no reason why a technology recommended for rural areas could not be applicable to urban areas. In my opinion, the application of the mind is more important than knowledge. Knowledge can be borrowed, but its application has to be your own.

Ideas have changed the world! It may be the case of the idea of James Watt who developed the concept of the steam engine, on which principle the train system was developed, or Newton's theory of gravity which he conceived when he saw an apple falling from the tree or Alexander Fleming's theory about penicillin. Ideas play a very important role in the solution of problems.

Purpose/aim

Being a follower of Mahatma Gandhi, I decided to start a silent revolution of non-violence and peace for the removal of "untouchability" through the liberation of human scavengers with the help of a toilet technology whereby the services of scavengers would not be required. To get them released from this occupation, I had to find out technologies which were appropriate, affordable, indigenous and culturally acceptable.

By the end of about two years, the sludge has been digested and converted to manure, a good soil conditioner. After two years or so, when the second pit is full, the first pit can be emptied of its human waste which has become manure, containing nitrogen, potassium and phosphate and which works as a bio-fertiliser to improve the yield of flowers, fruits and plants and the productivity of the field. In different geological conditions, this technology remains the same, only the building materials and period of emptying of the pits vary.

A squatting pan with a steep gradient for pour-flush and trap with a 20 mm water-seal is used in Sulabh toilets. The pan can be of ceramic, fibreglass, mosaic or cement concrete. Sulabh toilets require only between 1 and 1.5 litres to flush per use. Therefore, the Sulabh water-seal saves an enormous quantity of water. In the Sulabh system there is no chance of contamination of the drinking water supply lines, as in the case of a sewerage system, if the hand-pumps are located five metres away from the latrine pits. Open wells should be ten metres away from the same.

Photo: Sulabh International Social Service Organisation

Figure 2. Sulabh twin-pit, pour-flush, compost toilet – a simple solution to achieve the Millennium Development Goal on sanitation

The Sulabh toilets can be constructed even in areas where water table is high. The upper portion of the pits has to be kept two feet above the water table. The slab cover of the pits can be used for various household purposes like cleaning food-grain, cutting fish and vegetables, cooking or offering prayers, which is not possible in case of a septic tank. Sulabh toilets have been designed in such a way that the poorest of the poor, the middle class and even the rich can have toilet facilities, according to their financial capacity.

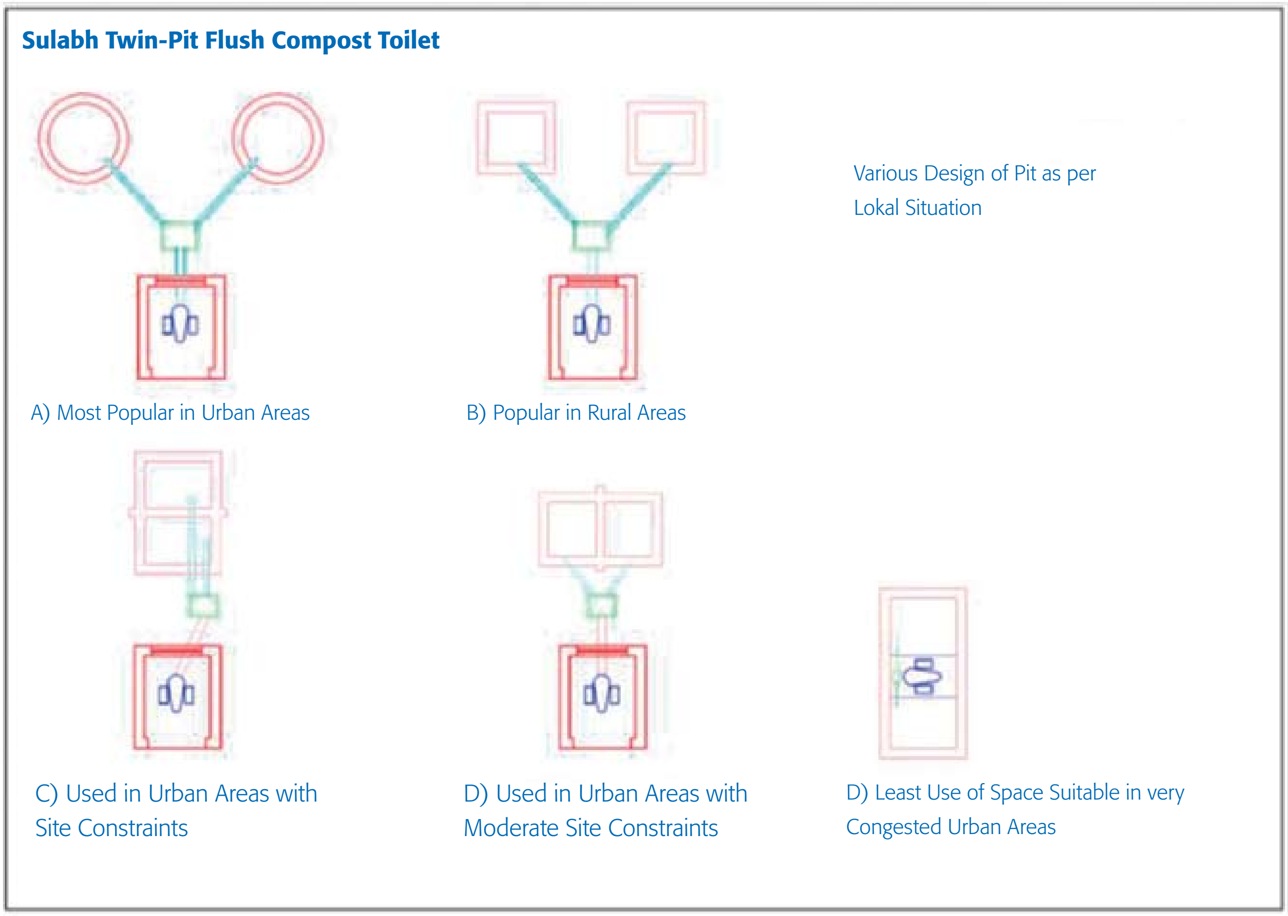
The Sulabh toilets can be constructed in a minimum space compared to other technologies of the world. The space required would be two metres in length, one metre in width, with a depth of maximum two metres. The pits may be of circular, rectangular or square in shape (Figures 3a and 3b). If space is available, the two pits of Sulabh toilets should be kept separated by a minimum distance of one metre. Because of this, at the time of cleaning the pit, no water is found at the bottom of the pit.

If there is less space, then two pits can be constructed side by side with a dividing wall of minimum 5 inches (Figure 3d). If there is a space constraint, the dividing wall may be of 10 inches and the upper portion may be of 15 inches. The pan on it can be attached to two drains (Figure 3e). Both the pits are covered with slabs. In narrow lanes, two pits can be made side by side, connected with pipes for discharge of human excreta into the pits (Figure 3c). In this way, Sulabh toilets can be constructed even in the smallest space. They can be constructed even at the door-step of a house or on the upper floor of a house. Locally available materials such as bricks, stones, logs and burnt clay rings, etc. are used for lining of the pits.

When the temperature fell to -140C in 1984 in Srinagar, the capital of Jammu and Kashmir, India, this technology worked very well, as the gases from the pits prevented the water in the water-trap from freezing, unlike the septic tank and sewerage system in which it did freeze.

We have installed more than 1.2 million individual household toilets and the Government of India has installed more than 54 million toilets based on the same technology. Thus, we have been able to improve the living conditions of the people, upgrade the environment, reduce diseases and also reduce poverty so that there are more man days for economic productivity. Because of this technology, women can now go to the toilet with dignity and in safety and girls go to school as they now have toilets. The infant mortality rate (IMR) for children under five has been reduced from 129 per 1000 live births in the 1970s to 57 per 1000 live births in 2006. Millions of "untouchable" scavengers have been released from this sub-human occupation and their human rights and dignity have been restored. The UNDP, in its Human Development Report 2003, has recommended the use of this technology by international agencies and developing countries.

In public toilets, pit latrines and septic tanks frequently get filled up; therefore, I innovated, invented and developed a technology to



Figures 3 a- e. Various designs of pits as per local situation recycle human waste. From a public toilet human excreta flows by gravity into an attached biogas digester. Before commissioning the digester, 30 to 40 kg of cow dung is initially put inside. After 30 days, biogas is produced. The biogas is channelled for lighting mantle lamps, warming oneself during the winter, cooking and also for conversion to energy for street lighting. The people in the vicinity also get the biogas which they use for cooking or lighting.

Five public toilets linked to biogas plants have been erected in Kabul, Afghanistan. All are functioning very well, even when the temperature in Kabul went down to -30°C in 2007; so this technology is suitable even for cold climates.

This technology can be used in housing estates, high-rise buildings, schools, colleges, hospitals, etc. In a septic tank, human excrement is of no use. Using Sulabh technology, methane, which comprises 65% of all the gases produced in such tanks, burns and is used for different purposes. It is not allowed to escape into the atmosphere. So this technology also helps to reduce global warming and mitigates climate change.

Earlier there was a social stigma and psychological taboo against handling human excreta. This arose because only people of the lowest economic strata were supposed to be associated with this work. Since human excrement was considered as the most hated object in society, it was difficult for any one to consider that a project related to its disposal could be financially viable. However, Sulabh made it financially viable under an arrangement whereby the cost of construction is met by the local body and the maintenance of the toilet blocks and the day-to-day expenses are met from the user fee. Sulabh does not depend on external agencies for finances and meets all its financial obligations through internal resources. Not all the toilet complexes are self-sustaining, particularly those located in slums and less devel-

Photo: Sulabh International Social Service Organisation

Figure 4. Front and side view of Sulabh Toilet Complex at Kothi compound, Rewa

Photo: Sulabh International Social Service Organisation

Figure 5. Human excreta based biogas is used for warming oneself, cooking, lighting mantle lamps and power-generation.

Figure 6. Sulabh Effluent Treatment (SET) technology

Photo: Sulabh International Social Service Organisation

oped areas. The maintenance of such toilet complexes is subsidised from the surplus income generated from toilet complexes in busy and developed areas.

Technology is important, but also important is how to deliver it to people. Simply developing the technology does not suffice. So, I developed a system of delivery of service to the beneficiaries at their door-steps. In Sulabh, ethics, morality and integrity are maintained in the delivery system. Sulabh workers go house to house, motivate and educate the beneficiaries and they have the onerous responsibility of going to local bodies to request grants on behalf of the beneficiaries to build toilets in their houses. We give them a guarantee that we will rectify any defects that develop within five years and, in that way, Sulabh has been able to gain the confidence of the people as well as the government and has gained credibility with them.

In India, there is a problem with maintenance and follow-up on work after its completion. Since we developed a system of maintenance and follow-up, the system worked successfully. While doing all these things, I had to take many unconventional decisions to relieve the scavengers and to bring them into the mainstream of society.

Two or three significant changes in this area have taken place in India. Previously, the subject of toilets was a taboo in Indian culture. Nobody talked about it while having meals, but now they talk about Sulabh while having lunch or dinner. We have been able to change the thoughts, attitudes and behaviour of the Indian people towards toilets and "untouchable" human scavengers. Secondly, the concept of "untouchability" is no longer attached to the profession of the construction and maintenance of toilets. Thirdly, in India, there are frequent communal clashes between Hindus and Muslims, but in the public toilets we have not found any tension so far amongst the users, irrespective of their religion and caste. Anybody can come and use the toilet and nobody discriminates against anyone else.

With the implementation of Sulabh on-site technologies, scavengers are liberated from their dehumanising work. They were the most oppressed and suppressed class of Indian society – humiliated and ostracised. I started vocational training programmes for them to help them develop their skills in various market-oriented trades, such as tailoring, embroidery, typing, short-hand, electrical jobs, audio-visual assembly and repair, beautician's courses, etc., to change the course of their lives. There is a sea change in the attitude and thinking of society, and now the scavengers intermingle with others in the mainstream of the society.

As education holds the key for any progress, especially for the downtrodden and oppressed, I started the Sulabh Public School, an English medium institution, in New Delhi in 1992 to prepare children from the weaker sections of society for a better life. Sixty per cent of the children attending the school come from scavenger families and

40% from other classes, so that they can inter-mingle with each other from childhood. The children share their "tiffins" with each other, which helps to break the social barriers. In Sulabh School Sanitation Clubs, teachers and students are both taught how to keep the toilets clean, which they do by taking turns.

In March 2003, a centre called Nai Disha (New Direction) was started at Alwar in the state of Rajasthan, for women who were engaged in the work of scavenging to rehabilitate them through vocational training. They were taught personal hygiene, basic literacy knowledge and were trained to make eatables, like papads, noodles, pickles, etc. The training programme is followed by rehabilitation so that they get sufficient time for their economic empowerment. The social transformation brought about can be gauged by the incredible fact that the same society that was averse touching a scavenger, today readily purchases products (even eatables) prepared by the hands of these very scavengers. They were given a stipend through banks and taught to maintain a bank account, which has also helped them to acquire self-confidence.

During the World Toilet Summit 2007, organised by Sulabh in New Delhi, the erstwhile scavengers walked the ramp with the top models of India, who displayed their handiwork. HRH the Prince of Orange of the Netherlands applauded their work, congratulated them and presented them with flowers.

For social interactions, I took the "untouchable" scavengers to the best restaurants. People laughed at me because they were unable to conceive, much less appreciate, this idea, but I wanted to show them that they could also come to these places. They were not meant only for the "elite" class of people. I took them to visit the Honourable Prime Minister of India, who gave them an audience. The Department of Economic and Social Affairs of the United Nations invited them to participate in the UN and to make a presentation on the theme of "Sanitation for Sustainable Development". Two erstwhile scavengers spoke from the podium. The women participated in a fashion show "Mission Sanitation"; they walked the ramp along with eminent Indian and American models who showcased their skills. Finally, they went to the Statue of Liberty to declare themselves free from the bondage and shackles of slavery and to tell the world that they were untouchables no more.

On their return from New York, the Honourable President of India gave them an audience and blessed them. The upper caste people who shied away even from the shadows of the "untouchable" scavengers, now sit with them and have food with them.

For doing all these things, the application of the mind is more important than knowledge. Knowledge can be borrowed, but one has to apply one's own mind to solve problems. You should have a killer's instinct, like in love and war, to solve a problem. Concentration of the mind is very important, just as a good dancer, flautist, poet and writer concentrate. In an Indian epic, "Mahabharat", the hero of the war, Arjuna, aims and pierces the eye of the rotating fish. When asked how he did it, he said he only saw the eye of the fish and nothing else. While the famous poet Samuel Taylor Coleridge was writing "Kublai Khan", somebody knocked at his door, his concentration was broken and he could not continue and complete his poem. The half-written poem is still taught in English literature.

Recently a Brahmin invited a scavenger to the marriage of his daughter, accepted a gift from her and gave her food along with her family members. This was unheard of in the social history of India, but has now happened. Now the pages of history have been turned and the scavengers have been accepted by society.

To arouse the interest of people in sanitation, I established the Sulabh International Museum of Toilets in 1992 in New Delhi. I was inspired to do so during my visit to Madam Tussaud's Museum in London. The Museum of Toilets has displayed the chronological development of sanitation over the last five thousand years. It has a unique display of Su-jok therapy by Dr. Sir Park of Korea, which shows that the call of nature can be controlled, or vice versa, by acupressure on the palm. People from more than 100 countries have visited Sulabh Centre for Sanitation and Social Change.

Eighty per cent of the diseases in the world are due to unsanitary conditions. To achieve integrated health care, I established the Sulabh International Institute of Health and Hygiene in 1994. Health centres have been set up in public toilets for preventive, curative and rehabilitative medical care of the poor and needy. Eleven thousand women in the urban slums of various states have been trained in good hygiene practices and manuals have been prepared for the same. Women volunteers have been trained to serve safe drinking water to urban slum dwellers.

Additionally, an Academy on Environmental Sanitation and Public Health was set up for planning, monitoring and implementing of projects relating to Environmental Sanitation. The focus of the Academy is on water, sanitation, health and hygiene, capacity building and training at national and international levels and for carrying out applied and fundamental research as well as consultancy in the area of environmental sanitation.

The Sulabh Encyclopaedia on Sanitation, a reference work, has given a new dimension to public health. It is a unique academic exercise, which was spread over a decade and compiled by a team of dedicated technical professionals with expertise in the area of sanitation.

Further, to make the sanitation sector more lucrative, technical and professional I have initiated the setting up of a University of Sanitation. It was realised that sanitation is a technical as well as a social problem. To overcome the problem in a heterogeneous society with respect to socio-economic and cultural aspects is more challenging. The magnitude of the problem also varies widely in different regions of the world. The University of Sanitation will help a lot to overcome the problem in different regions/societies. Thus, our vision and mission go hand in hand with the Millennium Development Goals.

Sulabh has Special Consultative Status with the Economic and Social Council (ECOSOC) of the United Nations. Sulabh's sanitation programmes have been acclaimed as outstanding innovations for improving the environment, ecology and community health, both in rural and urban areas. His Holiness, Pope John Paul II, gave me an audience in 1992 before the International St. Francis Prize for the Environment (Canticle of All Creatures) was bestowed upon me.

Conclusion and recommendations

I, together with the Sulabh technologies, their application, vision, implementation, commitment, capabilities and efficiencies, have been able to provide dignity to women – to use a toilet with privacy and safety. We have released millions of scavengers from their sub-human occupation and brought them into mainstream society by giving them education, training and empowering them on a par with others.

The technologies developed by me are suitable not only for developing countries, but also for developed ones. In household toilets of the Sulabh design, the gases produced are absorbed by the soil and they are not allowed to escape into the atmosphere. In the biogas digester, of the gases produced – methane, carbon dioxide, nitrogen, hydrogen sulphide and others – methane is easily combustible and can be burned for different uses. In this technology human excrement is recycled on-site and hence is one of the best examples of sustainable development.

The Sulabh technologies first help to reduce global warming because they help to reduce pollution of the atmosphere. Second, in both the technologies, enormous quantities of water are saved, helping "access to water for the common good". Third, in the technologies, bio-fertiliser is produced. Both technologies fulfil all the conditions of a sanitary latrine. Therefore, these technologies are universally applicable.

In brief, it can be said that the Millennium Development Goal on sanitation can be achieved by use of these technologies. Adopted with some modifications according to local conditions, and in a decentralised manner, we can solve the problem of low sanitation coverage. The Millennium Development Goal on sanitation cannot be achieved if we think in terms of sewerage and septic tank systems only.

My story can be compared with that of the seagull in the fable "Jonathan Livingston Seagull" by Richard Bach. The seagull was discouraged from flying high in the sky by his parents as his job was to fly from the shore to where the fishermen used to cut fish. He was insulted, humiliated and faced difficulties while flying high, but he finally succeeded. After he became successful, he trained other seagulls to fly high also. My story is the same. Because I belong to a Brahmin family, my father was sad and my father-in-law angry when I took up this job. In the same way as the seagull, I faced many difficulties and succeeded. We are training people in Sulabh technologies, which are patent-free, and empowering them. Already the national Government of India has replicated Sulabh Technologies in millions of rural and urban households under the total sanitation campaign. We have constructed public toilets in Bhutan and Afghanistan. We have trained professionals from 14 African countries so that they can install these technologies with some modifications in their respective countries. I suggest that the entire world, particularly the developing countries of Asia and Africa, should adopt the technologies mentioned above to solve the problem of sanitation to achieve the Millennium Development Goals.

Martin Luther King Jr. once said that even if a person's job was to sweep the road, he should sweep the road so well that all the angels in heaven should stop and say, "Here lives a wonderful sweeper!" I have tried to emulate the same in my life. ■

Ms. Catarina de Albuquerque
UN Independent Expert on the issue of human rights obligations related to access to safe drinking water and sanitation
iewater@ohchr.org

Water and sanitation as human rights

Understanding water and sanitation as human rights was central to the 2009 Stockholm Water Week theme of "Accessing Water for the Common Good". Human rights are aimed at universal access to drinking water and sanitation which is safe, affordable, physically accessible, culturally acceptable and sufficient in quantity. This paper briefly explains the mandate of the Independent Expert on the issue of human rights obligations related to access to safe drinking water and sanitation. It then turns to water and sanitation as human rights, outlining their content, their status as rights, some prevailing misconceptions and the purpose and contribution of human rights in development practice.
Keywords: Water and sanitation as human rights, legal dimension, accountability

The mandate of the Independent Expert

The mandate of Independent Expert on the issue of human rights obligations related to access to safe drinking water and sanitation was established by a resolution of the Human Rights Council in March 2008 (Human Rights Council, 2008).

The mandate consists of three main tasks:

Firstly, to develop a dialogue with Governments, the relevant United Nations bodies, the private sector, local authorities, national human rights institutions, civil society organisations and academic institutions, to identify, promote and exchange views on best practices related to access to safe drinking water and sanitation, and, in that regard, to prepare a compendium of best practices;

Secondly, to undertake a study, in cooperation with and reflecting the views of Governments and relevant United Nations bodies, and in further cooperation with the private sector, local authorities, national human rights institutions, civil society organisations and academic institutions, on the further clarification of the content of human rights obligations, including non-discrimination obligations, in relation to access to safe drinking water and sanitation;

Thirdly, to make recommendations that could help the realisation of the Millennium Development Goals, in particular of Goal 7.

Prior to the creation of the mandate, the High Commissioner for Human Rights submitted a study to the Human Rights Council in which she concluded that "it is now time to consider access to safe drinking water and sanitation as a human right, defined as the right to equal and non-discriminatory access to a sufficient amount of safe drinking water for personal and domestic uses – drinking, personal sanitation, washing of clothes, food preparation and personal and household hygiene – to sustain life and health." (OHCHR, 2007: Para. 66). This study also identified a number of areas that require further consideration, such as the normative content of human rights obligations in relation to access to sanitation, obligations in the context of private sector participation in the provision of water and sanitation and obligations in the context of disconnecting services (OHCHR, 2007: Para. 67).

The mandate of the Independent Expert was inter alia created to take this work forward. Like other experts appointed by the Human Rights Council, the Independent Expert undertakes country missions, and sends communications to Governments concerning alleged human rights violations falling within the mandate. Three missions were

Photo: Manfred Matz

undertaken last year: one to Costa Rica, another one to Egypt and a third mission to Bangladesh. For 2010, additional missions to countries are planned.

Content of water and sanitation as human rights

In the resolution establishing this mandate, States in the Human Rights Council acknowledged that they have human rights obligations related to access to safe drinking water and sanitation (Human Rights Council, 2008). In September 2009, the Human Rights Council reaffirmed that these obligations exist, focusing specifically on sanitation (Human Rights Council, 2009). Regardless of whether one recognises sanitation and water as distinct human rights, human rights obligations related to access to safe drinking water and sanitation are undeniable because they are so closely linked to other well-recognised human rights including the rights to health, housing and life.

Their normative content can broadly be described under the categories of availability, quality, accessibility, affordability, and acceptability (CESCR, 2003; de Albuquerque, 2009a).

Availability: Water supply for each person must be sufficient for personal and domestic uses. The human right to water is limited to these uses and does not cover water for productive uses, etc. Likewise, a sufficient number of sanitation facilities has to be available.

Quality: Water has to be safe for consumption and other uses. It has to be of such quality that it does not pose a threat to human health. Sanitation facilities must be hygienically and technically safe to use. To ensure hygiene, access to water for cleansing and hand washing is essential.

Physical Accessibility: Water and sanitation services must be accessible to everyone in the household or its vicinity on a continuous basis. Physical security must not be threatened by accessing facilities.

Affordability: Services also have to be affordable. Realising access to sanitation and water must not compromise the ability to pay for other essential needs guaranteed by other human rights such as food, housing and health care.

Acceptability: Sanitation facilities, in particular, have to be culturally acceptable. This will often require separate male and female facilities. Also, facilities have to be constructed in a way that ensures privacy and dignity.

Breaking down the rights in this manner helps to ensure that access is factually guaranteed. The existence of facilities is not sufficient, for instance, when elderly people or people with disabilities cannot access them. Physical access alone is not sufficient when people cannot afford expensive water and sanitation services. The existence of toilets is not sufficient when women do not use them because they are not sex-separated or do not guarantee their privacy.

States are obliged to respect, protect and fulfil these rights. The duty to respect means that the State must refrain from violating the rights. The duty to protect requires States to ensure that third parties do not interfere with the enjoyment of the rights. The duty to fulfil includes an obligation to facilitate, or taking positive measures to realise the rights, an obligation to promote the rights through awareness-raising and other measures, and an obligation to provide access when individuals are unable to realise it on their own. Water and sanitation are frequently considered within the ambit of economic, social and cultural rights, which must be realised progressively, to the maximum of available resources of the State. This means that not all components of the rights have to immediately realised, but that the State must take concrete and deliberate steps towards the full realisation of the rights (CESCR, 1990).

One crucial element is the adoption of a national action plan for sanitation and drinking water, with time-bound targets and a vision for universal access to safe and affordable drinking water and sanitation. Implementing such a plan will require a mix of legislative and policy measures, as well as built-in monitoring mechanisms to ensure continual progress. The steps required to realise the rights to water and sanitation will necessarily be different from country to country – indeed, the measures must be adapted to the local context in order to meet the needs of the people concerned. Human rights do not offer a one size fits all solution but instead a broad legal framework to guide policy and legislative action. The parameters offered by this framework assist in monitoring whether States are living up to their human rights obligations by taking the measures they have opted for.

Water and sanitation as human rights

While it should be undisputed that there are clear human rights obligations related to water and sanitation, the question remains as to whether water and sanitation are only encompassed by other human rights, or can be perceived as distinct human rights.

The so-called International Bill of Rights – consisting of the Universal Declaration on Human Rights and the first two UN human rights Covenants, on economic, social and cultural rights and on civil and political rights, respectively – does not include any explicit reference to the rights to water or to sanitation. At the time these treaties were drafted, the magnitude of the problem of lack of access to water and sanitation was not well known, understood or prioritised.

In recent years, the Committee on Economic, Social and Cultural Rights, which monitors the implementation of the Covenant on Economic, Social and Cultural Rights, has regularly taken up the issue of lack of access to water. In 2002, it adopted its General Comment N° 15 on The Right to Water (CESCR, 2003). General Comments are considered authoritative interpretations of international law, and this General Comment was particularly important to address the Covenant's (apparent) silence on the issue of water. According to the Committee, the right to water is consecrated in Art. 11 of the Social Covenant "implicitly", since that provision uses an open formulation as it guarantees the "right of everyone to an adequate standard of living for himself and his family, including adequate food, clothing and housing, and to the continuous improvement of living conditions". The preposition "including" means that the catalogue of rights contained in Art. 11 was not intended to be exhaustive. To justify this assertion, the Committee remarks that "the right to water clearly falls within the category of guarantees essential for securing an adequate standard of living, particularly since it is one of the most fundamental conditions for survival."

Because less attention has been devoted to sanitation than to water it is important to highlight the significance of sanitation for the realisation of other human rights, such as the rights to health, to education and to life. In the 2009 report to the Human Rights Council the human rights obligations related to access to sanitation are emphasised and explained (de Albuquerque, 2009a). The report defines sanitation in human rights terms as "a system for the collection, transport, treatment and disposal or reuse of human excreta and associated hygiene. States must ensure without discrimination that everyone has physical and economic access to sanitation, in all spheres of life, which is safe, hygienic, secure, socially and culturally acceptable, provides privacy and ensures dignity." (de Albuquerque, 2009a: Para. 63).

The report reviews how sanitation is linked to many other human rights but concludes that it is not sufficient to only examine sanitation through the lens of other human rights. Sanitation is crucial for a life with human dignity. It is as important as food, clothing and housing for maintaining an adequate standard of living. It can therefore be argued that sanitation – like water – is included as an implicit component of Art. 11 on the right to an adequate standard of living.

Human rights treaties that have been adopted subsequent to the International Bill of Rights support the recognition of sanitation and water as distinct human rights. The Convention on the Elimination of all Forms of Discrimination against Women (CEDAW), adopted in 1979 by the General Assembly and ratified by 186 States (as of 9 February 2010), includes sanitation and water supply as components of the right to an adequate standard of living, in its Article 14 dealing specifically with rural women.

The Convention on the Rights of the Child, adopted in 1989 by the General Assembly and ratified by 193 States (as of 9 February 2010), refers to clean drinking water and "environmental sanitation" in the context of guaranteeing the right of the child to the enjoyment of the highest attainable standard of health (Art. 24). More recently, the Convention on the Rights of Persons with Disabilities (CRPD) includes access to clean water services for persons with disabilities as part of the right to social protection and an adequate standard of living (Art. 28(2)(a)). At the regional level, human rights treaties regarding women and children in Africa also refer to the obligation to ensure access to clean drinking water. These treaties are legally binding on the States that ratify them and their implementation is monitored by expert bodies. Moreover, individuals have the possibility, under two optional protocols to CEDAW and to CRPD, to file complaints to these treaty bodies in cases where their rights are allegedly violated by a State Party.

Moreover, declarations and resolutions by the UN and by other organisations recognise safe drinking water and sanitation as human rights. While these are not legally binding, they show a strong political commitment to the recognition of water and sanitation as human rights and can also be used in the interpretation of legally binding treaties. For instance, the Mar de la Plata Action Plan (United Nations, 1977: 66) adopted by the United Nations Water Conference, the Dublin Statement on Water and Sustainable Development (International Conference on Water and the Environment, 1992: 2), the Cairo Programme of Action adopted by the United Nations International Conference on Population and Development (United Nations, 1994: Principle 2) and the Istanbul Habitat Agenda of the UN on Human Settlements (Habitat II) (United Nations, 1996: Para. 11) all recognise water as a human right, the latter two also encompassing sanitation. Additionally, other General Assembly and Commission on Human Rights Resolutions refer to clean water as a human right. Also, in 2006, the former Sub-Commission on the Promotion and Protection of Human Rights adopted Draft Guidelines for the Realization of the Right to Drinking Water Supply and Sanitation.

A human right to water and, in some cases, sanitation has also been recognised in several national Constitutions. Since the mid-1990s, an increasing number of States have included such provisions including Uganda, South Africa, Ecuador, Uruguay, the Democratic Republic of the Congo, the Maldives and most recently, Bolivia.

These numerous and ever increasing references to the right to water at the international, regional and national levels, in both binding treaties and non-binding political declarations indicate widespread acceptance of water as a human right. Concerning the right to sanitation, it has been less frequently recognised than the right to water; however, recent developments in human rights law show a clear trend towards recognition of this right also.

Misconceptions about water and sanitation as human rights

Although water has been widely recognised as a human right, and sanitation is increasingly recognised, there is still resistance towards recognising these rights. This hesitance frequently stems from misconceptions about human rights generally, and water and sanitation as human rights specifically. The following section aims to provide some clarification to common misunderstandings.

Is there sufficient water to ensure enjoyment of the human right to water in all countries? Yes. The right to water only covers water for personal and domestic uses, which accounts for a very small percentage of all water used. Agriculture and industry are the largest water users. Human rights require that personal and domestic uses be prioritised over other uses to ensure that all people have access to safe drinking water.

Is 20 litres per capita per day sufficient for the full realisation of the right to water? No. Twenty litres per capita per day is a minimum quantity required for basic human survival. Human rights have a focus on the individual – for example, a pregnant woman or someone living with HIV/AIDS, will require more water than other people, and human rights require that their needs be taken into account. Furthermore, geography and climate will affect the amount of water required per day for personal and domestic uses. Some have estimated that States should aim for at least 50 to 100 litres per person per day (Howard and Bartram, 2003) for full realisation of the right but this numerical value should not replace a contextual analysis.

Are the costs of achieving universal water and sanitation coverage prohibitive? No. Investments are costly, but the costs of not ensuring access to drinking water and sanitation are even higher in terms of public health and lost work and school days. Recent estimates show that for each dollar invested in water and sanitation, on average there is a return of 8 dollars in costs averted and productivity gained (Hutton et al., 2007: 20).

Do States have to provide access directly? No. Human rights do not require that States directly provide individuals with water and sanitation. States' primary obligation is to create an environment conducive to the realisation of human rights. Individuals are expected to contribute with their own means. Only in certain conditions, such as extreme poverty or natural disasters, when people, for reasons beyond their control, are genuinely unable to access water and sanitation through their own means, is the State obliged to actually provide services.

Is everyone – even those living in remote areas – entitled to piped water and a flush toilet connected to a sewerage network? No. States have to ensure that everyone has access to services that comply with the standards explained earlier, but different settings require different and flexible water and sanitation solutions. States have a margin of appreciation to adopt the measures most suited to the specific circumstances including low-cost technologies.

Do States have to provide services free of charge? No. Human rights do not require States to provide access to water and sanitation free of charge. Services have to be affordable and must not compromise the realisation of other human rights such as food, housing and health. Those who are able to must contribute financially or in kind. However, for those who are unable to pay, the State is under a duty to provide, meaning that no one can be deprived of access to safe drinking water and sanitation because of lack of financial resources. Subsidies or the provision of minimum essential levels of services free of charge can be suitable measures in that regard.

Do human rights prohibit private provision of water and sanitation services? No. Human rights do not require or favour a particular model of service provision. They do not exclude private provision. Yet, States must ensure – through adequate oversight and regulation, including effective monitoring and complaint procedures – that the actions of all actors do not result in human rights violations (OHCHR, 2007). Regarding this last question, the topic dominates the discourse on water, and for this reason, my thematic focus in 2010 is on the private sector, including State obligations in the context of private sector provision, and the responsibilities of private sector actors themselves.

Purpose and contribution of human rights in development practice

Understanding water and sanitation as human rights is particularly relevant in the context of development and poverty alleviation. The majority of organisations and programmes working on these issues are development organisations rather than human rights organisations. In this regard, it is crucial that we build bridges between the two sectors and see that development and human rights are complementary frameworks. We should all aim towards the same goal of ensuring that everyone has access to sanitation and water.

Photo: Anna Norström

Human rights place a particular emphasis on participation, non-discrimination and accountability. Good programming principles commonly applied in development practice overlap to a considerable degree with human rights principles. Meaningful participation and non-discrimination are crucial elements for a sustainable project, and thus have become central considerations in development programming.

The legal dimension

The added contribution of human rights stems from their legally binding nature. As objective legal standards, they provide a non-negotiable normative basis and a source of authority and legitimacy. Providing access to sanitation and water is no longer left to the States' discretion, but constitutes a human rights obligation. It becomes a matter of legal entitlements and claims, not of charitable benevolence of governments or development agencies.

The emphasis in human rights on participation is a crucial part of empowering people to claim their rights. Human rights also impose participation in decision-making. Participation has to be active, free and meaningful and thus has to go beyond mere consultation and information. It requires a genuine opportunity to express demands and concerns and influence decisions. Also, it is crucial to include all individuals and groups concerned. Capacity building and training is also required so that people are able to engage meaningfully. Only when existing policies are understood, can they be challenged and transformed into practice. Such activities show a close link to civil and political rights such as the freedom of expression and assembly.

Socio-economic rights further enhance participatory democracy by empowering marginalised segments of society to insist that institutions pay due attention to their needs, leading in the long term to structural transformation of discriminatory and exclusionary societal norms. Some countries have made important steps towards introducing participation in the water and sanitation sectors at the national level. For instance, Ghana's 2007 National Water Policy aims to ensure participation at the most local level on water-related issues (COHRE, 2009). In Kenya, participation is ensured through representation of all stakeholders on the boards and the involvement of community-based organisations and user groups in delivering services and determining sites of facilities. Additionally, the Water Services Regulatory Board specifically empowers people to organise Water Action Groups, which can include consumers and unserved populations, to negotiate directly with service providers and address their concerns to relevant institutions (Levin et al., 2009).

With human rights, non-discrimination is important, not because it will lead to more sustainable impact, although that is a laudable outcome, but because it is illegal to discriminate against people on certain grounds – non-discrimination is a right. More fundamentally, the recognition of socio-economic rights in general, and of the rights to water and to sanitation in particular, compel societal awareness of and political sensitivity to the needs and experiences of society's vulnerable and marginalised segments of people, who otherwise tend to be overlooked or denied in everyday social and political discourse. Human rights do not allow access to be extended only to those who are relatively easy to reach, but help to focus interventions on those who are normally excluded, for instance the extreme poor and people living in slums. Ensuring that the needs of all groups are included will also contribute to the sustainability of gains achieved through development interventions

Accountability mechanisms

Human rights require that accountability mechanisms be in place to hold the Government and other actors accountable for ensuring that these rights are not violated and for providing remedies in cases of alleged violations. Such mechanisms consist of administrative as well as judicial mechanisms including courts, national human rights institutions, informal justice systems and international courts, tribunals and quasi-judicial bodies. Explicitly recognising the rights to water and to sanitation in the Constitution and legislation is an important first step towards ensuring accountability, but efforts must extend beyond recognition to implementation. In Costa Rica, the Constitutional Court and the Ombudsman play a specific role in ensuring the enforcement of the rights to water and sanitation, and affirm the right of the community to participate in decisions affecting their access to water supply (de Albuquerque, 2009b).

However, accountability is not just about being able to go to court to claim one's right, as is sometimes assumed. It is also about empowering rights-holders to claim their rights and giving them a voice, particularly to the poor and excluded segments of the society in the local water and sanitation decision-making processes, and foster a dialogue with the relevant duty bearers. An enabling environment is crucial to ensuring that people are empowered to claim their rights, and demand that their rights be respected and fulfilled.

Conclusion

Human rights have a powerful and valuable contribution to make to discussions on water and sanitation. Human rights are not the solution to all problems, but with human rights, a special focus on those who are normally forgotten is guaranteed, accountability for State failures to ensure access to water and sanitation is maintained, and the issues are dealt with holistically, not only in terms of quantity and quality, but also accessibility, affordability and acceptability. These attributes of human rights are fundamental for moving towards our common goal of universal access. ■

References

- COHRE (2009) *The Significance of Human Rights in MDG-based Policy Making on Water and Sanitation: An Application to Kenya, South Africa, Ghana, Sri Lanka and Laos.* Geneva, Switzerland: Centre on Housing Rights and Evictions.
- CESCR (1990) *General Comment No. 3, The Nature of States Parties Obligations (Art. 2 Para. 1), 12 December 1990.* Committee on Economic, Social and Cultural Rights. E/1991/23, Annex III.
- CESCR (2003). *General Comment No. 15, The Right to Water (Arts. 11 and 12 of the International Covenant on Economic, Social and Cultural Rights), 20 January 2003.* Committee on Economic, Social and Cultural Rights. E/C.12/2002/11: Website publication http://www2.ohchr.org/english/issues/water/docs/CESCR_GC_15.pdf.
- de Albuquerque, C. (2009a) *Report of the Independent Expert on the Issue of Human Rights Obligations Related to Access to Safe Drinking Water and Sanitation.* A/HRC/12/24: Website publication http://www2.ohchr.org/english/bodies/hrcouncil/docs/12session/A-HRC-12-24_E.pdf.
- de Albuquerque, C. (2009b) *Report of the Independent Expert on the Issue of Human Rights Obligations Related to Access to Safe Drinking Water and Sanitation, Addendum, Mission to Costa Rica.* A/HRC/12/24/Add.1: Website publication http://www2.ohchr.org/english/bodies/hrcouncil/docs/12session/A-HRC-12-24-Add1_E.pdf.
- Levin, T., Nierenköther, M. and Odenwälder, N. (2009) *The Human Right to Water and Sanitation: Translating Theory into Practice.* Eschborn, Germany: GTZ.
- Howard, G. and Bartram, J. (2003) *Domestic Water Quantity, Service Level and Health.* Geneva, Switzerland: World Health Organization.
- Human Rights Council (2008) *Human Rights and Access to Safe Drinking Water and Sanitation.* A/HRC/RES/7/22: Website publication http://ap.ohchr.org/documents/E/HRC/resolutions/A_HRC_RES_7_22.pdf.
- Human Rights Council (2009) *Human Rights and Access to Safe Drinking Water and Sanitation.* A/HRC/RES/12/8: Website publication http://daccess-dds-ny.un.org/doc/RESOLUTION/GEN/G09/165/71/PDF/G0916571.pdf?OpenElement.
- Hutton, G., Haller, L. and Bartram J. (2007) *Economic and Health Effects of Increasing Coverage of Low Cost Household Drinking-Water Supply and Sanitation Interventions to Countries Off-Track to meet MDG Target 10.* Geneva, Switzerland: World Health Organization.
- International Conference on Water and the Environment (1992) *Development Issues for the 21st century, 26-31 January 1992, Dublin, Ireland, Report of the Conference.* Geneva, Switzerland: United Nations.
- OHCHR (2007) *Report of the United Nations High Commissioner for Human Rights on the Scope and Content of the Relevant Human Rights Obligations Related to Equitable Access to Safe Drinking Water and Sanitation under International Human Rights Instruments.* A/HRC/6/3: Website publication http://daccess-dds-ny.un.org/doc/UNDOC/GEN/G07/136/55/PDF/G0713655.pdf?OpenElement.
- United Nations (1977) *Report of the United Nations Conference on Water, Mar del Plata, 14-25 March* 1977. E/Conf.70/29. New York: United Nations.
- United Nations (1994) *Report of the International Conference on Population and Development, Cairo 5-13 September 1994. Annex, Cairo Programme of Action.* A/Conf.171/13/Rev.1.: Website publication http://daccess-dds-ny.un.org/doc/UNDOC/GEN/N95/231/26/IMG/N9523126.pdf?OpenElement.
- United Nations (1996) *Report of the United Nations Conference on Human Settlements (Habitat II), Istanbul, 3-14 June 1996. Annex II, Habitat Agenda.* A/Conf.165/14: Website publication http://daccess-dds-ny.un.org/doc/UNDOC/GEN/G96/025/00/PDF/G9602500.pdf?OpenElement.

Dr. Ines Dombrowsky
Research Fellow, Helmholtz Centre for Environmental Research
ines.dombrowsky@ufz.de

Benefit-sharing in transboundary water management through intra-water sector issue linkage?

Benefit-sharing has been advanced as a strategy to promote cooperation on transboundary rivers. However, the conceptual underpinning of benefit-sharing remains sparse. This paper analyzes whether issue linkages within the water sector can be understood as a form of benefit-sharing. The paper introduces two types of linkages: (1) of water uses with effects in reverse directions and (2) of water uses with upstream–downstream effects in river basins in which riparians hold reverse positions. It argues that whenever opportunities for these linkages exist, they may indeed contribute towards benefit-sharing. In particular, the type 2 linkage may be conducive towards the resolution of negative externality problems.

Keywords: transboundary rivers, benefit-sharing, externalities, side-payments, intra-sector issue linkage, property rights

Introduction

Whenever a river crosses national boundaries, its use by one riparian may entail external effects on co-riparians. This fact has given rise to a vivid debate on conflict and cooperation on international rivers. While some predict rising water conflicts and potential wars (Starr, 1991; Gleick, 1993; Lowi, 1993; Homer-Dixon, 1994; Klare, 2001), others have suggested that water may also serve as a catalyst for cooperation (Wolf, 1998; Wolf et al., 2003; Turton, 2000). In this context, benefit-sharing has been suggested as a strategy to move towards a cooperative use of international waters (Sadoff and Grey, 2002, 2005; Klaphake, 2005; Phillips et al., 2006). The main idea of the concept of benefit-sharing is to move from the sharing of water quantities to the sharing of the benefits the users receive from its use. However, as Phillips et al. (2006) argue, the concept of benefit-sharing has mainly been discussed in the professional water community, and the conceptual and academic underpinning of benefit-sharing remains scanty. Against this background, this paper examines to what extent issue linkages within the water sector (Dombrowsky, 2010a) can be considered as an underpinning of the concept of benefit-sharing. In a first step, the paper presents existing conceptualisations of benefit-sharing. In a second step, it presents the rationale for different types of intra-water sector issue linkage and selected examples. In a third step, it discusses whether these different types of intra-water sector issue linkage can be considered as a form of benefit-sharing.

The concept of benefit-sharing

The main idea of the concept of benefit-sharing is to move from the sharing of water quantities to the sharing of the benefits the users receive from its use. However, conceptualisations of benefit-sharing remain rather loose (Phillips et al., 2006). One argument is that by focusing on the benefits from the water instead on the allocation of water rights, a zero-sum game of water-sharing can be replaced by a positive sum game of benefit-sharing (e.g. Biswas, 1999). In other words, the underlying argument is that by focusing on benefits instead of quantities, difficult negotiations on water allocations may be avoided. For instance, Sadoff and Grey (2002: 396) argue that "[f]ocusing on the benefits derived from the use of water in a river basin, rather than the physical water itself, is another way to broaden the perspective of basin planners." They point out: "To negotiate the management and development of international shared rivers, riparians can focus their negotiations on the allocation of water rights or on the distribution of benefits derived from the use of water" (Sadoff and Grey, 2005: 422). Thus, according to this interpretation, the sharing of rights and the sharing of benefits can be understood as alternative negotiation strategies.

However, other authors question that the negotiation of benefits and the negotiation of rights can always be delinked. Phillips et al. (2006) argue that the equitable allocation of water resources and the sharing of benefits are two sides of the same coin and that an agreement on water allocations (rights) is a prerequisite for the sharing of benefits or compensation payments. Daoudy (2007) claims that optimal solutions may compromise the desire to achieve usage equity. These arguments are in line with other authors who argue that for water allocation problems an agreement on property rights is a prerequisite for an economic exchange scheme (e.g. Richards and Singh, 2001; van der Zaag et al., 2002).

Taking this debate further, Dombrowsky (2009) points out that whether the sharing of rights and the sharing of benefits can be delinked differs for negative and positive externality problems respectively. In the case of negative unidirectional externality problems, which may for instance be generated through water abstraction or wastewater discharge upstream, a basic agreement on property rights (the right to extract or pollute) is indeed a prerequisite for any benefit-sharing scheme. Once agreement on property rights has been reached, the parties may start trading these rights and optimising the use of the resource. For instance, if all rights are with the upstream party A, the parties may realise gains of cooperation if downstream party B compensates A for the benefits foregone from a reduction of its abstraction or pollution to the economically efficient level (where marginal benefits to A equal marginal costs to downstream party B) (Coase, 1960). Hence, for negative unidirectional externality problems benefit-sharing can be achieved through a side-payment (monetary compensation) under the condition that property rights are well defined and that transaction costs are sufficiently low.

The situation is different in the case of positive unidirectional externalities, such as the provision of flood control benefits for the downstream party through upstream retention measures. In this case, the question is whether the party benefiting from measures by the other party has an incentive to contribute towards the provision of the positive externality. Whether the benefiting party has an incentive to contribute depends on the specific situation (Dombrowsky, 2009). If it is individually rational for the party providing the positive externality to go ahead with its measure irrespective of a contribution from the benefiting party, a side-payment by the benefiting party may not necessarily be expected. However, the situation may be different, if collective provision could lead to higher welfare than unilateral provision, or if the measure is only collectively rational. In this case, side-payments from the benefiting party to the providing party would be individually rational and joint provision can be interpreted as a positive-sum game (Dombrowsky, 2009). Hence, whether or not the benefiting party can be expected to contribute towards the provision of the positive externality depends on the size and distribution of the costs and benefits (payoffs) of the respective management options at hand. However, in contrast to negative externality problems, no property rights to water are involved in the case of positive externalities. In other words, in the case of positive externality problems gains of cooperation can under certain circumstances be realised irrespective of the allocation of water rights. Hence, it depends on the type of problem whether the sharing of water rights and the sharing of benefits are structural alternatives or whether both need to be dealt with together.

Another part of the discussion relates to the types of benefits that can possibly be generated and shared. Sadoff and Grey (2002) distinguish four different types of benefits, benefits from the river, benefits to the river, reduced costs because of the river and benefits beyond the river. The idea is that cooperation can be driven by direct benefits from various water uses, by joint concerns for environmental protection, by the will to reduce the costs of conflict or by a broader interest in regional integration. Building upon this distinction Phillips et al. (2006) argue that benefits can be generated in the economic, the environmental or in the security arenas and that activities in these various spheres may have spill-over effects. They propose to identify security, economic and environment drivers in international river basins and, based on this, opportunities for development at various scales (household, sub-national, national, regional, global) within each of these spheres (so called Inter-SEDE model). While it is certainly true that in principal benefits may be generated in these different arenas, still neither Sadoff and Grey (2002) nor Phillips et al. (2006) explicitly address how these benefits are shared later on. For instance, if downstream country B increases the efficiency of its water use in agriculture, what are the implications for the other riparians and why would B be willing to share the benefits from this measure?

As Klaphake (2005) argues, benefit-sharing implies some form of balancing of unequal costs and benefits from water uses and water-related measures across national boundaries. He identifies two forms of benefit-sharing, (1) side-payments and (2) issue linkages. Side-payments have already been addressed above. Issue linkages, which can be understood as side-payments in kind, have indeed long been discussed as a means to address upstream–downstream conflicts, irrespectively of the discourse on benefit-sharing (LeMarquand, 1977; Priscoli, 1990; Wolf, 1997; Bernauer, 1997; Bennett et al., 1998; Meijerink, 1999; Marty, 2001; Mostert, 2003; Daoudy, 2005; Dinar, 2006). Issues are linked when different topics of negotiation are simultaneously discussed in order to reach agreement. It is usually assumed that negotiators link different issue areas of international relations, such as pollution and trade issues (e.g. Hauer and Runge, 1999). However, given that water is a multi-functional resource with an array of different uses, there may, in principle, be opportunities for issue linkage within the water sector (Bernauer, 1997; Klaphake, 2005; Dombrowsky, 2007, 2010a). The advantage of such an intra-water sector issue linkage could be that it may provide additional linkage options. In addition, they may be expected to involve lower transaction costs than "inter-sector linkages". The reason for this is that in the case of an inter-sector issue linkage, representatives from different sectors will have to negotiate with one another, and it may be difficult for them to appreciate the reciprocity within the arrangement unless a higher level authority fosters such linkages. Therefore, the question is what types of intra-water sector issue linkages can be conceived and whether they can be considered as a form of benefit-sharing.

Opportunities for intra-water sector issue linkage?

The starting point for the conceptualisation of intra-water sector issue linkage is the observation that the use of transboundary rivers may entail different types of unidirectional externalities that may lead to inefficient water uses (e.g. Rogers, 1993, 1997). As mentioned above these externalities may be negative and positive. Furthermore, typically these externalities are directed downstream, however – and this is more counter-intuitive, but important for intra-sector issue linkage – certain downstream measures may also have external effects directed upstream (see Figure 1). River works preventing fish migration or a dam flooding upstream may have negative externalities directed upstream (Figure 1c). Downstream measures improving the upstream navigability of the river would have positive effects directed upstream (Figure 1d). An additional consideration for the conceptualisation of intra-water sector issue linkages is that in some cases two riparian countries share more than one river but hold different riparian positions on these rivers. An example is the USA and Mexico (see below).

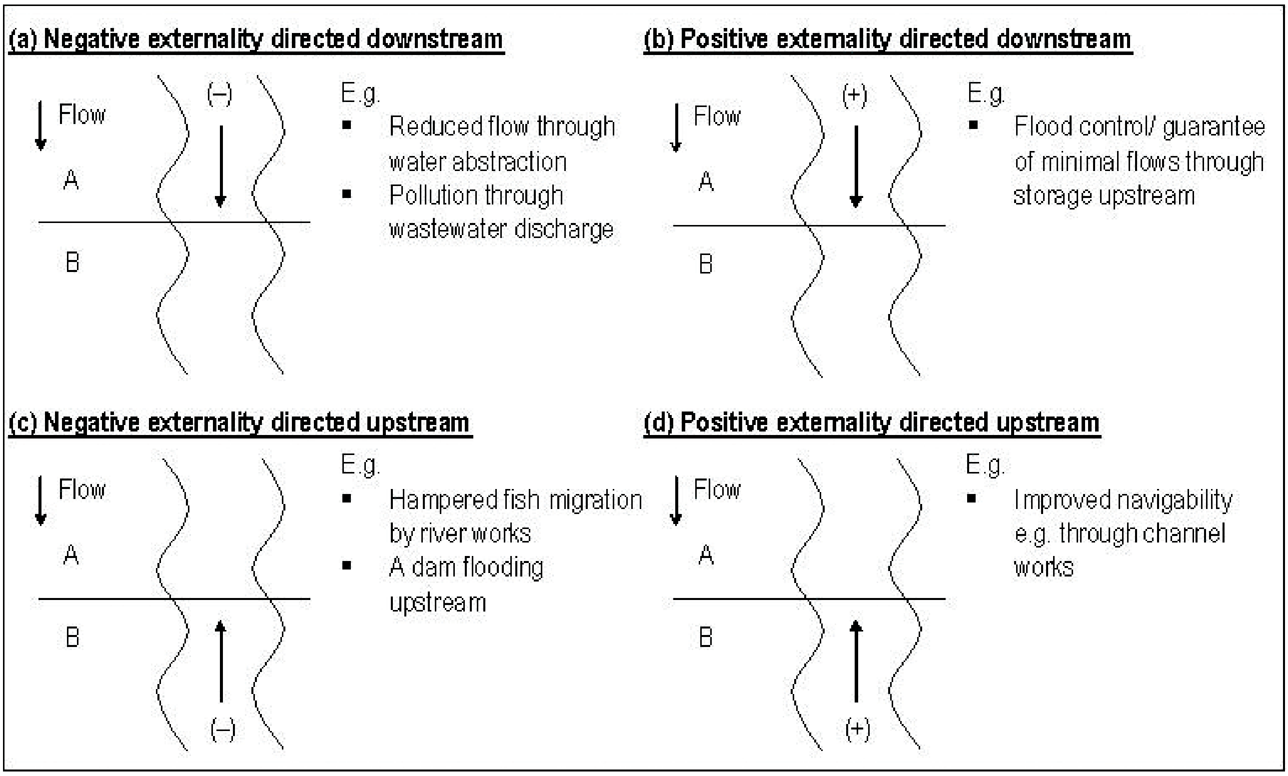


Figure 1. Typology of externality problems in the use of transboundary rivers
Source: Dombrowsky (2010b), reprinted by permission of the publisher (Taylor & Francis Group, http://www.informaworld.com)

Photo: Gety Images

The basic idea of intra-water sector issue linkage is to reach agreement among two riparian countries by mutual concessions within the water sector. Two main types of intra-water sector linkage may be distinguished: (1) the linkage of water uses or measures with effects in reversed directions, and (2) the linkage of water uses or measures with rectified effects in river basins in which riparians hold reversed positions (Dombrowsky, 2010a).

Type 1: Linking water uses with effects in reversed directions

In the case of intra-sector issue linkage type 1 – linkage of water uses with effects in reversed directions – upstream country A's remediation of a negative externality or its provision of a positive externality directed downstream is conditioned by downstream country B's remediation of a negative externality or its provision of a positive externality directed upstream, and vice versa. In this case, four different combinations of negative and positive externalities can be distinguished: a. -/-, b. -/+, c. +/+, d. +/- (see Figure 2). If the two countries share more than one river but are in the same riparian position in these rivers, the linkage may also take place across more than one river basin.

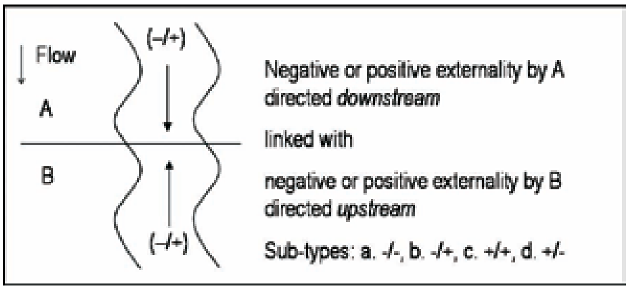


Figure 2. Linking water uses with effects in reversed directions (type 1 intra-water sector linkage)
Source: Dombrowsky (2010a: 136), reprinted by permission of the publisher (Taylor & Francis Group, http://www.informaworld.com)

It can be argued that an example for type 1 linkage took place in the Scheldt–Meuse River Basin. In the period between 1967 and 1995 the use of the Scheldt and the Meuse Rivers gave rise to different rounds of negotiation between Belgium and its regions Flanders and Wallonia on the one hand and the Netherlands on the other (Meijerink, 1999; Meijerink, 2008). The starting point for these negotiations was a Belgian Flemish interest to improve the access to the port of Antwerp on the Scheldt River. In order to achieve this, different measures on Dutch territory were suggested. The Netherlands made any river works on the Scheldt conditional on an improvement of water quality in the Scheldt and Meuse Rivers and on a guaranteed minimum river flow on the Meuse River. Hence, the basic idea of these negotiations was an intra-water sector issue linkage type 1b: the downstream country B made the provision of a positive externality directed upstream conditional on upstream's remediation of various negative externalities directed downstream.

However, it turned out that according to the initial concept the main costs for the improvement of the water quality of the Scheldt and Meuse Rivers and for the guarantee of a minimum flow would have had to be born by Wallonia. Hence, the negotiations were complicated by the fact that within Belgium, the costs and benefits of such a package deal were unequally distributed among the Belgian regions and no internal Belgian solution could be found. A breakthrough could only be reached in the early 1990s. First, the 1992 UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes motivated a separate multilateral negotiation track on water protection in the two rivers. Second, constitutional reforms in Belgium allowed the regions to negotiate water issues on their own behalf. In consequence, Flanders and the Netherlands started to negotiate bilaterally a linkage between the deepening of the navigation channel on Dutch territory and the provision of a minimum flow through measures within Flanders. Furthermore, in an attempt to speed up these negotiations Flanders suggested linking them to negotiations on a high speed train from Rotterdam to Antwerp which was of great interest to the Dutch. However, these negotiations were complicated by the fact that the Belgian federal government held competences with respect to infrastructure measures. While a principal agreement on the bilateral water issues could be reached, the Netherlands made agreement on these issues conditional on progress on the train issues. In response, Flanders made its agreement to the multilateral Scheldt and Meuse conventions that had in principal been agreed in early 1994 conditional on Dutch agreement on the deepening programme (Meijerink, 1999: 174).

In 1995, a breakthrough was reached after agreement was reached on a procedure on finding an alignment for the high speed train. In consequence, Flanders and the Netherlands signed three conventions, one dealing with the deepening of the Scheldt, one with the flows of the Meuse, and one revising the Scheldt statute. In addition, Flanders signed the Scheldt and Meuse River protection conventions that had already been signed by all the other parties in 1994. Hence, it can be argued that an intra-water sector linkage of type 1b was at the core of a broader package deal that also included an inter-sector linkage. It remains questionable, however, whether the inter-sector linkage was a necessary precondition for agreement in this case. In hindsight, Flanders considered the proposal to link the water negotiations with those on the high speed train as a tactical error (Meijerink, 1999: 170). It is not unlikely that in this specific case an agreement on the basis of the intra-sector linkage alone might have been possible and that it would have been achieved more quickly than the final more comprehensive package.

Type 2: Linking of water uses with upstream – downstream effects in river basins in which riparians hold reversed positions

Type 2 intra-water sector issue linkage may apply if the countries share more than one river basin in which they hold reversed riparian positions. In this case, country A's remediation of a negative externality or its provision of a positive externality directed downstream in river 1 may be linked to country B's remediation of a negative externality or its provision of a positive externality directed downstream in river 2. Alternatively, the two countries may also link two externality problems that are both directed upstream. In this case, different sub-types are conceivable again, as indicated in Figure 3.

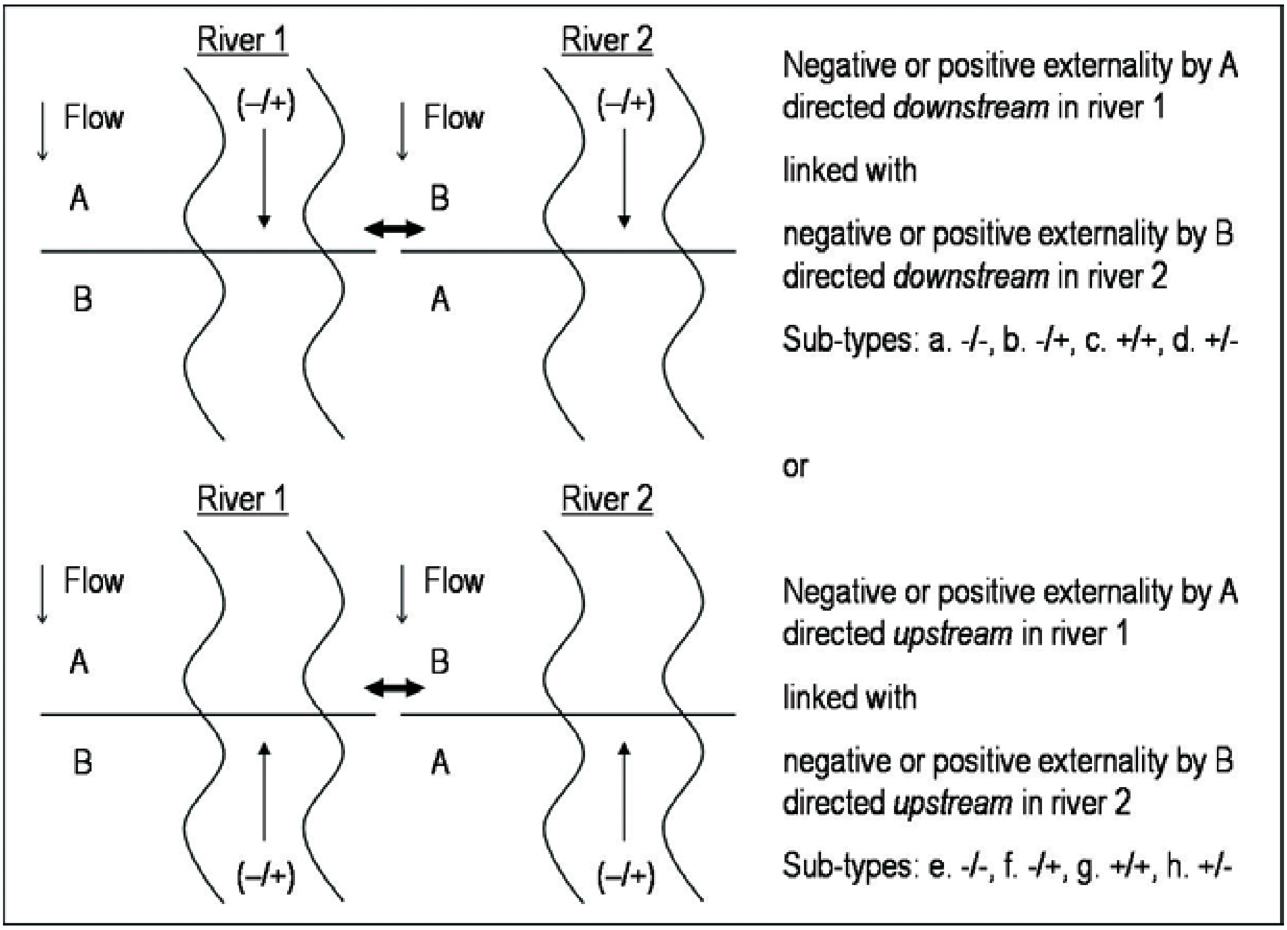


Figure 3. Linking water uses with upstream–downstream effects in basins with reversed riparian positions (type 2 intra-water sector linkage)
Source: Dombrowsky (2010a: 136), reprinted by permission of the publisher (Taylor & Francis Group, http://www.informaworld.com)

It can be argued Mexico and the USA pursued a type 2 intra-water sector issue linkage in their Colorado–Rio Grande negotiations in the first half of the 20th century; two rivers in which the two countries hold quasi reversed riparian positions. The USA is upstream and Mexico is downstream on the Colorado River. The Rio Grande is fed by tributaries in the USA and Mexico before it constitutes the common border between Mexico and Texas. While the Rio Grande river is not a transboundary river in a strict sense, at the beginning of the 20th century Mexico contributed about 70% of the Rio Grande water on which Texas relied for its agricultural development (Fischhendler and Feitelson, 2003).

In the early 1900s the riparian countries started negotiations on water allocation agreements on these rivers (Fischhendler and Feitelson, 2003; Fischhendler et al., 2004). Initially, the negotiations on the two rivers were conducted independently from each other; however no final agreements could be reached. Given that the USA was in an advantageous position on the Colorado while Mexico was so on the Rio Grande, in 1926 the USA agreed to the Mexican proposal to link the respective negotiations. Hence, the idea was to make the reduction of a negative externality directed downstream by the USA on the Colorado conditional on the reduction of a (potential) negative externality by Mexico on the Rio Grande. Thus, the proposed linkage constituted a type 2a intra-water sector linkage. However, it took almost twenty years of negotiations until an agreement could be reached.

Initially, the negotiations were delayed through contradictory legal positions held by the riparian countries. However, the linkage of the two river basins made these inconsistencies untenable. In consequence, the two countries abandoned their absolute positions and agreed on what can be interpreted as the doctrine of limited territorial sovereignty, which assumes that the right of one riparian to use the river is constrained by the rights of other riparian to do so (McCaffrey, 2003). Further delays occurred due to internal opposition within the USA. The proposal to negotiate the rivers jointly was supported by the U.S. State Department and Texas, but rejected by the seven U.S. States sharing the Colorado River. While the State Department was able to convince the upstream Colorado States that they would not suffer from an agreement, the downstream Colorado States California and Nevada continued to resist, arguing that the proposed linkage contradicted the U.S. Constitution and threatened their control over the water resources. In the end, they only agreed to a deal on the condition that the powers of the International Boundary and Water Commission are limited to the boundary waters alone.

At the international level, a breakthrough could be reached when the U.S. government realised that it had to resolve the U.S.–Mexican transboundary water dispute if it wanted to realise its broader foreign policy objectives, such as a credible Good Neighbor Policy with Mexico and Mexico's support for the United Nations. An agreement was achieved in 1944 when Mexico agreed to support the establishment of the United Nations and the USA in return accepted a comprehensive water agreement specifying minimum water provisions by the USA on the Colorado and by Mexico on the Rio Grande. As such, the case represents an example of a type 2a intra-water sector linkage based on the mutual reduction of negative externalities directed downstream in two river basins in which the riparian countries hold reversed riparian positions. However, similar to the Scheldt–Meuse case, this intra-water sector linkage was accomplished by linking it to a non-water issue, Mexican support for the establishment of the United Nations.

Discussion: intra-water sector issue linkage as benefit-sharing?

The above first of all shows that different types of issue linkages within the water sector are conceivable, namely linkages (1) of water uses or measures with effects in reversed directions and (2) of water uses or measures with rectified effects in river basins in which riparian countries hold reversed positions. Furthermore, the examples given indicate that there is empirical evidence for these two classes of intra-water sector issue linkages which suggested, at least in the two cases presented, that in the end the negotiation package went beyond a pure intra-water sector solution.

Based on these insights, the question is whether intra-water sector issue linkage can be considered as a contribution to or form of benefit-sharing. The general answer is a clear yes. Intra-water sector issue linkages can be considered as a very concrete form of direct benefit-sharing, as they generate benefits of cooperation within the water sector itself. Where such opportunities exist, interest-based transboundary water cooperation is possible and both parties are made better off vis-à-vis the status quo through a quid pro quo arrangement.

Still, we cannot expect that the status quo will always be accepted as a starting point for linkages (Phillips et al., 2006; Dombrowsky, 2007). Whenever water abstraction or pollution rights are disputed among co-riparians, there is still a need for an implicit or explicit agreement on the starting point for negotiations, and as such on an agreement on underlying property rights. However, in these situations intra-water sector issue linkage may still have distinct advantages compared to other negotiation strategies. In general an advantage of issue linkage is that it may reduce some of the problems associated with side-payments (e.g. Mäler, 1990). It has been argued that affected states may reject a side-payment as this appears to endorse a victim-pays principle. Furthermore, offering a side-payment may be associated with the reputation as a weak negotiator. Finally, the anticipation of side-payments may provide incentives for strategic behaviour by the party advantaged by the status quo in order to extract larger side-payments. Issue linkage may reduce at least two of these disadvantages. First, it may reduce a loss of face associated with side-payments – although it may not necessarily solve the underlying property rights issues. Second, whenever the parties agree on a linkage without further monetary compensations it may reduce strategic behaviour.

Furthermore, the type 2a intra-sector linkage – the linkage of two negative externality problems in basins in which the riparian countries hold reversed positions – appears to be particularly conducive towards the resolution of property right issues. As the Colorado–Rio Grande example suggests, the simultaneous consideration of two negative unidirectional externalities in basins with reversed positions may motivate the two countries to abandon absolute legal doctrines and to adopt a doctrine of limited territorial sovereignty. Hence, all other things being equal, this constellation appears to be particularly conducive towards cooperation.

From a policy perspective, the conceptualisation of intra-water sector linkages presented in this paper may assist in the systematic search for opportunities to realise mutual benefits and thus promote "benefit-sharing" on transboundary rivers. At the same time, the examples introduced indicate that whenever such solutions are pursued, the spatial allocation of benefits and costs and getting all relevant players at the sub-national level on board remain critical.

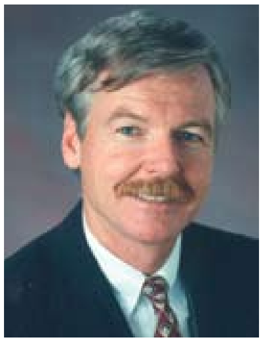
From a research perspective, a larger N case study may provide further insights into the practicalities of such intra-water sector issue linkages. In particular, it would be of interest to learn whether intra-water sector issue linkage works in more "securitised" river basins than the Colorado–Rio Grande and the Scheldt–Meuse cases. ■

References

- Bennett, L.L., Ragland, S.E. and Yolles, P. (1998) Facilitating International Agreements through an Interconnected Game Approach: The case of river basins. In *Conflict and Cooperation on Trans-Boundary Water Resources* (Eds. Just, R.E. and Netanyahu, S.) Boston, USA: Kluwer Academic Publishers.
- Bernauer, T. (1997) *Managing International Rivers. In Global Governance: Drawing Insights from the Environmental Experience* (Ed. Young, O.R.). Cambridge, USA: The MIT Press.
- Biswas, A.K. (1999) *Management of International Waters: Opportunities and Constraints. International Journal of Water Resources Management* 15(4): 429–41.
- Coase, R.H. (1960) *The Problem of Social Cost. The Journal of Law and Economics* 3: 1–44.
- Daoudy, M. (2005) *Le Partage des Eaux entre la Syrie, l'Irak et la Turquie : Négociation, Sécurité et Asymétrie des Pouvoirs.* Paris, France: CNRS.
- Daoudy, M. (2007) Benefit-Sharing as a Tool of Conflict Transformation: Applying the Inter-SEDE Model to the Euphrates and Tigris River Basins. *Economics of Peace and Security Journal* 2(2): 26–32.
- Dinar, S. (2006) Assessing Side-payments and Cost-sharing Patterns in International Water Agreements: The Geographic and Economic Connection. *Political Geography* 25(4): 412–37.
- Dombrowsky, I. (2007) *Conflict, Cooperation and Institutions in International Water Management: An Economic Analysis.* Cheltenham, UK and Northampton, USA: Edward Elgar.
- Dombrowsky, I. (2009) Revisiting the Potential for Benefit-sharing the Management of Transboundary Rivers. *Water Policy* 11(2).
- Dombrowsky, I. (2010a) The Role of Intra-Water Sector Issue Linkage in the Resolution of Transboundary Water Conflicts. *Water International* 35(2): 132–49.
- Dombrowsky, I. (2010b) Erratum. *Water International* 35(3).
- Fischhendler, I. and Feitelson, E. (2003) Spatial Adjustment as a Mechanism for Resolving River Basin Conflicts. *Political Geography* 22(5): 557–83.
- Fischhendler, I., Feitelson, E. and Eaton, D. (2004) The Short-term and Long-term Ramifications of Linkages Involving Natural Resources: the

US-Mexico Transboundary Water Case. *Environment and Planning C: Government and Policy* 22(5): 633–50.
- Gleick, P. (1993) *Water in Crisis.* Oxford, UK: Oxford University Press.
- Hauer, G. and Runge, F.C. (1999) Trade-Environment Linkages in the Resolution of Transboundary Externalities. *The World Economy* 22(1): 25–39.
- Homer-Dixon, T.F. (1994) Environmental Scarcities and Violent Conflict. Evidence from Cases. *International Security* 19(1): 5–40.
- Klaphake, A. (2005) Kooperation an internationalen Flüssen aus ökonomischer Sicht. Das Konzept des Benefit Sharing. Bonn, Germany: Deutsches Institut für Entwicklungspolitik.
- Klare, M.T. (2001) The New Geography of Conflict. *Foreign Affairs* 80(3): 49–61.
- LeMarquand, D.G. (1977) International Rivers: *The Politics of Cooperation.* Vancouver, Canada: Westwater Research Center, University of British Columbia.
- Lowi, M. (1993) Water and Power: *The Politics of a Scarce Resource in the Jordan River Basin.* Cambridge, UK: Cambridge University Press.
- Mäler, K.-G. (1990) International Environmental Problems. *Oxford Review of Economic Policy* 6(1): 80–107.
- Marty, F. (2001) *The Management of International Rivers: Problems, Politics and Institutions.* Frankfurt, Germany: Peter Lang.
- McCaffrey, S. (2003) *The Law of International Watercourses: Non-Navigational Uses.* Oxford, UK: Oxford University Press.
- Meijerink, S.V. (1999) *Conflict and Cooperation on the Scheldt River Basin: A Case Study of Decision Making on International Scheldt Issues between 1967 and 1997.* Boston, USA: Kluwer Academic Publishers.
- Meijerink, S.V. (2008) Explaining Continuity and Change in International Policies: Issue Linkage, Venue Change, and Learning on Policies for the River Scheldt Estuary 1967–2005. *Environment and Planning* A 40(4): 848–66.
- Mostert, E. (2003) *Conflict and Co-operation in the Management of International Freshwater Resources: A Global Review.* Paris, France: UNESCO, IHP, WWAP.
- Phillips, D.J.H., Daoudy, M., Öjendal, J., Turton, A.R. and McCaffrey, S. (2006) *Trans-boundary Water Cooperation as a Tool for Conflict Prevention and for Broader Benefit-Sharing.* Stockholm, Sweden: Ministry of Foreign Affairs.
- Priscoli, J.D. (1990) Does Water Integrate or Separate Us? *Water International* 15(4 (Epilog)): 236–9.
- Richards, A. and Singh, N. (2001) No Easy Exit: Property Rights, Markets, and Negotiations over Water. *Water Resources Development* 17(3): 409–25.
- Rogers, P. (1993) The Value of Cooperation in Resolving International River Basin Disputes. *Natural Resources Forum* 17: 117–31.
- Rogers, P. (1997) International River Basins: Pervasive Unidirectional Externalities. In *The Economics of Transnational Commons* (Eds. Dasgupta, P., Mäler, K.-G. and Vercelli, A.) Oxford, UK: Clarendon Press.
- Sadoff, C.W. and Grey, D. (2002) Beyond the River: The Benefits of Cooperation on International Rivers. *Water Policy* 4(5): 389–403.
- Sadoff, C.W. and Grey, D. (2005) Cooperation on International Rivers. A Continuum for Securing and Sharing Benefits. *Water International* 30(4): 420–7.
- Sadoff, C.W., Whittington, D. and Grey, D. (2002) *Africa's International Rivers: An Economic Perspective.* Washington, DC, USA: World Bank.
- Starr, J.R. (1991) Water Wars. *Foreign Policy* 82:17–36.
- Turton, A.R. (2000) Water Wars: Enduring Myth or Impeding Reality? In *Water Wars: Enduring Myth or Impeding Reality* (Eds. Solomon, H. and Turton, A.R.) Durban, South Africa: African Centre for the Constructive Resolution of Disputes.
- van der Zaag, P., Seyam, I.M. and Savenije, H.H.G. (2002) Towards measurable criteria for the equitable sharing of international water resources. *Water Policy* 4(1): 19–32.
- Wolf, A.T. (1997) International Water Conflict Resolution: Lessons from Comparative Analysis. *International Journal of Water Resources Development* 13(3): 333–65.
- Wolf, A.T. (1998) Conflict and Cooperation along International Waterways. *Water Policy* 1: 251–65.
- Wolf, A.T., Yoffe, S.B. and Giordano, M. (2003) International Waters: Identifying Basins at Risk. *Water Policy* 5: 29–60.

Photo: Digital Vision



Mr. Arthur Guy Baggett, Jr.
Member, State of California Water Resources Control Board and Faculty Member of San Joaquin College of Law
abaggett@waterboards.ca.gov

Legal, ecological, water quality and water rights considerations in interbasin water transfers

Interbasin water transfers have the potential to severely impact "source" and "receiving" water basins. Socio-economic impacts on source basin communities, in-stream effects on fish and wildlife, and water and air quality degradation are all potential impacts of transfers. California water rights laws and environmental statutes guide the transfers to minimise and mitigate these impacts. The Imperial Irrigation District to San Diego County Water Authority transfer is an example of the application of the law to resolve conflicts. As water shortages occur due to population growth and climate change, and as the private water markets expand, these laws are critical to protect public resources.
Keywords: Interbasin water transfers, water quality, water rights.

Introduction

The interbasin transfer of water from one basin to another dates from the earliest days of civilization. The cities of Mesopotamia developed extensive systems to move water from the mountains to the low fertile valleys between the Tigris and Euphrates Rivers for use in irrigated agriculture and municipal water supplies (Van de Mieroop, 1997). The Romans developed a complex system of aqueducts dating back to 312 B.C. (Hansen, 1983). These engineering feats were accomplished without environmental review or balancing competing interests and concerns.

Urban population growth will result in the use of interbasin transfers to supplement water supplies throughout the world. The proposed transfer of many cubic kilometres of water from the Ken River to the Betwa River Basin is illustrative of the economic and environmental issues raised by an interbasin transfer of water (Ecoworld, 2010). In the United States, there are currently many interbasin transfers being proposed and developed. For example, the Southern Nevada Water Authority is proposing to move 185 cubic kilometres of water from five hydrologic basins in northern and eastern portions of the state to Las Vegas, one of the fastest growing cities in the United States (Southern Nevada Water Authority, 2010).

Early interbasin transfers in the United States

New York City built the first water system in the United States based on an interbasin transfer, when it moved water from the Croton River to the city in 1842. New York City's current water diversion from the Catskill Mountains was completed in 1915, eventually impounding 580 billion gallons (NYC, 2009) of water in 19 reservoirs. On the west coast of the United States, San Francisco secured its current water supply by building the Hetch Hetchy Reservoir in Yosemite National Park. This project stores nearly 445 million cubic metres of water (SFPUC, 2009). This water is moved by gravity 350 kilometres from the Sierra Nevada Mountains across California's Great Central Valley and under the Coast Range and the San Francisco Bay via tunnel and siphon (Bancroft Library, 2007). Water from the Owens Valley of eastern California was diverted to serve the city of Los Angeles. This trans-basin diversion would ultimately provide the impetus for the development of a new law and to regulate how water can be transferred from one basin to another in California.

Owens Valley transfers to Los Angeles

The Owens River lies 375 km north of Los Angeles in a deep valley between two ranges of mountains that reach to heights of over 4,600 metres above sea level: the Sierra Nevada Mountains to the west, and the White Mountains to the east. Immediately to the north lies the Mono Basin. In the early 1900s, Los Angeles was desperate for a reliable source of water for its rapidly growing population. Owens Lake was at an elevation of nearly 1,350 metres above Los Angeles. The water from this lake could be delivered by siphon and aqueduct without pumping. Prior to announcing any plan to construct a project to move the water out of the valley to the urban areas to the south, Los Angeles purchased over 90% of the private property, along with the water rights. The battle between the rural occupants of the Owens Valley and Los Angeles interests over water became the theme for many articles and books, including the movie Chinatown (Reisner, 1986).

In 1940, the Los Angeles Department of Water and Power obtained rights to extend the Owens Valley project to the Mono Basin by appropriating the entire flow of the five streams that flow into Mono Lake. As a result of the continuous diversion of water by the city, the level of Mono Lake declined precipitously. Years later in 1983, the California Supreme Court would order (National Audubon Society v. Superior Court, 1983) that the public trust doctrine (p. 7 et seq.), first established in ancient Rome, be applied to the waters being diverted from the Mono Basin (Stevens, 1980). The court ruled that the diversions were causing the lake level to drop, thereby harming migratory birds roosting on the islands in the lake and causing toxic air pollution to rise from the exposed benthic soils (National Audubon Society v. Superior Court, 1983).

The court ordered the State Water Resources Control Board (SWRCB) to re-evaluate the water rights and diversion requirements of Los Angeles. The result was the broadest application of the public trust doctrine in modern times. The SWRCB required a restoration of the lake to a level that would protect the avian population and air quality in the lake basin.

Photo: Arthur Guy Baggett, Jr.

Figure 1. Mono Lake progression from 1968 to 1995
Source: Mono Lake Committee (2009)

The most recent order in the on-going Owens Valley dispute was a settlement of a federal court case that required Los Angeles to re-water the dried up Owens Lake Basin to abate severe air pollution in the Owens Valley being caused by winds eroding the dried up lake bed (see Figure 2) (Little, 2000).

Photo: Arthur Guy Baggett, Jr.

Figure 2. Blowing alkali dust at Owens Lake
Photo: Richard Ellis

The issues raised over the decades due to the transfer of Owens Valley water resulted in the application of existing environmental law, and the passage of additional water rights legislation, to remedy impacts on the environment and to address problems and inequities that result from interbasin transfers.

Water rights and environmental laws

Environmental consequences of moving large quantities of water from one basin (source basin) for use in a different watershed (receiving basin) have resulted in numerous developments in the law and new applications of existing environmental laws and regulations within the United States, particularly in the west. The following is a summary of the issues and law of interbasin transfer as applied in the Imperial Irrigation District (IID) and San Diego County Water Authority's long-term transfer of water from the Colorado River and Imperial Valley to the coastal area of San Diego County in California (SWRCB, 2002).

Water rights law in California

In order to examine the issues associated with interbasin water transfers, it is necessary to have a basic understanding of water rights law. While each state has its own unique case and statutory law, the basic system applied in California and other western states is based on the public ownership of water, the prior appropriation doctrine, and the law prohibiting "waste and unreasonable use."

Public ownership of water resources

The primary tenant of water law in the western United States is ownership of the water by the people. California Water Code section 102 provides that "All water within the state is the property of the people of the state, but the right to the use of water may be acquired by appropriation in the manner provided by law."

Prior appropriations

The second tenant is the law of prior appropriation. Miners were largely responsible for the origination of the system recognising prior appropriative water rights. Early miners and immigrants to California formed communities that applied their own standards of fairness in apportioning water. Those standards were 'first come, first served' with priority to the diligent (Rogers and Nichols, 1967). Statutory and case law now defines in detail how one can store, divert, and use the waters of the state. Under a prior appropriative system, the party with the oldest right has first priority to the available water. Junior right holders may not exercise their rights until all older rights have been satisfied. This system makes it relatively clear who has the right to make use of each unit of water as flow levels fluctuate (Hutchins, 1971).

Prohibition against waste and unreasonable use

The third basic tenant of California water law is the prohibition against the waste and unreasonable use of water. The law applies to all water rights and prohibits waste of water. It also requires reasonableness of use, method of use and method of diversion for all uses of water.

The California Constitution, article X, section 2 states:

"It is hereby declared that because of the conditions prevailing in this State, the general welfare requires that the water resources of the State be put to beneficial use to the fullest extent of which they are capable, and the waste or unreasonable use or unreasonable method of use of water be prevented, and that the conservation of such waters is to be exercised with a view to the reasonable and beneficial use thereof in the interest of the people and for the public welfare. The right to water or to the use of flow of water in or from any natural stream or water course in this State is and shall be limited to such water as shall be reasonably required for the beneficial use to be served, and such right does not and shall not extend to the waste or unreasonable use or unreasonable method of use or unreasonable method of diversion of water."

The application of the law is very site- and fact-specific. For example, in *Joslin v. Marin Municipal Water District* (1967), the court balanced the social utility of the municipal use of water against the use of water for the accumulation of gravel. The court held that the use of water for gravel transport was unreasonable as a matter of law under article X, section 2, and that no right attaches to unreasonable use (*Joslin v. Marin Municipal Water District, 1967*).

Statutes regulating water transfers

The California legislature has adopted numerous statutes to protect water right holders, the environment, and the source basin economy. The statutory requirements establish three basic rules: (1) that the transfer causes "no injury" to any legal user of water (California Water Code, §§ 170, 1706, 1727, 1736, 1810 (2009)); (2) that it must not result in any "unreasonable effects" to fish or wildlife (California Water Code, §§ 1727, 1736, 1810 (2009)); and (3) that if it is water from the State Water Project, the transfer must have "no unreasonable economic impacts" to the overall economy of the county from which the water is transferred (California Water Code, § 1810 (2009)).

The law of "no injury" originally applied to other water rights holders in the source basin. In the case of water transfers, the law has expanded to include third party impacts such as the socio-economic burden a transfer would place on a source basin's population. As the IID transfer case illustrates, these impacts now extend to erosion and the loss of jobs, income, tax revenue, air quality, and in-stream flows for fish and wildlife, and the resulting reduced water quality of the source basin (SWRCB, 2002).

The public trust doctrine

The public trust doctrine also has a significant effect on California water use. The doctrine not only requires specific consideration be given to protect public trust values, but also provides for ongoing state jurisdiction to modify water rights to protect public trust resources as they may change over time. A good discussion of the potential use and history of the doctrine can be found in The Public Trust Doctrine in Natural Resources Law by Professor Joseph L. Sax (Sax, 1970).

Environmental laws and issues

An interbasin transfer of water can raise many environmental issues. Source basin impacts can result in the dewatering of the surface and groundwater within the source basin, resulting in air pollution from exposed soils. Lower flows can result in increased concentration of water pollutants, and decreasing quantity of water can diminish wildlife populations.

The Clean Water Act

The federal Clean Water Act places limits on water pollution within the waters of the United States. Pollution can include an increase of ambient water temperatures, salinity changes, low levels of dissolved oxygen, nutrient loading, and invasive species. Lower stream flows can result in increased ambient water temperatures that impact micro-invertebrates and fishery resources. Low stream and lake levels, particularly when coupled with nutrient loading, can result in dissolved oxygen levels detrimental to the health of the ecosystem. Low surface and groundwater levels can also result in degradation such as salt-water intrusion.

The source basin can be impacted by diversion of water out of the basin. The receiving basin can also be impacted by water pollutants being imported into it from the source basin. Under the Clean Water Act, a point source of pollution cannot violate water quality standards (CWA, § 301(b)(1)(C) (2009)). A point source is usually an end-of-pipe discharge such as from a wastewater treatment plant, industrial outfall, or other discrete source. In a case involving the City of New York's diversions from the Catskill reservoir system, however, one federal circuit court decided that the waters transferred from one basin into the stream of another basin resulted in "the discharge of a pollutant" (Catskill Mountains Chapter of Trout Unlimited, Inc. v. City of New York, 2006). A different federal circuit court reached a different conclusion in a Florida case that did not require water managers to acquire a water pollution permit to pump pollutant-laden water from run-off canals into Lake Okeechobee (Friends of Everglades v. South Florida Water Management District, 2009). The United States Supreme Court will resolve any differences between the federal circuit courts of appeals. There is still great uncertainty as to whether interbasin water transfers in the United States require a water pollution permit issued under the federal Clean Water Act.

The Endangered Species Act

The Endangered Species Act (ESA) of 1973 (ESA, 2009) is one of the strongest federal environmental laws. The intent of Congress in enacting the ESA was "to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved… and to provide a program for the conservation of such species." (ESA, § 2(b) (2009)). The "Federal agencies shall cooperate with state and local agencies to resolve water resource issues in concert with conservation of endangered species" (ESA, § 2(c)(2) (2009)). The law prohibits any person from "taking" listed species, which includes disturbance of habitat (ESA, § 9(a)(1)(B) (2009)). Habitat protection is a primary means for the implementation of the ESA (Moore et al., 1996).

The Clean Air Act

An interbasin transfer must also comply with federal environmental statutes that protect air quality. The Clean Air Act of 1970 regulates sources of anthropogenic air pollution (CAA, § 101 (2009)). For example, if a diversion causes a lakebed to be exposed to drying by the sun and air thereby resulting in the creation of particulate pollution, then air quality regulations must be addressed prior to transferring water.

The National Environmental Policy Act and the California Environmental Quality Act

If a federal permit is necessary to complete a transfer or if a federal agency carries out a transfer, then compliance with the National Environmental Policy Act of 1969 is required (NEPA, 2009). This act requires specific standards of public notice and disclosure based on studies that evaluate the potential environmental impacts of the project. California law has a very similar requirement based on the California Environmental Quality Act.

Case Study: Imperial Irrigation District (IID) water transfer to San Diego County Water Authority (SDCWA)

In water right Order WRO 2002–0016, the California State Water Resources Control Board (SWRCB) approved a long-term transfer of conserved water from IID to SDCWA pursuant to an agreement between IID and SDCWA, and conditionally approved a petition filed by IID to change the point of diversion, place of use, and purpose of water use. The proposed transfer is for a term of 45 to 75 years. In granting this approval, the SWRCB found that the transfer will not result in a substantial injury to any legal user of water and will not unreasonably affect fish, wildlife, or other interim beneficial uses, subject to specified conditions (SWRCB, 2002).

Physical setting

The IID is located within the Salton Trough, a deep valley in the southeastern corner of the state which lies below sea level. The Mexicali Valley in northern Mexico bounds the Salton Trough to the south. About 40 miles to the east is the Colorado River, which provides water to support the agricultural economy of the Salton Trough. The Colorado River is also a vital source of water for the municipal and industrial areas of the coastal plain. SDCWA obtains water from aqueducts at near Parker Dam 300 km upstream of the IID Colorado Diversion at the All American Canal that flows just north of the United States–Mexico border.

Figure 3. Colorado River Basin
Source: SWRCB – State Water Resources Control Board

Parties of interest

The parties that participated in the hearing on the IID to SDCWA interbasin transfer included the proponents, the local government of Imperial County, the Colorado River Indian Tribes, a number of environmental groups (including the Sierra Club, the National Audubon Society, the Defenders of Wildlife, and the National Wildlife Federation) and the Colorado River Basin Regional Water Quality Control Board. The conditions placed on the transfer dealt with the gamut of legal and environmental impacts to both source and receiving basins.

Water rights issues

The only party to raise the "no injury" rule by claiming substantial injury as a legal user of the water in question was the Colorado River Indian Tribes. They argued that the transfer would decrease hydroelectric power generation. The tribes supported their right to use of water for agricultural and domestic purposes, but could not demonstrate that they in fact had a right to use the water for hydroelectric power generation; therefore they were not entitled to mitigation for lost revenue. A related issue was impact on the downstream use in the country of Mexico. In 1944, the United States and Mexico negotiated a water treaty concerning Colorado River flows. The treaty obligated the United States to deliver to Mexico 1.85 cubic kilometres per year (Wilbur and Ely, 1948). Because existing rights were protected, the transfer did not result in substantial injury to any legal user of water.

Photo: Gety Images

Application of water transfer statutes: unreasonable effects on fish and wildlife

The potential for water transfers to result in unreasonable impacts to fish, wildlife, and other in-stream beneficial uses was more problematic. The impacts of greatest concern were due to the increase in concentration of various pollutants; water being made available for the transfer was water that would be saved by fallowing agricultural land and by implementing water conservation measures on land remaining in production. Conservation measures were of greatest concern because they had the potential to increase concentration of salts and metals.

The Salton Sea is home to roughly 400 species of birds. On any given day, between 100,000 and 3,000,000 of these birds use the habitat in and around the sea. Some, like the endangered brown pelican, use the main body of the sea directly by foraging on the abundant fish in the areas that are sustained by IID drainage water and high groundwater levels.

The Salton Sea is an important part of a network of North American wetlands. Because approximately 95% of the wetlands that existed in 1850, when California became a state, have been destroyed, the remaining 5% are of great importance. The Salton Sea is an important stop along the Pacific flyway for migratory birds; it is also an important breeding area. The sea supports 25 to 30% of the U.S. population of American white pelicans and 90% of the population of eared grebes, as well as the some of the largest breeding colonies of double-crested cormorants and cattle egrets in North America. The sea has grown increasingly important as the Colorado River Delta has become degraded because of the decease in river flows over time.

The fish in the Salton Sea are important not only to the species that forage on them directly, but also to sports fishermen who often find excellent fishing in the sea. The tilapia, a fish native to the African continent, provides most of the forage base for the birds that frequent the sea. It is believed that tilapia were introduced to the sea sometime in 1964 or 1965 and by the early 1970s were the dominant fish in the sea. They are successful because of their ability to thrive in the sea's warm, often oxygen-deficient, and hyper-saline water.

Selenium

The potential increase in selenium concentration was of great concern. The selenium was imported into the Salton Sea Basin from sources in the upper Colorado River Basin. Selenium toxicity causes reproductive failure in adult fish and birds. The Colorado River Basin Regional Water Quality Control Board had imposed measures under its Clean Water Act authority to reduce concentrations to acceptable levels. To compensate for the potential detrimental effects on water quality and wildlife, the transfer parties were required to create managed marsh habitat to treat the drainage and stream waters flowing from fields where increased water conservation measures were installed. Evidence demonstrated that fallowing of lands actually had a positive impact by reducing the importation of selenium into the basin; thus no mitigation was required.

Lowered lake level

Because the Salton Sea is located in a closed basin, all natural and anthropogenic activities potentially affect the water quality. Studies demonstrate that under pre-transfer conditions, the sea is projected to decrease in elevation. The lowering elevation results in increasing concentrations of salts and metals and stress on the ecosystem. Lower elevation levels also could allow access to several small islands, which serve as a roosting habitat for shore birds in the sea.

Modelling indicates that the IID transfer will accelerate the decrease of the Salton Sea's elevation, thereby increasing salinity. This would result in the current ecosystem becoming unsustainable by 2017. To mitigate for the salinity increase resulting from the transfer, IID and SDCWA are required to implement a habitat conservation plan to assure that the sea's current water quality is protected until 2017. This will not solve the basic problem, but will mitigate for the contribution caused by the water transfer and allow time for other solutions for the sea's water quality to be developed.

Endangered species

There are a number of listed endangered species in the Salton Sea and Colorado River. Under the federal ESA, the Secretary of the Interior may permit a take of a listed species if impacts will be minimised and the taking will not reduce the likelihood of the survival or recovery of a threatened or endangered species. A natural community conservation plan was approved which mitigates for impacts to the Salton Sea's listed species. The United States Fish and Wildlife Service required mitigation measures under a Biological Opinion to protect listed species in the Colorado River.

Impacts caused by population growth in the receiving water basin

The receiving basin was also required to mitigate for potential impacts from population growth in the San Diego area resulting from the transfer. Any population growth would require a new source of water. SDCWA is planning for growth through the conversion of agricultural lands within the San Diego area, water reclamation plants, increased conservation programmes and the development of sea water desalinisation plants. The authority reports biannually to the SWRCB on progress in developing additional sources of water.

Air quality

Air quality impacts due to exposure of shoreline caused by receding lake levels was of particular concern given the potential emission of small particles less than 10 micrometres in diameter. These particles can have a severe impact on human and animal health. IID is required to reduce emissions by implementing best management practices, such as using soil stabilisation chemicals on fallowed lands, use of return flow waters and other methods required by the Imperial County Air Pollution Control District. Because the air quality impacts of shoreline exposure are difficult to predict based on current studies and technology, IID is required to implement additional study and mitigation programmes as deemed necessary by the air quality districts.

Socio-economic impacts in the source basin

A different challenge is to minimise or mitigate the socio-economic impacts to a feasible extent. It is estimated that, if the entire transfer were based on fallowing of farmlands, 1,400 jobs would be lost. Fallowing would not only increase the unemployment rate, but would also adversely affect local government by reducing its tax base and increasing its administrative costs. Economic impacts will vary depending on the quality of lands fallowed and the crop types being replaced. The state is required to study the nature and extent of any impacts of land fallowing and the extent to which funds gained from the transfer do not mitigate for these costs. Additional mitigation funding requirements may be imposed if the studies indicate they are necessary.

This transfer has proceeded with the above mitigation requirements and studies. The mitigations required are working as intended.

Photo: Gety Images

Water markets: the need for environmental and legal controls to protect the public resources and source water basin

Water shortages due to drought, urban population growth, and climate change are occurring throughout the world. The application of market forces will be an effective way to achieve a balance between supply and demand, to facilitate efficiency by disclosing non-competitive and inefficient water users, and to stimulate use of technical and procedural innovations to maximise water use efficiency. While increasing conservation and recycling will result in more efficient use of water, interbasin transfers will continue to play a large role in assuring a reliable supply of water. It is important to note that use of water involves an unusually complex mix of price-responsive and non-price responsive social values. The interrelations among water uses, in-stream public trust needs, and non-consumptive uses such as flood control, power generation, and recreation must all be considered.

Market forces do have limits; they do not necessarily address the highest social and environmental interests. Focused regulation and government intervention are often necessary to protect social interests that the market does not price. The concern still exists that the need for increased water sources will overpower public resource protection. This is a concern of the environmental justice movement as well as the traditional non-governmental organisations.

To counter the loss of incidental environmental habitat, regulatory protections and mandatory water quality and quantity allowances for fish and wildlife may be appropriate. Land use issues should be addressed through land use regulations. Because of the concern in many agricultural areas and among local governments that water markets may lead to underproduction of essential crops, policymakers might consider subsidising production of essential crops to make them more competitive with other demands for water. A full and integrated set of laws and institutions and their judicious application are required to assure equitable and efficient use of the world's water resources (California State Water Resources Control Board, 2002).

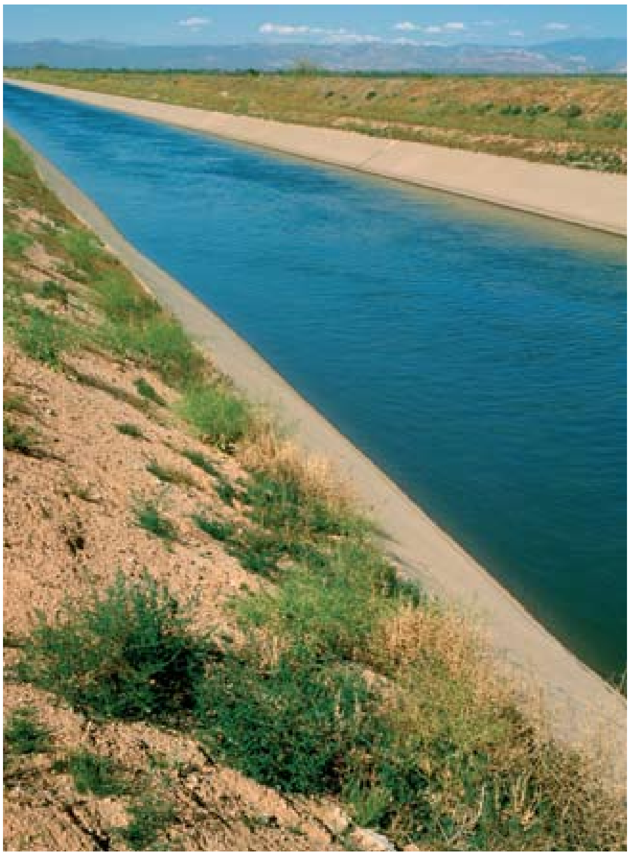


Photo: BrandXPictures

Climate change

Climate change will affect the rights of competing users of water resources. A study of the Sacramento Basin in California estimated, for example, that if temperatures increased by 2 degrees Celsius and precipitation patterns remain unchanged, summer flows (June–August) would decline by 22%, while winter runoff (December–February) would increase by 8% (Gleick, 1987). The estimates were based on changes in temperature only.

Climate change will affect the initial surface runoff into stream systems, rates of evaporative loss, seepage to groundwater aquifers, recharge from those aquifers, and rates of consumptive use for irrigation along entire stream systems. Until climate change is better understood, the magnitude of these changes and estimates of reliability will be difficult to predict.

Climate change will increase the ambient air temperature in the southwestern United States. This would result in increased evapotranspiration. In the case of transfer proposals, water authorities often limit the quantity of water transferred from an existing user to another place or type of use to the seller's historic consumptive use, to prevent impairment of other water rights. For example, half of the water diverted to an irrigated field might currently be lost to evapotranspiration while the remainder returns to a useable water body. If the right is transferred, the buyer's diversion right would be established to allow expected consumption equal to half of the original diversion right (Miller et al., 1997).

The prospect of climate change makes it difficult to forecast future uses and availability of water and to keep existing supplies reliable. Once climate models are scaled to specific watersheds, existing law will have to be applied to resolve future conflicts. For example, the law prohibiting waste and unreasonable use could be used to address site-specific re-evaluation of water use on a case by case basis. The public trust doctrine also allows for the re-examination of past allocation decisions where a change in circumstances or a passage of time warrants the review (Atwater and Markle, 1988).

Conclusion

Government agencies and private water markets will increasingly use interbasin water transfers to meet future demands for water. Creating institutions and regulations to address the impacts of increasing urban growth and the potential impacts of global climate change on regional supplies is essential. Water rights laws, environmental regulations, and administrative procedures need to be developed and updated, possibly to provide reliable water supplies, and minimise disputes and degradation in both source and receiving water basins. ■

References

- Attwater, W. and Markle, J. (1988) Overview of California Water Rights and Water Quality Law. Pacific *Law Journal* 19: 957–1030.
- Bancroft Library (2007) A Brief History: *San Francisco's Water Supply.* Librarians Association of the University of California: Website publication http://www.lib.berkeley.edu/WRCA/SFh2o//history.html.
- California State Water Resources Control Board (2002) Water Transfer Issues in California. Website publication http://www.waterboards.ca.gov/waterrights/water_issues/programs/water_transfers/docs/watertransferissues.pdf.
- *Catskill Mountains Chapter of Trout Unlimited v. City of New York,* 451 F.3d 77 (2nd. Cir. (N.Y.), 2006).
- CAA – Clean Air Act of 1970 (2009), §§ 101–618, Title 42, United States Code, §§ 7401–7671q.
- CWA – Clean Water Act of 1972 (2009), §§ 101–607, Title 33, United States Code, §§ 1251–1387.
- Ecoworld (2010) *India's Water Future – Are Interbasin Water Transfers a Solution?*, Website publications http://www.ecoworld.com/waters/indias-water-future.html.
- ESA – Endangered Species Act of 1973 (2009), §§ 1–18, Title 16, United States Code, §§ 1531–1544.
- *Friends of Everglades v. South Florida Water Management District,* 570 F.3d 1210 (11th Cir. (Fla.), 2009).
- Gleick, P.H. (1987) Regional Hydrological Consequences of Increases in Atmospheric CO2 and Other Trace Gases. Climate Change 10: 137–161.
- Hansen, R.D. (1983) Water and Waste Water in Imperial Rome. *Water Resource Bulletin* 19: 263–69.
- Hutchins, W.A. (1971) *Water Rights Laws in the Nineteen Western States.* U.S. Department of Agriculture Miscellaneous Publication #1206. Washington D.C., USA: U.S. Department of Agriculture.
- *Joslin v. Marin Municipal Water District,* 67 Cal.2d 132, 429 P.2d 889 (Cal., 1967).
- Little, J.B. (2000) Dust Settles in Owens Valley. *High Country News.* High Country News: Website publication http://www.hcn.org/issues/177/5732.
- Miller, K.A., Rhodes, S.L. and MacDonnell L.J. (1997) Water Allocation in a Changing Climate: Institutions and Adaptation. *Climate Change* 35:157–177.
- Mono Lake Committee (2009) *The Mono Lake Story.* Mono Lake Committee: Website publication http://www.monolake.org/about/story.
- Moore, M. Mulville, A and Weinberg, M. (1996) Water Allocation in the American West: Endangered Fish Versus Irrigated Agriculture. *Natural Resources Journal* 36: 319–357.
- *National Audubon Society v. Superior Court,* 33 Cal.3d 419, 658 P.2d 709 (Cal., 1983).
- NEPA – National Environmental Policy Act of 1969 (2009), §§ 1–209, Title 42, United States Code, §§ 4321–4347.
- NYC – New York City Department of Environmental Protection (2009) *History of New York City's Water Supply System.* New York City: Website publication http://www.nyc.gov/dep/htm/drinking_water/history.html.
- Reisner, M. (1986) *Cadillac Desert: The American West and Its Disappearing Water.* New York, New York, USA: Viking Press.
- Rogers, H.E. and Nichols, A.H. (1967) *Water for California: Planning, Law & Practice, Finance.* San Francisco, California, USA: Bancroft-Whitney.
- SFPUC – San Francisco Public Utilities Commission (2009) *Hetch Hetchy Water and Power.* City of San Francisco: Website publication http://sfwater.org/Dept.cfm/MC_ID/18/MSC_ID/134/MTO_ID/701/MO_ID/20.
- Sax, J.L. (1970) The Public Trust Doctrine in Natural Resources Law: Effective Judicial Intervention. *Michigan Law Review* 68(3): 471–566.
- Security Pacific Historical Photograph Collection, Los Angeles Public Library, as reproduced in Hundley, Jr., N. (2001) *The Great Thirst,* p. 164. California, USA: University of California Press.
- Southern Nevada Water Authority (2010) *Clark, Lincoln and White Pine Counties Groundwater Development Project:* Website publication http://www.snwa.com/html/system_gdp.html.
- SWRCB – State Water Resources Control Board (2002) *Revised Order WRO 2002–0013.* Sacramento, California, USA: State Water Resources Control Board.
- Stevens, J.S. (1980) The Public Trust: A Sovereign's Ancient Prerogative Becomes the People's Environmental Right. U.C. *Davis Law Review* 14(2): 195–232.
- Van de Mieroop, M. (1997) *The Ancient Mesopotamian City.* Oxford, UK: Oxford University Press.
- Wilbur, R.L. and Ely, N. (1948) *The Hoover Dam Documents*, H.R. No. 717, 80th Congress, 2nd Session A100.

Mr. David S. McCauley
Principal Climate Change Specialist, Asian Development Bank
dmccauley@adb.org

Water and climate change in Asia: facing up to the impacts and costs

The Asia and Pacific region has a very large population at particular risk from climate change, especially in the water and agriculture sectors. Concrete responses are beginning at various levels, with development agencies responding to developing country demands by providing increasing levels of technical and financial support. Climate change is a real game changer for water managers, but adapting to climate change – while requiring innovation – will draw upon and reinforce what we already know to be the best practices of the water profession.

This paper begins with a brief review of the causes and consequences of climate change as they affect water management in Asia and the Pacific. We then examine the costs that this will impose on the economies and peoples of the region. Current and prospective responses being taken by countries of the region are also summarised, as well as the financial support being made available to address these challenges. The paper concludes by looking ahead to what appear to be the main short- and longer-term implications of climate change for international economic development, particularly in the Asia and the Pacific region.
Keywords: Asia, climate change, climate change impacts, game changer, best practice.

Climate change: causes and consequences

The Cassandra Curse on the environment and climate change communities has largely been lifted, and we now hear about the dangers of global warming in the popular media nearly every day. It is worth briefly reviewing causes and consequences when it comes to tracking the impacts of this grand – and reckless – experiment being conducted with our planet. The concentrations of carbon dioxide (CO_2) and other greenhouse gases in our atmosphere are now above the highest levels observed over the past 800,000 years (Luthi et al., 2008). As of late 2009, the CO_2 level was already 387 parts per million (ppm) (NOAA/ESRL, 2009). As indicated in Figure 1, this is well outside the bounds of natural variability. The paleoclimate record also shows an undeniable correlation between the level of CO_2 and average air temperature. It is troubling that greenhouse gas concentrations are still rising rapidly. Scenarios developed by the UN Intergovernmental Panel on Climate Change (IPCC) indicate that in the absence of rather drastic global action, CO_2 equivalent levels will reach at least 650 ppm by the end of this century, resulting in a 2 to 6° C average temperature increase globally. Alarmingly, many impacts seem to be occurring more quickly than the IPCC anticipated in its latest assessment in 2007. For example, new studies suggest that the Arctic Ocean may have ice-free summers by 2030 (Stroeve et al., 2008), and that sea levels may increase by around one metre this century (Rahmstorf, 2007), almost twice the IPCC (2007) estimate.

The G-8 has agreed that they should collectively act to hold the average temperature increase to no more than 2° C compared to pre-industrial levels, and the G-20 has agreed that developed countries should reduce their emissions by at least 80% by 2050. This will be a daunting task, as evidenced by the difficulties encountered in the intergovernmental negotiations towards a post-2012 climate change regime under the United Nations Framework Convention on Climate Change (UNFCCC).

As any good hydrologist should know, a warming of Earth's atmosphere means it will hold more energy in the form of evaporated water,

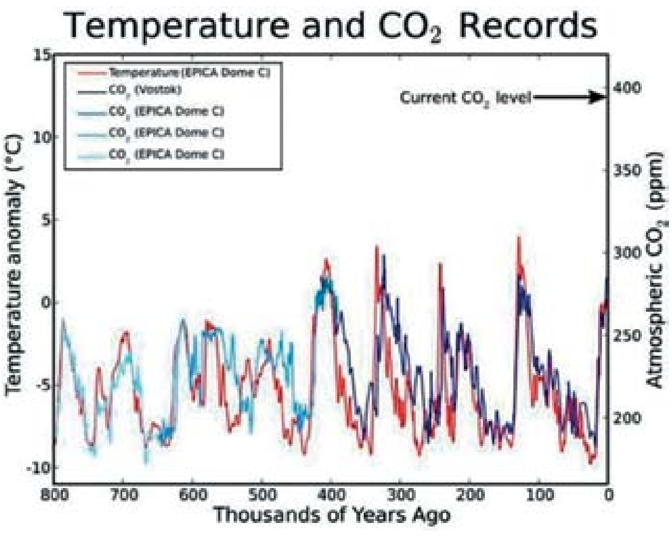


Figure 1. Correlation between the level of CO2 and air temperature

and this energy will be redistributed across the planet, with air circulation being the principal means of exchange. That is why an increase in the intensity of extreme storm events is anticipated and may already be occurring. We will also see direct impacts of warming on the global water cycle, such as the melting of polar ice caps, ice shelves and glaciers; and rising ocean temperatures, each contributing to rising sea levels. There are some other direct effects of higher CO_2 levels in the atmosphere. In particular, the acidity of our oceans will increase as they absorb more CO_2, and this will put a wide range of coastal and marine organisms under stress. There may also be some mildly positive effects from higher CO_2 levels in the atmosphere, principally on plant productivity.

Figure 2 is a well-known representation of climate change consequences adapted from the Stern Review on the Economics of Climate Change (Stern, 2007). It highlights both the uncertainty in projected temperature increases for each assumed level of atmospheric CO_2, and the increasing severity of impacts as temperatures increase. For example, an atmospheric CO_2 equivalent level stabilised at 430 ppm translates into an average temperature rise in the range of 1 to 3°C. Even under this extremely optimistic scenario, crop yields will fall; glaciers will disappear; water scarcity will greatly increase; and ecosystems ranging from coral reefs to forests will come under stress, resulting in accelerated species loss. Accompanying these changes will be a growing intensity of storms, forest fires, flooding and heat waves. Finally, and most troubling, there is a rising risk of irreversible change – of reaching so-called tipping points, above which self-reinforcing processes (like methane release from melting tundra or reduced sunlight reflection from surface ice) make it more difficult, if not impossible, to rein in the process of global warming.

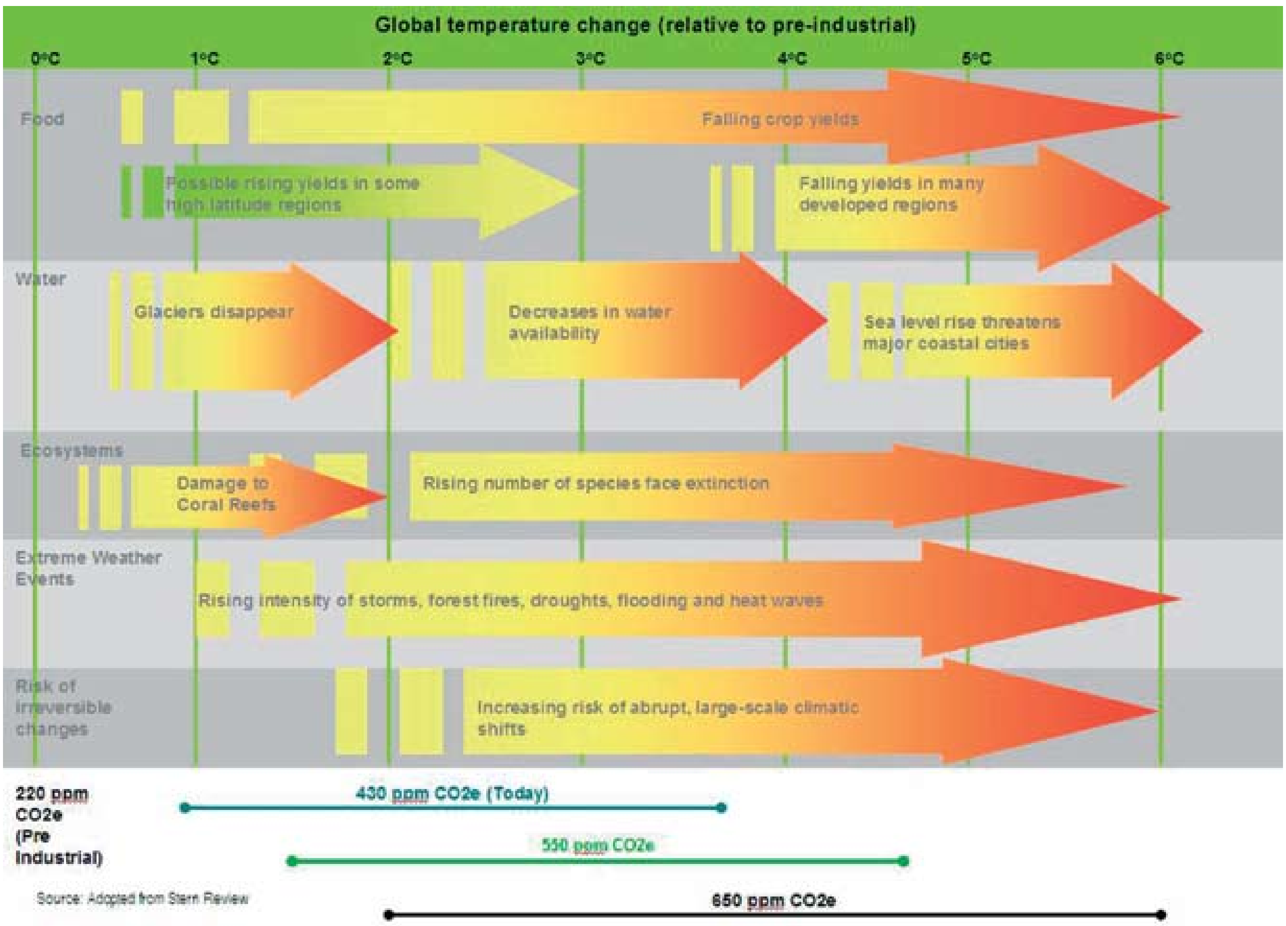
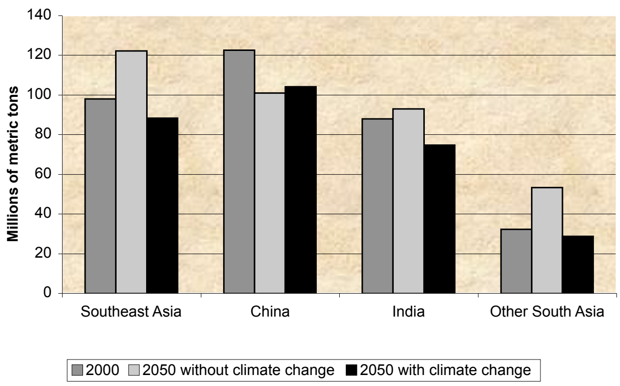


Figure 2. Projected impacts of climate change

Climate change costs in Asia

These impacts, and the resources required to cope with them, threaten to undermine the impressive reductions in poverty achieved in Asia over the past two decades. There is no question that the additional actions required will be costly. A number of efforts are underway to put a price on these impacts and adaptive responses, particularly because financing for adaptation has become so central to the UN climate negotiations. The World Bank has prepared preliminary estimates of adaptation costs based on seven country case studies using economic modelling. This study places annual developing country adaptation cost estimates in the range of US$75 to 100 billion (World Bank, 2009). A recent internal ADB estimate has suggested that the least developed countries of Asia and the Pacific alone will face adaptation costs of about US$15 billion in total over the next decade.

Further, an ADB-commissioned study by the International Food Policy Research Institute (IFPRI) of climate change impacts on Asian agriculture has estimated adaptation costs over the next 10 years to be US$24 billion for just this sector (Asian Development Bank and International Food Policy Research Institute, 2009). This refers to investments in adaptation measures only; and does not take into account the losses from foregone agricultural production or impacts on food prices. These latter impacts will be substantial, as the IFPRI study predicts falls in both irrigated rice production and wheat production by 2050 (Figure 3). Global food prices will rise as a result (Figure 4).



Source: Asian Development Bank and International Food Policy Research Institute (2009)
Figure 3. Likely impact of climate change on Asian rice production

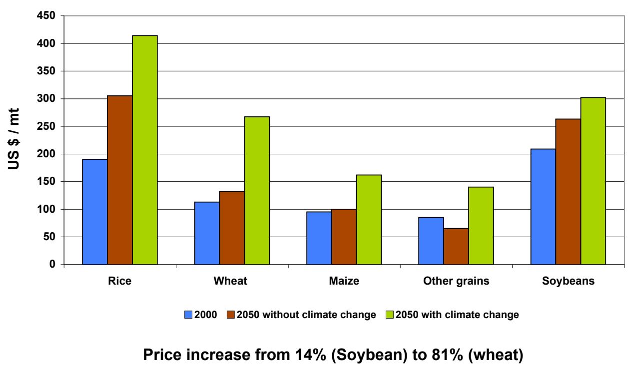


Figure 4. Impact on international food prices

ADB has conducted a study of the combined economic impacts of climate change on the four largest economies of Southeast Asia – Indonesia, the Philippines, Thailand and Viet Nam. The results of this analysis indicate a 1% sacrifice in GDP (Figure 5) in 30 years' time, with GDP losses growing to between 6 and 7% by the end of the century (Asian Development Bank, 2009). Much of this will come from costs incurred in the agriculture and water sectors, especially in the region's largest river basins. Disaggregated modelling of impacts is getting underway for some of these basins.

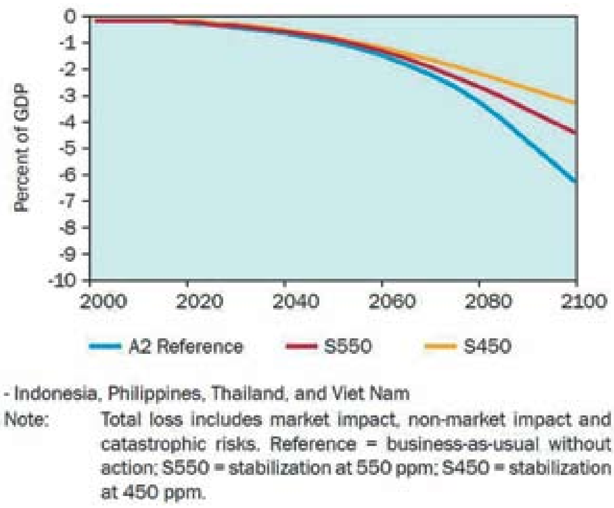


Figure 5. Mean GDP loss due to climate change in four Southeast Asian countries*

How are these costs to be financed? Although the costs of adaptation to climate change cannot be known with precision, they are clearly measured in billions of dollars per year. How can Asian and Pacific countries, particularly those struggling to reduce existing poverty and inequality, possibly afford the adaptation investments required to protect against damage to their economies?

Responses to the climate challenge

Asian and Pacific countries are, by and large, taking climate change very seriously. The majority either have in hand or are developing some form of national climate change action plan, policy or strategy, which generally includes both mitigation and adaptation responses. They are making their demands heard in international forums, especially in the United Nations Framework Convention on Climate Change (UNFCCC) negotiations towards a post-2012 global climate agreement. Some are already planning and evaluating defensive measures against rising sea levels and increased flooding, as in Ho Chi Minh City, where a levee system is under examination. A recent ADB-commissioned study found that roughly 40% of the city lies within 1 metre of current sea levels, and by 2050 as many as 11 million people will be at risk from sea level rise and extreme weather events. Asian and Pacific countries are also responding through the strengthening of knowledge-sharing partnerships, including creation of a network of Asian water hubs established through the Asia-Pacific Water Forum (Figure 6).

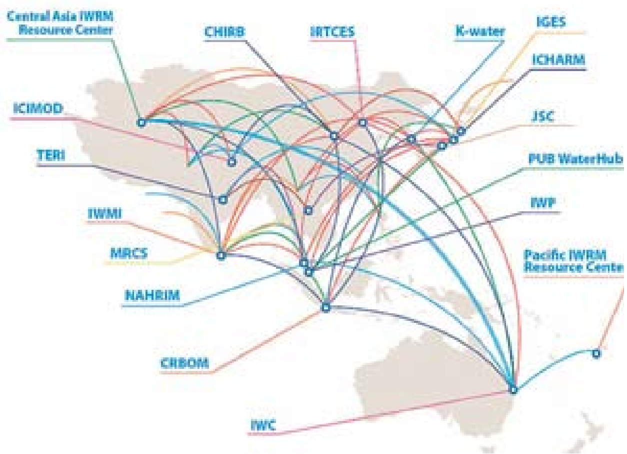


Figure 6. Network of Asian and Pacific water knowledge hubs

Most countries of Asia and the Pacific are now convinced that an altogether new development paradigm is needed; one that takes account of the physical, economic and political impacts of climate change. Developed countries tend to see Asia as the fastest-growing source of new emissions: a competitor for the global atmospheric commons and hence a target for mitigation financing and technical support to ensure that future development follows a low-carbon path. But low-carbon development strategies remain dependent on largely unproven technologies and financial mechanisms. Asian and Pacific countries understandably view the political pressure for low-carbon growth as yet another negative impact of a climate change problem they did little to create. They are asked to join global efforts to curb GHG emissions, and they are committed to doing so. But the risk of constrained economic growth on future well-being is just as real as the physical impacts of climate change. Fairness requires that the economic risks are managed as well as the physical risks.

Dedicated financial assistance is already flowing, and the flow is increasing. A number of publicly-supported global climate change funds exist, including the Global Environment Facility (GEF), established in the early 1990s. GEF anticipates a substantial replenishment to expand from providing US$250 million a year in mitigation funding to as much as US$1 billion per year, and it aims to make another US$250 million available annually for adaptation, as a supplement to resources already flowing through the Least Developed Countries Fund and the Special Climate Change Fund.

The World Bank and the regional development banks, including the ADB, facilitated establishment of the Climate Investment Funds (CIF) with financing from developed countries. The CIF has four windows: (i) the Clean Technology Fund, with about US$5 billion pledged for "transformative" mitigation actions; (ii) the Pilot Program on Climate Resilience, with nine countries and two regional programmes already identified, and more than US$600 million already pledged to allocate for adaptation actions; (iii) the Forest Investment Program, with more than US$550 million pledged, to help prepare for the new carbon market mechanism of Reduced Emissions from Deforestation and Degradation (or REDD); and (iv) the Scaling-up Renewable Energy for Low-income Countries Program, expected to make at least US$300 million available to help ensure that rural populations are not denied access to energy as a consequence of the shift to low-carbon development.

Since the Bali Action Plan was adopted in 2007, attention was focused on the negotiations leading up to Copenhagen. The UNFCCC's Adaptation Fund, financed by a 2% levy on the Clean Development Mechanism (CDM) and other contributions, provides some insight into what sort of financial mechanism is likely to be built into a post-2012 climate change regime. The Adaptation Fund has an international Board, with developing countries in the majority. Its operations have been delayed as it has struggled to come to agreement on how developing countries can get direct access to funds, without having to go through UN bodies or multilateral development banks. These issues have now largely been settled, and there is agreement on the principle that, given sufficient capacity, institutions in the developing world should be direct recipients of this financing.

Photo: BrandXPictures

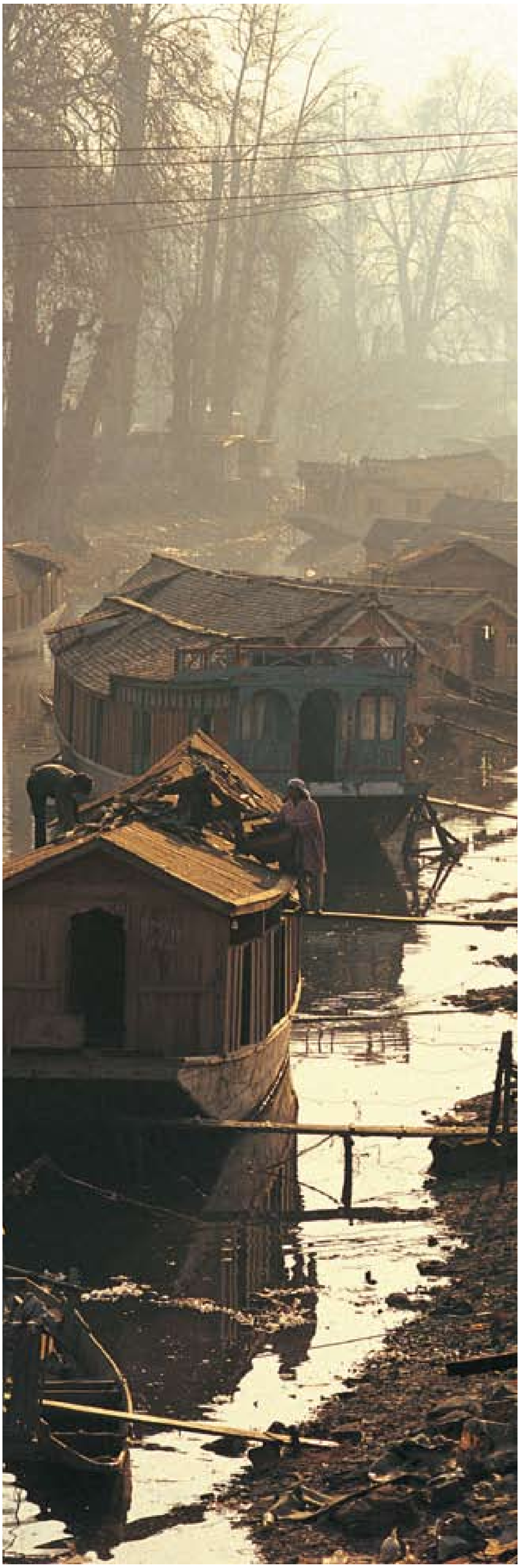


Photo: BrandXPictures

In response to developing country demands and an acknowledgement of the financing needed to shift away from high-carbon development patterns, a number of proposals were put forward in the lead up to Copenhagen that would establish new, larger climate funds. Some of these suggest public financing levels of up to US$100 billion per year, which will test the generosity of developed country legislatures. Others rightly acknowledge the very important – even leading – role that must be played by the private sector in raising sufficient investments. But there is arguably more climate change funding available right now than can be fully programmed. That does not mean efforts should slow. ADB itself has allocated US$50 million of its own resources to an in-house Climate Change Fund to accelerate action.

Much of the adaptation support seen in Asia is targeting the water and agriculture sectors. For example, the main adaptation windows administered by GEF have seen their resources heavily weighted toward water investments. Fourteen out of 18 projects financed by the LDCF and 14 of 16 projects under the SCCF are tied in some way to water management – based on developing country demands. The focus of these projects has ranged from securing urban water supplies to building drought resilience to dealing with increased threats from glacial lake outbursts. While the GEF funds are global programmes, Asian countries have been major recipients.

Between the new CIF financing being channelled through the multilateral development banks, the GEF and the Adaptation Fund, multilateral mechanisms are likely to channel between US$8 and US$12 billion in new, dedicated climate change funding to developing countries through 2012. And this does not take account of the US$7 to US$13 billion already available annually for clean energy investments (and some adaptation support) through normal financing channels of the multilateral development banks. ADB alone spent US$1.7 billion on clean energy projects in 2008. Between 2010 and 2012, that translates into US$30 to US$50 billion available through well-established multilateral institutions and channels. And the bilateral climate change programmes of developed countries are also expanding. Further financing will be provided through bilateral assistance channels.

While the great majority of these resources will be targeted to mitigation actions, there should still be billions of dollars available to move ahead with adaptation measures, with the water sector and the Asia and Pacific region arguably the highest priority. In addition to infrastructure investments, a wide range of institutional adjustments will be called for. And to be efficient, market forces will need to be harnessed through policy instruments like water charges or pollution permitting.

If all of this sounds familiar, it should not be surprising. Climate change is a game changer for water managers, but adaptation to climate change, while requiring major new investments and heavy doses of innovation, will fundamentally be based upon and reinforce what we already know to be best practices in the water profession. While dealing with a daunting new set of threats, water-related interventions will mostly be extensions of good development practice that is well established. Such practices, including integrated water resources management (IWRM), diversification of sources, demand management and the use of seasonal forecasts, are increasingly well documented, for example Ludwig et al. (2009).

Looking ahead

Our recent history of steady advances in the ability to manage and allocate water resources should provide some comfort as we tackle the additional challenges posed by climate change. There will certainly be a need for fundamental new changes to water resources management as well. Historical climatic and hydrological patterns will no longer be trustworthy guides for the future, and improved forecasting at seasonal and interannual time scales will be needed. Such forecasts will in turn require improved and widely disseminated projection scenarios based on the disaggregation and downscaling of General Circulation Models, with a particular emphasis on improving model simulations over the Asia and Pacific region. We will need to greatly strengthen disaster risk prediction, preparedness and response. And with the water and agriculture sectors at greatest risk, much of the new adaptation financing should flow to these sectors.

We do not know yet exactly what scale and form the new global public funding will take. The broad framework for a financial mechanism under a post-2012 agreement will likely be decided over the next 1–2 years with the financing details taking a bit longer. While there will continue to be a call for balance between adaptation and mitigation financing, it is difficult to see how adaptation can survive as a distinct concept – and especially as a way of organising finance – much beyond the terms of the new climate change agreement. Large sums will be made available in the short run to help developing countries deal with the incremental costs of adapting to a changing climate – especially because this problem is largely not of their making.

But looking ahead 10 years or so, climate change mainstreaming will have advanced. Can we readily imagine an engineer, when designing a new dam, bothering to compare his or her cost estimates with what would have been the cost of constructing the dam in the absence of climate change? By then, the practice of accounting for locally predicted changes in precipitation patterns and temperatures as a result of global change will be routine. Moreover, the heavy overlap between what's called for to ensure the application of best practices in water management and adaptation needs illustrates the imperative of mainstreaming adaptation into the development process. There are temporary political constraints to this at the global level, due primarily to the need to show that adaptation financing is new and additional to development aid flows. But in time the financial accounting and field realities will win out.

So adaptation will probably survive as an operational concept in only a few special cases. The first is in response to the unfortunate situation faced by Small Island Developing States, who must cope with the prospect of being submerged by a rising sea. Their plight is so obviously tied to climate change, that they will receive special aid. Second, there will probably be an acknowledged need for special international relief financing tied to weather-related disasters. This may take the form of a dedicated, UN-managed account with criteria for its dispersal tied to acknowledged climate change impacts. There may also be targeted assistance to address the special problem of climate-induced migrants, who may number as many as 50 million by 2050 according to some estimates (Asian Development Bank and University of Adelaide, 2009). And finally, the climate crisis should result in an overall increase in funding for the water sector, since the increased burden imposed by climate change will be inextricably tied to the need for better water management.

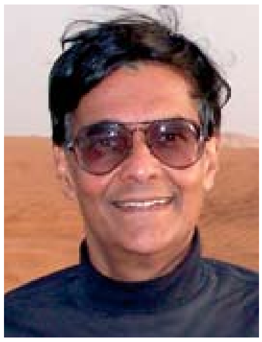
This places a heavy and growing responsibility on the water professions, especially in Asia, with its hundreds of millions living in vulnerable areas along coasts, in basins fed by glaciers, or on semi-arid lands subject to more frequent drought. All of the available economic analyses indicate that investing now will be much less costly than waiting for the impacts to arise. So it is time for action. The financial resources are there and will likely expand. And along with the seas and flood waters, the countries of Asia and the water profession should rise to this challenge.

Acknowledgements

The author wishes to acknowledge valuable inputs from Charles Rodgers, Senior Water and Climate Change Consultant, Asian Development Bank. ■

References

- Asian Development Bank (2009) *The Economics of Climate Change in Southeast Asia: A Regional Review.* Manila, Philippines: ADB.
- Asian Development Bank and International Food Policy *Research Institute (2009) Building Climate Resilience in the Agriculture Sector of Asia and the Pacific.* Manila, Philippines and Washington, DC, USA: ADB and IFPRI.
- Asian Development Bank and University of Adelaide (2009) *Climate Change and Migration in Asia and the Pacific (Executive Summary).* Manila, Philippines: ADB.
- Ludwig, F. Kabat, P., van Schaik, H. and van der Valk, M. (Eds.) (2009) *Climate Change Adaptation in the Water Sector.* London, UK: Earthscan.
- Luthi, D., Le Floch, M., Bereiter, B., Blunier, T., Barnola, J.-M., Siegenthaler, U., Raynaud, D., Jouzel, J., Fischer, H., Kawamura K. and Stocker, T.F. (2008) High-Resolution Carbon Dioxide Concentration Record 650,000–800,000 Years Before Present. *Nature* 453: 379–382. doi:10.1038/nature06949.
- NOAA/ESRL (2009) *Trends in Atmospheric Carbon Dioxide,* NOAA/Earth System Research Laboratory: Website publication http://www.esrl.noaa.gov/gmd/ccgg/trends.
- Rahmstorf, Stefan (2007) A Semi-Empirical Approach to Projecting Future Sea-Level Rise. *Science* 315(5810): 368–370.
- Stern, N. (2007) *The Economics of Climate Change: The Stern Review.* Cambridge, UK: Cambridge University Press.
- Stroeve, J., Serreze, M., Drobot, S., Gearheard, S., Holland, M., Maslanik, J., Meier, W. and Scambos, T. (2008) Arctic Sea Ice Extent Plummets in 2007. *Eos* 89(2): 13–14.
- World Bank, 2009. *The Costs to Developing Countries of Adapting to Climate Change – New Methods and Estimates (Consultation Draft).* Washington, DC, USA: World Bank.



Prof. Mohan Munasinghe
Chairman, Munasinghe Institute for Development (MIND); Director-General, Sustainable Consumption Institute (SCI), University of Manchester; Honorary Senior Advisor to the Government of Sri Lanka; and Co-laureate, 2007 Nobel Prize for Peace (Vice Chair, IPCC-AR4)
mohan@mindlanka.org

Integrated solutions for water, sustainable development and climate change issues: Applying the sustainomics framework

This paper practically addresses major global challenges involving water, sustainable development and climate change, which are interlinked. Water and climate change issues undermine development prospects and worsen existing problems, especially poverty. A longer term vision should go below the surface level development indicators, addressing deeper issues systematically and focusing on both immediate drivers and underlying pressures. The most effective approach is to integrate climate change and water policies into a national sustainable development strategy, using the sustainomics framework for "making development more sustainable", with balanced and integrated analysis from three main perspectives – social, economic and environmental. Several applications of practical tools are shown at the global, national and local levels.

Keywords: sustainable development, climate change, water, sustainomics

Introduction

Water problems are closely linked to the two major challenges of the 21st century – sustainable development and climate change. Water and climate change issues undermine development prospects by worsening existing problems, including poverty, hunger and illness (IPCC, 2007, 2008; IARU, 2009). Current solutions are piecemeal and inadequate. The novel argument in this paper is that these issues can, and must, be addressed together. The sustainomics framework for "making development more sustainable" is described, which provides the most effective solution – by integrating water and climate change policies into a national sustainable development strategy (Munasinghe, 2007). The approach relies on a balanced and integrated analysis from three main perspectives – social, economic and environmental. A longer term vision of sustainable development is set out, that goes below surface level indicators of development, addressing deeper issues systematically and focusing on both immediate drivers and underlying pressures. Several case studies at the global, national and local levels illustrate practical applications of the methodology.

Water and development

Water is essential for human activity – for drinking and sanitation, agriculture, hydropower, fisheries, industry, etc. (UNICEF/WHO, 2005). It is also crucial for ecosystem services, which support life on the planet (MA, 2005). Key issues in the water sector include; meeting growing water needs for development and poverty alleviation, mobilising funds to meet rising costs, maintaining financial viability, improving governance, ensuring diverse, affordable and reliable water services, protecting the environment, and balancing competing uses (World Bank, 2005).

Safe drinking water is unavailable to 900 million people, while over 2 billion lack adequate sanitation (World Bank, 2005). Over US$11 billion per year is needed to meet the drinking water and sanitation targets of the Millennium Development Goals (UNICEF/WHO, 2004). In 2001, two million people died from infectious diarrhoeas – two thirds were children under five, and most deaths were preventable (UNICEF/WHO, 2005). Poor people living in the slums often pay five to ten times more per litre of water than wealthy people living in the same city (UNDP, 2006) As incomes rise, urban-industrial water demand increases, often leading to competition with rural-agricultural users.

Photo: Gety Images

Water scarcity exacerbates other development problems among the 3 billion people who survive on less than US$2 per day and almost a billion who are malnourished – many of them children. Two billion do not have access to electricity, while billions are also sick, exposed to environmental degradation (air, land and water), lack shelter and are vulnerable to disasters (IPCC, 2008; UNDP, 2009; Alcamo et al., 2007).

Climate change – risk multiplier

Climate change is a major risk multiplier, systematically worsening all other problems. The latest scientific evidence indicates that global warming is unequivocal and almost certainly caused by increased greenhouse gas (GHG) emissions from post-industrial human activities (IPCC, 2007; IARU, 2009). Global warming is already worsening water-related problems. Climate change will likely intensify into the foreseeable future, with severe consequences for the inhabitants of planet Earth.

The IPCC (2007) comprehensively describes past and present trends. For over 10,000 years, atmospheric carbon dioxide concentrations were stable at 275 parts per million by volume (ppmv). However, following the industrial revolution, these concentrations rose rapidly, now exceeding 385 ppmv. During the past 100 years, this excess CO2, together with other minor GHG, like methane and nitrous oxide, have acted as a blanket to trap excess solar radiation and warm the planet's surface an average of 0.75 °C, through a process called climate forcing. There is other convincing evidence of accelerating climate change – including a systematic rise in the mean sea level (17 cm during the past century), melting of ice in polar areas and glaciers, increased damage caused by extreme weather events, less precipitation in dry areas and more in wet areas, and significant changes in ecosystems and animal behaviour.

If emissions are not curbed, by 2100, CO_2 concentrations will be about twice the pre-industrial level (i.e. 550 ppmv). Even if GHG emissions were sharply cut, temperatures would still rise by at least 1.5 °C by 2100. Increasing scientific evidence suggests that 2 °C (corresponding to 400–450 ppmv) is the "dangerous" risk threshold, which implies that global emissions of greenhouse gases need to peak by 2020 at the latest. The post IPCC-AR4 data emerging during the past three years indicates that the situation is indeed worsening (IARU, 2009). By 2100, the average global temperature will increase by over 3 °C above current levels, and the mean sea level will rise at least half a metre. Extremes of temperature and precipitation will worsen, and the melting of ice will accelerate. Weather events will also become more extreme – especially tropical cyclones and heat waves.

Groups most vulnerable to climate change impacts are the poor, elderly and children, including those living in rich countries (IPCC, 2007). The most affected regions will be the Arctic, sub-Saharan Africa, small islands, and Asian megadeltas. High risks will be associated with low-lying coastal areas, water resources in dry tropics and subtropics, agriculture in low-latitude regions, key ecosystems (like coral reefs) and human health in poor areas.

Such impacts make many of the Millennium Development Goals (MDGs) even more difficult to achieve (MDG, 2009). Major MDGs include: eradicating extreme poverty and hunger, achieving universal primary education, promoting gender equality and empowerment, reducing child mortality, improving maternal health, combating HIV/AIDS, malaria and other diseases, ensuring environmental sustainability and building a global partnership for development.

Climate–water interactions

Climate change will have severe adverse impacts via the hydrological cycle, especially on the vulnerable poor (IPCC, 2007). More droughts and floods are already causing social instability, food insecurity and long-term health problems (especially in growing mega-city slums). Sea-level rise and worsening storms could affect hundreds of millions by 2050.

The two human responses to climate change are adaptation and mitigation. Making development more sustainable by mainstreaming adaptation and mitigation measures into a sustainable development strategy is considered the most effective solution (Munasinghe, 2002; IPCC, 2007; IARU, 2009). Adaptation refers to adjustments in human and natural systems that reduce vulnerability to climate stresses, moderate damage and enhance benefits – such as building higher sea walls, or strengthening water systems against droughts. Mitigation covers activities that reduce GHG emissions, which will worsen future climate change – such as reducing energy use, halting deforestation, or absorbing atmospheric CO_2 by growing biomass.

Water and development are interlinked with both adaptation and mitigation. For example, more sustainable water management will make adaptation and mitigation more effective, by enhancing agriculture and forestry. Conversely, many adaptation and mitigation policies can help make water use and overall development more sustainable. Effective longer-term response measures include strengthening water system resilience, building the adaptive capacity of vulnerable socioeconomic and ecological systems and managing disaster risks. More data and analytical capability is crucial.

Current global problems and ineffective solutions

In this section, key emerging global risks are analysed and shortcomings in present day remedies are highlighted, prior to presenting a sustainable development vision for the future. The world is currently facing multiple economic, social and environmental threats, where short-sighted policies enable a few people to enjoy immediate gains while the unsuspecting majority will pay huge "hidden" costs in the future. These threats can interact catastrophically, unless they are addressed urgently and in an integrated fashion, by making development more sustainable (Munasinghe, 2007, 2009). Piecemeal responses have proved to be ineffective, since the problems are interlinked.

Economic, social and environmental risks

The economic collapse is the most urgent and visible global problem. An asset "bubble", driven by investor greed, rapidly inflated the value of financial instruments well beyond the true value of the underlying economic resource base. The collapse of this bubble in 2008 caused the global recession (OECD, 2009; Taylor, 2009). It is estimated to contain some $100 trillion of "toxic" assets (up to twice the annual global GDP).

Meanwhile, poverty and inequity continue to be major social problems, undermining the benefits of the rapid economic growth of recent decades, and excluding billions of poor from access to productive resources and basic necessities, like safe water and sanitation, food, energy, health care and shelter (World Bank, 2009). In 2000, the top 20% of the world's population by income consumed 60 times more than the poorest 20%. Poverty is now exacerbated by the economic recession, which is worsening unemployment and access to survival needs.

Finally, mankind faces major environmental problems because myopic economic activities continue to severely damage the natural resource base on which human well being ultimately depends (MA, 2005; UNEP, 2008). Climate change is the classic global manifestation of this threat, but equally serious issues are the degradation of local water, air and land resources. Ironically, the worst impacts of climate change will fall on the poor, who have very little responsibility for causing the problem (IPCC, 2007).

And what are our current policy priorities as we face these challenges? Governments have very quickly found about US$5 trillion dollars for stimulus packages to revive shaky economies (G20, 2009). However, only about US$100 billion per year is devoted to poverty reduction, and far less to combat climate change (World Bank, 2009). Furthermore, the recession has dampened enthusiasm to address more serious long-term poverty, climate and other environmental and social issues.

World leaders missed a golden opportunity to simultaneously address these multiple threats, by using the US$4 trillion dollars of stimulus funds more effectively. A much larger share should have been invested in the key areas of green resources and infrastructure, especially water (as well as agriculture, renewable energy, and transport), sustainable livelihoods and safety nets for the poor, and social development (typically education, health and safety), to stimulate the economy, increase employment, reduce poverty and protect the environment (including the climate). Instead, funds were used to protect current expenditures – especially wasteful subsidies and bank bailouts that merely restored the failed status quo. The momentum for longer-term change was lost.

In the water sector alone, an investment of US$11–12 billion per year (a fraction of the stimulus funds) would have helped achieve the Millennium Development Goal 2015 targets for drinking water and sanitation (UNICEF/WHO, 2004). On average, every US$1 invested in water and sanitation provides an economic return of US$8, plus other benefits due to improved health, well-being and productivity.

Long-term vision of sustainable development

Unless multiple global problems are addressed promptly, humanity faces a difficult future. A brighter alternative pathway is discussed below.

A longer-term vision is summarised in Table 1. The top row shows how our current focus on surface level indicators, like poverty, inequity, exclusion, resource scarcities and conflict, poor governance and environmental harm, is driven by powerful phenomena like globalisation and unconstrained market forces based on the "Washington Consensus". Problems are addressed myopically, in a reactive uncoordinated and piecemeal manner (the "silo" mentality). Therefore, present trends pose significant risks that could lead to a global breakdown, due to the ineffectiveness of governments seeking to cope with multiple, interlinked crises. Merely undertaking policy reforms to correct for market deficiencies would be inadequate to deal with these threats. Instead, deeper issues need to be addressed systematically (as described below).

The second row in Table 1 shows that an immediate transitional step forward is possible, by influencing key common drivers of change – consumption patterns, population, technology and governance. These drivers shape the main issues in the top row, and managing them will help address multiple issues in an integrated manner, controlling global trends and market forces.

Using known practical measures that make development more sustainable today, business and civil society could help governments move proactively towards the ultimate goal of sustainable development. This transitional step involves early action to overcome global inertia – specific measures using existing experience and tools are described below. To begin this process, a comprehensive practical framework called "sustainomics" was proposed at the 1992 Rio Earth Summit – see Box 1 (Munasinghe, 1992a).

The third row follows on from the successful implementation of the second (transition) row. Here, in coming decades our children and grandchildren could pursue their long-term goal of a truly global, sustainable development paradigm. They would need to work on deep underlying pressures linked to basic needs, social power structure, values, perceptions, choices and the knowledge base. Fundamental changes are necessary, driven by social justice and equity concerns through inspired leadership, a networked, multistakeholder, multi-level global citizens' movement, responsive governance structure, improved policy tools, advanced technologies and better communications (including the internet).

Main issues	**Poverty, inequity, exclusion, conflict, environmental harm, climate etc.**		**Present human responses** Business-as-usual with high risks from unrestrained, myopic market forces (Washington consensus, globalisation, etc.) Reactive: piecemeal, mainly government
Immediate drivers	**Consumption, population, technology, governance**		**Practical transition step (Sustainomics)** Making development more sustainable (MDMS), using systematic policy reform based on existing knowledge, to manage market forces. Proactive: integrated govt., business, civil society
Underlying pressures	**Basic needs, social power structure, values, choices, knowledge base**		**Long term goal (new SD paradigm)** Fundamental global sustainable development transition through multi-level, multistakeholder, citizens networks, advanced policy tools responsive governance and better technologies. Proactive: integrated civil society, business, government.

Table 1. Current risks and future vision
Source: Adapted from Munasinghe (2007)

Photo: BrandXPictures

Box 1: Sustainomics
– a practical framework for action

Decision makers invariably are pre-occupied with immediate problems, like growth, poverty, water and energy scarcity, food security, disease, unemployment and inflation. New issues, like environmental harm and climate change, have also emerged. The transitional, integrative step 2 shown earlier in Table 1, would help to make decision makers more aware of the interconnections among these problems and show how to integrate solutions into a national sustainable development strategy. One promising approach to do so is "sustainomics" – developed over the past 20 years. It draws on the following basic principles and methods (Munasinghe, 1992a, 2002).

Making development more sustainable (MDMS) for empowerment and action

First, making development more sustainable (MDMS) becomes the main goal. It is a step-by-step method that empowers people to take immediate action, which is more practical because many unsustainable activities are easy to recognise and eliminate – like conserving and recycling water. While implementing such incremental measures, we also continue parallel efforts to achieve long-term sustainable development goals. One key test for potential water and climate policies would be whether they would make development more (or less) sustainable.

Sustainable development triangle with a balanced and integrated viewpoint

Policy issues need balanced and integrated analysis from three main perspectives – social, economic and environmental (Figure 1). Interactions among these three domains are also important. The economy is geared towards improving human welfare, primarily through increases in the consumption of goods and services. The environmental domain focuses on protection of the integrity and resilience of ecological systems. The social domain emphasises the enrichment of human relationships and achievement of individual and group aspirations. Climate change and water are linked to all three domains. First, economic growth drives water use and emissions that cause climate change, while water scarcity and climate change impacts will undermine future development prospects. Second, water availability and climate have severe social implications, worsening poverty and equity. Third, water stress and climate change will exacerbate ongoing ecological damage, while environmental harm (like deforestation) will worsen water scarcity and climate. Win–win options, which satisfy all three criteria, will best integrate water, climate and development. In other cases, judicious trade-offs would be required to resolve potential conflicts.

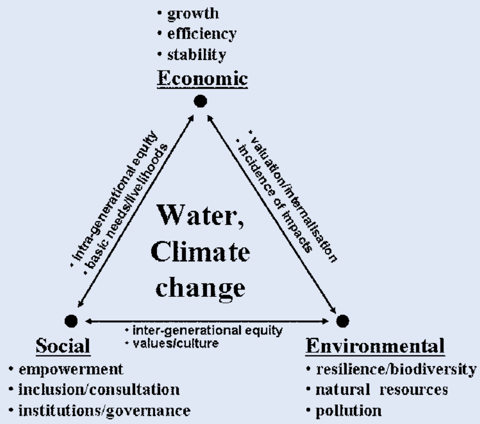


Figure 1. Water and climate change are interlinked with the economic, social and environmental dimensions of sustainable development. Source: Adapted from Munasinghe (1992a)

Transcending conventional boundaries for better integration

A comprehensive analysis must transcend conventional boundaries imposed by discipline, space, time and stakeholder viewpoints and values. Trans-disciplinary analysis is needed to find innovative solutions to complex problems of water, sustainable development and climate change that cut across conventional disciplines. Spatial analysis must range from the local to the global – typically from the community to the transboundary river basin and planetary scales. The time horizon will extend to decades or centuries. Cross-stakeholder data sharing, transparency and cooperation (especially civil society and business working with government) need to be strengthened, by promoting inclusion, empowerment and participation. It is also essential to replace unsustainable values, like greed, with sound moral principles, especially among the young.

Full cycle application of practical and innovative analytical tools

The sustainomics framework uses a variety of practical full cycle tools – both new methods and conventional ones. They are applied innovatively to encompass the full operational cycle from initial data gathering to practical policy implementation, monitoring and feedback. Furthermore, life cycle analysis of the entire value chain is required, from raw material extraction to consumer end use and disposal, based on economic, social and environmental perspectives. This will help identify areas where innovation can improve production sustainability, reform pricing and derive the full water and carbon footprints. It will not only identify the most desirable "win–win" policies that simultaneously yield economically, environmentally and socially sustainable paths, but also resolve trade-offs among water use and other conflicting goals. Practical analytical tools are described below.

Applications

Some representative applications of sustainomics tools and approaches to the water resources, climate and development nexus, are summarised below. Many more case studies are provided in Munasinghe (2009).

Global consensus on climate and development

Sustainomics principles can be applied at the global level, to coordinate stakeholders in all countries and reshape human activities on an unprecedented scale. But, sadly, current trends have fallen short of expectations. The 1992 UN Framework Convention on Climate Change (UNFCCC, 1992), accepted by over 190 countries, provided a promising start. By 2005, to implement the UNFCCC, 174 countries had ratified the rather weak 1997 Kyoto Protocol. It specified that by 2012, Annex I (industrialised) countries would collectively reduce their emissions 5% relative to 1990 levels, while Non-Annex I (developing) countries were exempt from emissions reductions. Unfortunately, the largest GHG emitter, the USA, rejected it. Global emissions have risen over 70% from 1970 to 2004, with major increases occurring since Kyoto.

The first principle of sustainomics (making development more sustainable), suggests how a long-term consensus might evolve, to help reconcile climate responses and development aspirations – this is essential for the transition described in Table 1. The evolution of such a consensus is shown in Figure 2. On this stylised curve of environmental risk against a country's level of development, poor nations are at point A (low GHG emissions and low GNP per capita), rich nations are at point C (high GHG emissions and high GNP per capita), and intermediate countries are at point B.

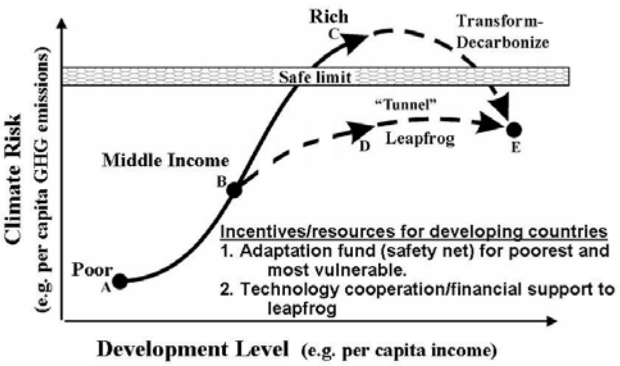


Figure 2. Integrating climate change into a sustainable development strategy by de-carbonizing and leapfrogging
Source: Adapted from Munasinghe (2002)

Equity and climate justice principles are relevant here. To date, over 80% of GHGs have been emitted by rich countries, and in 2005, the average per capita GHG emissions in industrial countries were four times greater than those in developing countries. But poor countries will be most affected by climate change. Thus, developing countries need to focus on vulnerability and adaptation, especially to alleviate poverty and protect their poor. Rich countries (which are better endowed financially and technically), should lead the mitigation effort and also assist poorer countries in both adaptation and mitigation work. Middle-income countries will need to join the mitigation effort over time, as they become richer.

The following elements are essential for a workable global compact on climate change:

- Industrial countries (already exceeding safe limits) should mitigate and follow the future growth path, CE, by restructuring their development patterns to delink carbon emissions and economic growth, thereby making their development path more sustainable;
- The poorest countries and poorest groups must be provided an adaptation safety net, to reduce vulnerability to climate change impacts;
- Middle-income countries could adopt innovative policies to "tunnel" through (along BDE – below the safe limit), by learning from the past experiences of the industrialised world;
- Developing countries should be encouraged (with technical and financial assistance) to simultaneously continue to develop (and grow) more sustainably, by following a growth path that is not only less carbon-intensive, but also reduces vulnerability to climate change impacts.

Recently, despite major expectations, the Copenhagen UN Climate Summit in December 2009 produced another weak, non-binding statement. Significant progress will be needed in the coming years to address the four points set out above.

Global adaptation response

Pre-planned adaptation is especially effective in the case of coastal areas threatened by sea level rise, flooding and storms (IPCC, 2007). If global warming reaches 2 °C and present expenditures on coastal protection remain constant, models indicate that about 55 to 90 million more people per year will be affected by 2080. However, these numbers may be drastically cut down to less than 10 million, by simple measures that involve marginal increases in annual coastal protection spending, matching GDP growth rates.

National level applications

At the national level, action is facilitated by the practical tools of sustainomics including macro- and sector modelling, environmentally adjusted national income accounts, poverty analysis, water modelling, sustainable pricing (see Box 2) and the Action Impact Matrix (AIM – described below). At the project level, other useful methods are available for sustainable development analysis – like cost–benefit analysis, multi-criteria analysis and environmental and social assessment. At all levels, the choice of appropriate sustainable development indicators is also vital. The range of policy instruments includes pricing, taxes and charges, regulations and standards, quantity controls, tradable permits, financial incentives, voluntary agreements, information dissemination and research and development.

Macroeconomic, water and sustainable development analysis

A recent example analysing national macro-policies shows the complex trade-offs involving the second principle of sustainomics (the sustainable development triangle). In West Africa, macroeconomic–environmental studies have shown that deforestation was accelerated by trade policies promoting timber exports and rapid aggregate economic growth, combined with imperfections like, subsidies for land-clearing (policy distortion), and open access forests (market failure) (Rowe et al., 1992; Munasinghe, 1996; Gbetnkom, 2005). This exacerbated rural poverty, degraded watersheds and ecosystems, increased GHG emissions and undermined adaptation. Such imperfections make private (market) decisions deviate from socially optimal ones.

The problems of deforestation, watershed degradation and ecosystem damage were addressed by implementing complementary measures (like eliminating land-clearing subsidies and enhancing forest protection) – most importantly, without reversing the macro-policies that promoted growth and reduced poverty. In Figure 2, suppose the vertical axis represents watershed degradation (instead of carbon emissions). The highly peaked path ABCE could result from economic imperfections and environmental externalities. Corrective policies would help to reduce such distortions and leapfrog through the sustainable tunnel BDE. Such a tunnel path is also more economically optimal (e.g., like a "turnpike" growth path).

Water sector applications

Action Impact Matrix (AIM)

Among the various sustainomics tools, the Action Impact Matrix (AIM) is a unique method that helps to practically integrate water, climate change and sustainable development (Munasinghe, 2007). This approach has been used successfully in a number of countries during past decades. It helps to identify and prioritise issues arising from the two-way interaction: how (a) the main national development policies and goals affect (b) the key adaptation and mitigation options relating to water; and vice versa. It also determines the priority policies and strategies in economic, environmental and social spheres that will help implement integrated measures to address water, development and climate change issues.

The AIM methodology relies on a fully participative stakeholder exercise. Between 10 and 40 experts are drawn from government, academia, civil society and the private sector – representing relevant disciplines and sectors. They usually interact intensively over a period of two days to build a preliminary AIM. This participative process is as important as the product (that is, the matrix), since important synergies and cooperative, team-building activities emerge. The collaboration helps participants to better understand opposing viewpoints, resolve conflicts, promote cooperation and ownership, and facilitate the implementation of the agreed policy remedies.

Figure 3 shows a typical AIM summarising the effects of key climate change vulnerabilities, impacts and adaptation (columns 1 to 10) on the main national goals and policies (rows A to G) in Sri Lanka during 2007. The first status row (S0) indicates that natural variability already has an impact on the vulnerabilities. The second status row (S1) shows how climate change impacts will further affect each column – for example, in column 1 impacts on agricultural production will worsen from -1 (low harmful) to -2 (moderately harmful) due to climate change.

Box 2: Sustainable water pricing

Sustainable water pricing uses the three elements of the sustainable development triangle (Munasinghe, 1992b).

First, it would be economically efficient to set water prices at long run marginal cost. This applies mainly to "blue water" used by humans, drawn from accessible lakes, rivers, aquifers etc. (Rockström et al., 2009).

Second, adding environmental externality costs (appropriately valued), including pollution taxes, would further reduce water use. This component of water pricing applies to "green water", diverted from precipitation and the soil, which is normally used by plants (Rockström et al., 2009), and to "brown water", which is polluted by industrial and agricultural wastes (Munasinghe, 1992b).

Third, from the social viewpoint, it would be equitable to provide subsidised water prices or lifeline rates targeted to the poor who cannot afford to pay the full price for their basic water needs, and to fund adaptation of those who suffer adverse impacts. This refers to "red water" that supplies the basic human needs for drinking and hygiene (Munasinghe, 1992b). Otherwise, simply raising prices would become an inequitable, unethical and ultimately unsustainable solution – that is, a way of rationing water and reserving it for the rich, while worsening the plight of the poor. This same argument would apply to carbon taxes and climate change.

Notation
+ Beneficial
- Harmful
3 High
2 Moderate
1 Low

	Key Vulnerabilities, Impacts and Adaptation (VIA)	(1) Agricultural Output	(2) Hydro-power	(3) Deforestation	(4) Biodiversity (flora & fauna)	(5) Wetlands & Coast Ecosys.	(6) Water Resources	(7) Poor Communities	(8) Human Health	(9) Infra-structure	(10) Industry & Tourism
S0	Status (Nat. Variability)	-1	0	-2	-1	-1	-2	-1	0	2	2
S1	Status (+CC Impacts)	-2	-1	-2	-2	-2	-3	-2	-1	-1	-1
	Dev. Goals/Policies (with CC Impacts)										
A	Growth	-1	-1	-1	-1	-1	-2	-2	-1	-1	-1
B	Poverty alleviation	-2	0	-1	-1	-1	-2	-2	-2	-1	-1
C	Food Security	-3	0	-1	-1	-1	-3	-1	-1	0	0
D	Employment	-1	0	-1	0	-1	-2	-1	-2	-1	-2
E	Trade & Globalisation	-2	-1	0	0	0	-1	-1	0	-2	-1
F	Reduce Budget Deficit	-1	-1	0	0	0	0	0	-2	0	-1
G	Privatisation	0	1	1	0	0	1	0	0	-1	-1

Figure 3. Effects of climate change vulnerabilities, impacts and adaptation on development policies and goals in Sri Lanka. Source: Author

When scanning the entire matrix, the cells with values of -3 or -2, which indicate the more adverse effects, should be given greater priority, while cells with values of 0 or 1 may be ignored. Thus, the value of -3 in cell C1 indicates that climate change will be very harmful to food security via the agriculture sector. Similarly, we note that cell C6 also has a value of -3, showing that the lack of water resources will also threaten food security. The AIM is built using a spreadsheet, with each cell hyperlinked to a separate sheet describing details of why such values were given, including literature citations – for example, the detailed description for cell C1 describes all major crops in Sri Lanka, under different temperature and rainfall conditions.

In summary, the food security row, C, raises the alarm, because both declining agricultural production and water resource shortfalls will have highly harmful impacts (matrix cells C1 and C6 respectively). Thus, food security issues should have a high priority, in subsequent policy analysis.

Water, agriculture and food security

Accordingly, a more detailed study of water, food security, and agriculture was carried out using a Ricardian agriculture model, to identify how past output changes in important crops, like rice, tea, rubber and coconut, had depended on natural variations in climate – mainly temperature and rainfall (Munasinghe, 2007). Then, a downscaled regional climate model was used to make detailed temperature and precipitation predictions specific to Sri Lanka, up to the year 2050. The combined results of both models showed that climate impacts on future rice cultivation would be negative and significant (almost a 12% yield loss by 2050) – affecting poor farmers in the dry zone of Sri Lanka, where incomes are lowest. Meanwhile, some areas in the wet zone, where tea is grown and incomes are higher, would experience gains (a 3.5% yield increase by 2050).

These findings raised several important policy issues.

- Rice is the staple food in Sri Lanka and a large portion of the population depends on rice farming. Thus, adaptation measures are essential to protect national food security, protect livelihoods and reduce the vulnerabilities of the rural poor in the dry zone.
- The differential impacts of climate change on poor farmers and richer landowners have income distribution and equity implications that also need to be addressed.
- Population movements from the dry to the wet zone are a potential demographic risk that policy makers need to deal with early.

Disaster vulnerability and social capital: comparing impacts of the Asian tsunami and hurricane Katrina

The Sri Lanka AIM also identified serious coastal zone vulnerabilities and impacts on poverty alleviation goals (matrix cell B5 in Chart 6), due to sea level rise and storm surges. The 2004 Asian tsunami (although not climate related) had many similar effects. The tsunami and hurricane Katrina struck within 9 months of each other. Despite many differences, a comparison of the two disasters provides useful lessons about the social dimensions of the sustainable development triangle (see Box 1), and the key role of social capital in increasing community resilience against disasters (Munasinghe, 2007).

Asian tsunami

The December 2004 Asian tsunami, triggered by a Richter scale 9 magnitude earthquake off the coast of Indonesia, was the most devastating disaster in modern history, killing over 250,000 people in South and East Asia. In Sri Lanka, about 35,000 people were killed (one in every 570 persons), and over half a million were displaced (one in every 40 persons). This was a catastrophic blow to a small developing country of around 20 million people, with a per capita income of barely US$1000 per year.

For many weeks, the government was overwhelmed and civil breakdown was predicted. Fortunately, civil society in Sri Lanka proved remarkably resilient and helped to hold the country together – apparently, the social capital embedded within traditional communities in affected areas and throughout the nation, played a crucial role. After several months, government relief efforts and assistance pouring in from abroad took on the major burden of relief and recovery, although civil society continued to play a significant role.

Hurricane Katrina

The story of New Orleans after hurricane Katrina struck (in late August 2005), was somewhat different. Damage from Katrina to the Gulf Coast was about US$100 billion, making it the costliest hurricane in U.S. history. The storm killed about 1840 people (less than 2 per 1000 persons of the 1.3 million population) – far fewer than in Sri Lanka. Also, unlike the tsunami, which wreaked damage within a few hours, Katrina built up over a week (23–29 August) and there should have been sufficient time to prepare – given the advanced early warning systems, and technological and economic resources available. Nevertheless, a large city within a country of 300 million (with a 2006 per capita income of US$44,000 per year), suffered a major social breakdown involving looting and violence. Subsequent relief and recovery efforts have sought to remedy immediate problems, but the vulnerability of social structures raises more serious long-term questions about the lack of social capital.

Most disaster studies focus on economic and environmental factors, but the sustainomics framework highlights the role of the social dimension. Further research is ongoing regarding the factors underlying social resilience, and methods of making development more sustainable by building social capital to complement the traditional restoration of economic and environmental capital, and reduce overall disaster vulnerability.

Simple water filtration method for cholera prevention in Bangladesh

Economic valuation and multi-criteria analysis (MCA)

There are many practical techniques to placing a monetary value on environmental impacts. Multi-criteria analysis (MCA) is another complementary sustainomics tool that may be applied, especially when the economic valuation of social and environmental effects is problematic (Munasinghe, 1992a, 2007). It allows policymakers to look at all three elements of the sustainable development triangle (economic, social and environmental) in a balanced manner – in large part, by quantifying and displaying trade-offs in differing units of measurement, since some impacts cannot be measured solely in monetary terms.

Water contamination and cholera

Scarcity of safe drinking water is a global problem that will worsen with poverty, population growth and extremes of flooding and drought due to climate change. Cholera is a waterborne diarrheal disease spread by drinking unsafe water, which kills many children in developing countries. About 5.5 million cases of cholera occur annually.

In Bangladesh, most villagers depend on untreated surface water for drinking. During the summer, aridity increases the abundance of the Vibrio cholerae (VC) bacterium which causes cholera (Sack et al., 2003). During monsoon flooding, wells are submerged, sanitary latrines get flooded, and contamination of drinking water by VC bacteria also leads to cholera outbreaks. Water purification by boiling or chlorination becomes difficult under such conditions. Thus, as extremes of flood and drought increase with climate change, cholera epidemics will become more serious.

A simple, cheap and socially acceptable method was devised that removes 99% of VC attached to plankton, by filtering contaminated water using four layers of old sari cloth. Tests with 15,000 villagers showed that 90% of the population accepted the sari filtration system in their daily lives, and the cholera incidence was about half the rate suffered by a control group (who did not use filtering). Sari filtration provided major health benefits, while satisfying sustainomics criteria – low economic cost, socio-cultural acceptability and environmental soundness, while being readily accessible under extreme weather conditions.

MCA

Conventional water project evaluation uses cost–benefit analysis (CBA), where all impacts are valued in monetary terms. However, when environmental and social effects cannot be easily valued, multi-criteria analysis (MCA) is attractive.

Figure 4 uses MCA to assess our simple sari-based water purification method within the SWAMP framework. Outward movements along the axes trace improvements in three indicators – economic efficiency (net monetary benefits), social equity (improved benefits for the poor), and environmental protection (reduced water pollution). Triangle ABC shows the existing situation. Economic harm occurs (loss of earnings, medical costs, etc.), because of rising morbidity and mortality rates. Social equity is low because the poor are most affected, while environmental pollution is also bad. Next, triangle DEF indicates a "win–win" option with the simplified sari filtration technique, in which all three indices improve. Economic losses fall due to better health. Social gains accrue to the rural poor, especially women and children. Environmental benefits arise from cleaner water.

After realising such "win–win" gains, further improvements may require tradeoffs. For example, triangle GIH suggests that a better water supply (e.g. wells and surface water providing purified, pipe borne supply, or nanotechnology-based filtering techniques) may yield further environmental and social benefits, but with increased economic costs. After adopting the clearly desirable "win–win" move from ABC to DEF, shifting further from DEF to GIH, will require difficult tradeoffs among the three criteria. However, one may narrow the options. Suppose a small economic cost, FL, yields the full social gain, DG, (e.g. by targeting poor households), while a large cost, LI, is required to realise the environmental benefit, EH, (e.g. better water supply and sanitation). Here, the social gain may be more cost effective than the environmental benefit, especially if purely budgetary constraints limit cost increases to less than FK.

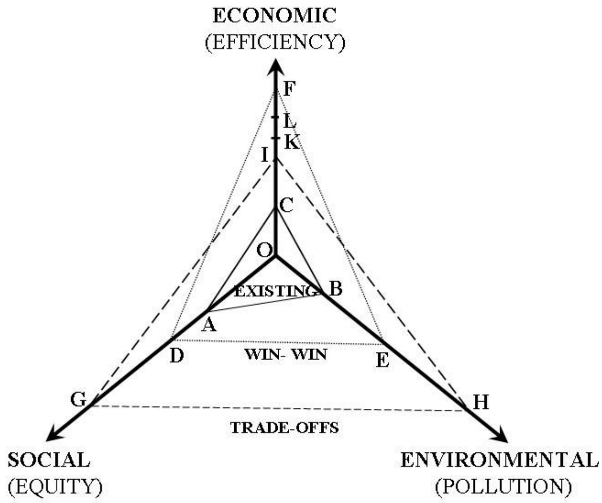


Figure 4. Multi-criteria analysis applied to sustainable water management and planning.
Source: Adapted from Munasinghe (2007)

Concluding remarks

Water scarcity, climate change and sustainable development are interlinked problems that pose serious risks to humanity. Short-sighted and piecemeal policies have not proved effective so far. The paper outlines how a longer-term vision of sustainable development needs to go below surface level indicators of development, by addressing deeper issues systematically and focusing on both immediate drivers and underlying pressures.

It is possible to conclude on a mildly optimistic note. Although the issues are complex and serious, multiple problems could be solved together, provided we begin immediately. We know enough already to take the first steps that will transform the risky "business-as-usual" scenario into a safer future. The sustainomics framework for making development more sustainable is an effective method that integrates solutions to these multiple challenges into a coherent sustainable development strategy. The approach relies on a balanced and integrated analysis from three main perspectives – social, economic and environmental. Civil society and business must play a bigger role in helping governments find and implement solutions. A number of case studies at the global, national and local levels illustrate practical applications of the methodology. ■

References

- Alcamo, J., Floerke, M., and Maerker, M. (2007) Future Long-term Changes in Global Water Resources Driven by Socio-economic and Climatic Changes. *Hydrological Sciences* 52(2): 247–275.
- Gbetnkom, D. (2005) Deforestation in Cameroon: Immediate Causes and Consequences. *Environment and Development Economics* 10(4): 557–72.
- G20 (2009) *The Global Plan for Recovery and Reform. Final Communique.* London, UK: G20 Summit: Website publication http://www.londonsummit.gov.uk/resources/en/PDF/final-communique.
- IARU (International Association of Research Universities) (2009) *Climate Change: Global Risks, Challenges and Decisions – Synthesis Report.* Copenhagen, Denmark: IARU, University of Copenhagen.
- IPCC (Intergovernmental Panel on Climate Change) (2007) *Climate Change 2007: Synthesis Report.* Fourth Assessment Report of the IPCC. London, UK: Cambridge University Press.
- IPCC (Intergovernmental Panel on Climate Change) (2008) *Climate Change and Water.* IPCC Technical Paper VI, London, UK: Cambridge University Press.
- MA (Millennium Ecosystem Assessment) (2005) *Ecosystems and Human Well-Being: Synthesis.* Washington, DC, USA: Island Press.
- Millennium Development Goals (MDG) (2009) *Millennium Development Goals Report* 2009. New York, USA: United Nations.
- Munasinghe, M. (1992a) *Environmental Economics and Sustainable Development.* Paper presented at the UN Earth Summit, Rio de Janeiro. Environment Paper No. 3. Washington, DC, USA: World Bank.
- Munasinghe, M. (1992b) *Water Supply and Environmental Management.* Boulder, CO, USA: Westview Press.
- Munasinghe, M. (1996) *Environmental Impacts of Macroeconomic and Sectoral Policies.* International Society for Ecological economics. Washington, DC, USA: World Bank.
- Munasinghe, M. (2002) The Sustainomics Trans-disciplinary Meta-framework for Making Development More Sustainable. Paper presented at the UN World Summit on Sustainable Development (WSSD), Johannesburg. *International Journal of Sustainable Development* 5(1-2): 125–82.
- Munasinghe, M. (2007) *Making Development More Sustainable: Sustainomics Framework and Practical Applications.* Colombo, Sri Lanka: MIND Press, Munasinghe Institute for Development.
- Munasinghe, M. (2009), *Sustainable Development in Practice: Sustainomics Methodology and Applications.* Cambridge, UK: Cambridge University Press.
- OECD (Organisation for Economic Co-operation and Development) (2009), *The Road to Recovery Update on the OECD's Strategic Response to the Financial and Economic Crisis.* Paris, France: OECD: Website publication: http://www.oecd.org/dataoecd/40/14/42528786.pdf.
- Rockström, J., Falkenmark, M., Karlberg, L., Hoff, H., Rost, S. and Gerten, D. (2009) Future Water Availability for Global Food Production: The Potential of Green Water for Increasing Resilience to Global Change. *Water Resources Research 45*, W00A12, doi:10.1029/2007WR006767.
- Rowe, R., Sharma, N.P. and Browder, J. (1992) Deforestation: problems, causes, and concerns. In *Managing the World's Forests: Looking for Balance Between Conservation and Development* (Eds Sharma, N.P. and Dubuque, I.A.). Dubuque, Iowa. Kendall/Hunt Publishing Company.
- Sack, R.B., Siddique, A.K., Longini, I., Nizam, A., Yunus, M., Islam, S., Morris, J.G., Ali, A., Huq, A., Nair, G.B., Qadri, F., Shah, M. Faruque, Sack, D.A. and Colwell, R.R. (2003) A Four-year Study of the Epidemiology of Vibrio cholerae in Four Rural Areas of Bangladesh. *Journal of Infectious Diseases* 187: 96–101.
- Taylor, J.B. (2009) *The Financial Crisis and the Policy Responses: An Empirical Analysis of What Went Wrong.* Rock Center for Corporate Governance Working Paper No. 30; NBER Working Paper No. w14631: Website publication: http://ssrn.com/abstract=1341170.
- UNDP (United Nations Development Programme) (2006) *Beyond Scarcity: Power, Poverty and the Global Water Crisis.* Human Development Report 2006. New York, USA: UNDP.
- UNDP (United Nations Development Programme) (2009) *Overcoming Barriers: Human Mobility and Development.* Human Development Report 2009. New York, USA: UNDP.
- UNEP (United Nations Environment Programme) (2008) T*he environmental food crisis – the environment's role in averting food crises.* Nellemann, C., MacDevette, M., Manders, T., Eickhout, B., Svihus, B., Prins, A. G., Kaltenborn, B. P. (Eds). A UNEP Rapid Response Assessment. New York, USA: UNEP, GRID-Arendal: Website publication http://www.unep.org/pdf/FoodCrisis_lores.pdf
- UNFCCC (United Nations Framework Convention on Climate Change) (1992) *Framework Convention on Climate Change: Agenda 21*. New York, USA: United Nations.
- UNICEF/WHO (United Nations Children's Fund/World Health Organization) (2004) *Meeting the MDG drinking water and sanitation target: a mid-term assessment of progress.* Joint Monitoring Programme for Water Supply and Sanitation. Paris, France: UNICEF/WHO.
- UNICEF/WHO (United Nations Children's Fund/World Health Organization) (2005) *Water for life: making it happen.* Joint Monitoring Programme for Water Supply and Sanitation. Paris, France: UNICEF/WHO.World Bank (2005) World Development Report 2005: *A Better Investment Climate for Everyone.* Washington, DC, USA: World Bank.
- World Bank (2009) *World Development Report 2009: Reshaping Economic Geography.* Washington, DC, USA: World Bank.

Dr. Thia-Eng Chua
Regional Programme Director (rtd.), PEMSEA – Partnerships in Environmental Management for the Seas of East Asia
chuathiaeng@gmail.com

Securing waters in coastal areas of the seas of East Asia: The PEMSEA experience

The Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) adopted the integrated management approach in planning and managing watersheds, river basins, estuaries and coastal seas to address a host of environmental and sustainable development challenges. PEMSEA demonstrated the effectiveness of integrating policy and management functions through several integrated coastal management (ICM) initiatives, and developed the concept and practices of ICM into an integrated management system. PEMSEA also developed and facilitated the implementation of the Sustainable Development Strategy for the Seas of East Asia, by providing policy, human resource and financial support to develop national coastal and ocean policy, coastal legislation and multi-sector partnerships.

Keywords: integrated coastal management, Sustainable Development Strategy for the Seas of East Asia, PEMSEA

Background

The seas of East Asia face a host of environmental management and human security challenges arising from severe ecosystem degradation, deteriorating water quality, overexploitation of natural resources, increasing threats from natural and man-made disasters, and loss of ecosystem services. These challenges are exacerbated by heavy population pressure and unsustainable economic development (PEMSEA, 2007; Chua et al., 2008). Rapid coastal urbanisation, caused by unregulated migration to urban centres, has resulted in loss or weakening of human productivity in rural areas. Overexploitation of underground water endangers freshwater supplies for towns and cities.

Improvement of living standards has changed consumption and use patterns, especially in urban centres. This contributes to a high carbon society and thereby accelerates pressure on food and energy supplies, as well as generating more solid waste which finds its way into coastal waters and forms marine litter. The increasingly felt negative impacts of climate change further challenge the national and regional capacity of most countries, particularly the capability to cope with simultaneous and cumulative environmental threats to life and property. Capacity to secure the sustainable use of coastal seas, given the complex, diverse and yet interconnected socio-economic, political, cultural and ecological characteristics of the countries and people of the region, is also challenged (Chua, 2006).

International and national efforts to combat or reduce these threats have taken various forms and different intensities. Over the last five decades several environmental and marine international conventions, protocols and agreements, particularly the recent climate convention, have brought greater awareness and, to a certain extent, national commitments to put environment and climate concerns on national priority agendas. However, there are insufficient on-the-ground actions to realise these international commitments effectively. Ten years after the 1998 Lisbon Declaration on the oceans, a review found that the state of seas and oceans had not improved but, in fact, had further deteriorated (Mario Soares Foundation, 2008). The reviewers called for more action to implement responsible ocean governance and underscored the need to step up implementation at local, national and regional levels.

Southeast Asia has a relatively long history in the implementation of integrated management of coastal and marine resources. Exploratory efforts in Thailand and the Philippines in the mid-70s expanded to Brunei Darussalam, Indonesia, Malaysia and Singapore in the 80s (Scura et al., 1992). By the 90s several other countries, including Cambodia, China, DPR Korea, RO Korea and Vietnam, had also replicated various forms of integrated coastal management (ICM), largely driven by increased donor support (Chua, 2006). Multilateral financial institutions, such as the Asian Development Bank and the World Bank, also contributed to the expansion of ICM efforts in the region and the world at large (ADB, 2003; Krishnamurthy et al., 2009). Global proliferation of ICM practices in more than 147 countries (Sorensen, 2002) has greatly enriched the concept and practice of integrated management of river basins, estuaries and coastal seas (Krishnamurthy et al., 2009), but reviews of ICM practices in Southeast Asia showed that ICM is still in its evolutionary phase (Chua ,1998, 2006) and that long-term efforts are still needed to improve the practical application of the integrated management concept, the institutional and legislative arrangements, the enforcement capability, and also the human and financial resources to plan and manage coastal areas in a sustainable manner.

The goals of sustainable coastal and ocean development can only be achieved with a long-term, holistic management approach. The coastal areas constitute 20% of the surface area of the planet but their interface with watersheds and coastal seas makes this narrow belt of coastal lowland and adjacent waters one of the most productive regions on earth, in terms of biological richness and economic contributions to GDP (Tropical Coasts, 2009). Securing environmental and economic sustainability of the coastal seas therefore requires comprehensive management of human activities. It will require concerted management efforts to adopt an ecosystem-based approach that considers the inter-relationships between upstream watersheds, downstream estuaries and adjacent coastal seas; many of these ecosystems cut across jurisdictional boundaries. Ecosystem-based management is thus one of the fundamental principles of sustainable coastal development. Ecosystem-based management, adaptation, integration and inter-relationships (Chua, 2006) are the four key pillars in the management of these very complex and complicated coastal ecosystems.

Analysis

Integrated management

Managers responsible for economic and environmental issues have increasingly realised the need for integrated management of coastal lands and seas, particularly the need for a paradigm shift from the conventional single sector planning and management practice or "I" approach to an integrated planning and management or "T" approach (Figure 1). Traditionally, government administrative structures and functions have been organised to facilitate the development and regulation of individual economic sectors, such as the establishment of regulatory agencies to manage the development of fisheries, maritime transport, energy, tourism, ports and harbours, etc. In theory the line agencies are expected to collaborate and cooperate with each other, especially on issues that transcend jurisdictional boundaries and responsibilities. In practice, however, there have been serious communication gaps and a lack of willingness to cooperate, primarily due to competition for resources and power.

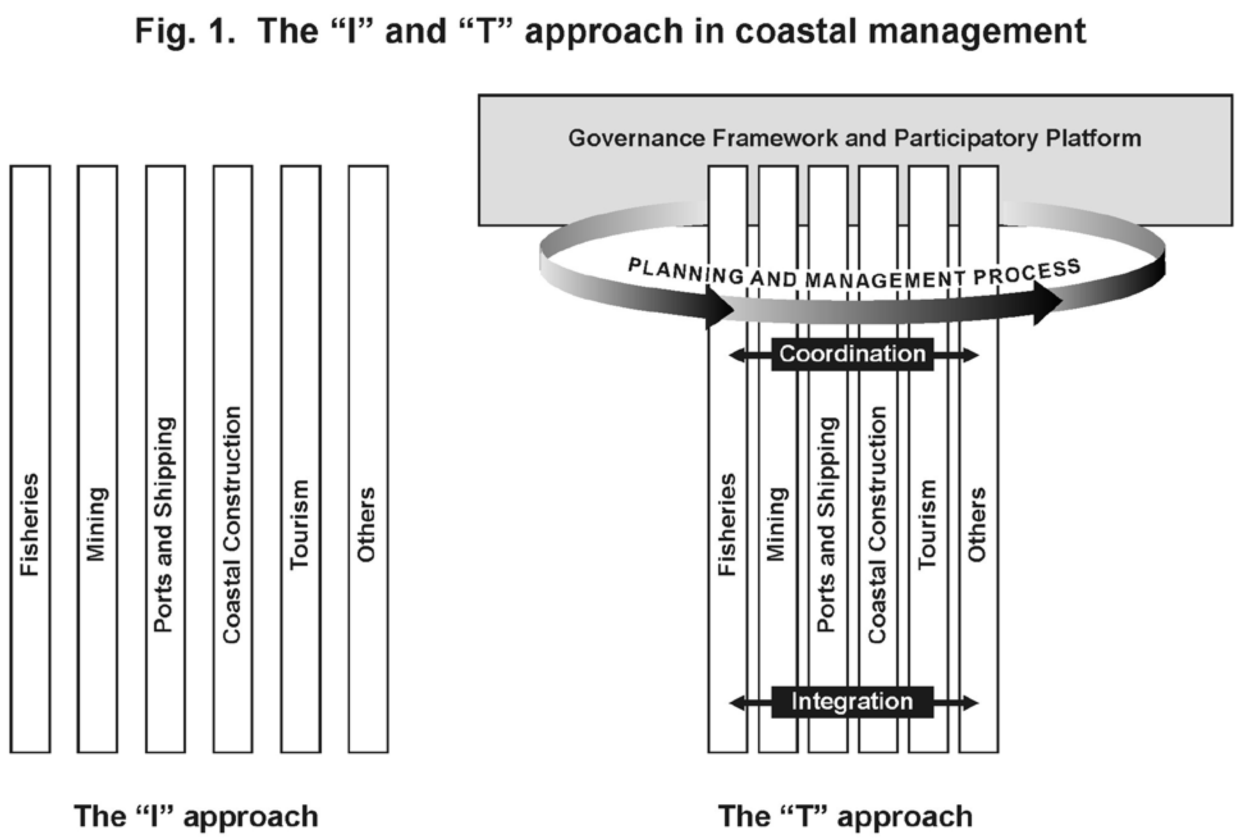


Figure 1. The "I" and "T" approaches in coastal management

Photo: BrandXPictures

In contrast, area-wide management of coastal land and the adjacent sea requires integration of policy and management to govern sector development. The "T" approach to planning and management practice ensures appropriate institutional coordination and integration of sector policy and management functions of line agencies. This can be made possible through a common governance framework structured to achieve a common vision and specific objectives, and participatory platform mechanisms to enable participation of key stakeholders in decision-making and implementation.

In practice, the "T" approach is more easily adapted by developing countries where the lack of human and financial resources makes integrated planning and management more attractive. In contrast, the "T" approach faces a greater challenge in developed nations, such as Japan and RO Korea, where the roles and responsibilities of line agencies are very well defined and defended, as line agencies are usually efficient within their line of responsibility. But this often leaves cross-sector and cross-agency management issues in a "no man's land" as these issues are considered outside their "mandates".

The basic principles guiding integrated management include sustainable development, ecosystem-based management, adaptive management, the precautionary principle, conservation, accountability, flexibility, transparency and inclusiveness (Fisheries and Oceans Canada, 2002; Chua, 2006). These principles, based on scientific information, can be applied at all levels of coastal and ocean governance. Integrated management is the leading approach in Canada's Ocean Strategy, and includes planning and management of larger bays, gulfs and the coastal seas.

The integrated management approach is also being advocated in several regional seas in Europe, such as the Baltic Sea, the Black Sea, the North Sea, and the Mediterranean Sea where ecosystem-based management objectives were established based on scientific findings (Kimball, 2003). The Baltic Sea, which is one of the more successfully managed regional seas, is similar to the East Asian Seas in terms of spanning both developed and developing nations with different political systems, but differs in terms of population and socio-economic, legislative, political and environmental complexity. Experience and lessons from the Baltic Sea in the application of ICM and the implementation of regional conventions (Helsinki Commission, 2003; Melvasalo, 2008) are extremely useful for the sustainable planning and management of the East Asian Seas.

Both vertical and horizontal integration are essential components of integrated management. To increase the effectiveness of implementation of national policy, legislation and national action programmes, vertical integration will reduce conflicts and ambiguities in central and local authority institutional functions. Similarly, horizontal integration will ensure watershed, river basin, estuary and coastal seas are included in development and environmental planning and management. Hence, integrated management is both advocated in water resource management (Rogers and Hall, 2003; Jonch-Clausen, 2004; Rees, 2002) as well as the management of coasts and oceans (Chua et al., 2006; Cicin-Sain and Knetch, 1998).

Implementing international conventions is an important national obligation. Conventionally these international instruments are implemented by the national agencies concerned. However, the integrated management approach facilitates integrated implementation of some of these relevant international instruments at the local level (Chua et al., 2008).

Partnerships in Environmental Management for the Seas of East Asia (PEMSEA)

For various political, cultural and socio-economic reasons, the East Asian Seas is one of three regional seas in the world without a formal regional convention. The other two are the regional seas of the NW Pacific and South Asia (Kimball, 2003). Governance of these regional seas is facilitated through non-binding regional action plans (Melvasalo, 2008). The lack of strong political commitments and the financial disparity between countries in the region has greatly reduced effectiveness and efficiency in the management of the regional seas of East Asia.

Through the intervention of the Global Environment Facility (GEF), United Nations Development Programme and the International Maritime Organization, a regional programme for Marine Pollution Prevention and Management was established in 1994 to promote regional cooperation in the environmental management of the seas of East Asia. The lessons learnt from this pilot programme have led to the realisation and development of a new mode of regional cooperation through partnership arrangements. As a result, building "Partnerships in Environmental Management for the Seas of East Asia" (PEMSEA) became the main focus of the 2nd and 3rd phases of GEF support.

Within a span of 16 years, PEMSEA placed a strong focus on the implementation of action programmes at the local level and promoted policy and legislative reforms at national and regional levels. PEMSEA forges regional cooperation and partnerships to mobilise public and private sector resources for implementing international conventions, thereby strengthening national commitments and regional responsibility for responsible ocean governance. PEMSEA also developed and implemented a regional marine strategy known as the Sustainable Development Strategy for the Seas of East Asia, promoting policy, human resource and financial support through national coastal and marine policy and legislation (Figure 2). Much of PEMSEA's effort was devoted to building working models in governance, partnerships, integrated management planning and management at various demonstration sites in the region.

Top-down and bottom-up approaches in coastal management

PEMSEA adopts a two-pronged approach in the application of integrated management to secure the coastal seas of the region in accordance with the socio-economic and political systems of the concerned countries. On the one hand, PEMSEA, working in close consultation with national agencies, promotes the importance of the oceans and coastal seas, and underscores the increasing contributions of the marine sector to national GDP. It organises national and regional policy and technical workshops to involve policymakers, business communities and experts in forging national policy reforms to establish national coastal/ocean policy, strategies and legislation. On the other hand, PEMSEA puts considerable effort towards encouraging local governments in coastal provinces, municipalities, cities and districts to adopt the ICM approach in addressing their local concerns. The two approaches are not mutually exclusive but complement and support each other.

Addressing local and national concerns

Environmental and human security concerns in coastal areas require both policy and management interventions by both national and local governments. In general, these concerns are in the following key areas:

a) Managing natural and human-induced hazards

The seas of East Asia are located in an area prone to earthquakes and typhoons, often followed by storm surges, tsunamis, landslides and floods that result in heavy loss of life and property and, in some severe situations, cause more than substantial loss of national or local GDP. Approximately 10–20 typhoons of varying magnitude and scale hit some parts of the region each year. In recent years, the trend has been for typhoons to increase in intensity and become more frequent. Concerned local governments in many countries are not fully prepared and equipped with the capacity to respond. The outcome is devastating loss of human life and property in affected areas.

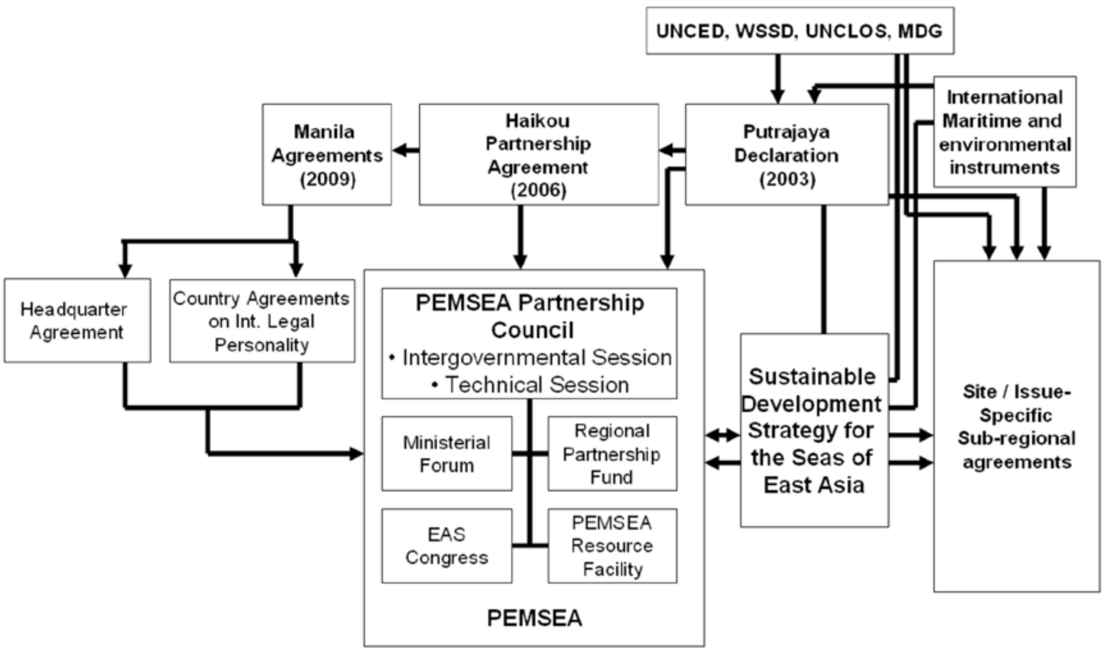


Figure 2. PEMSEA partnership operating arrangements

However, some disasters are caused by human activities. Oil and chemical spills (caused by spillage from oil tankers, oil drilling wells, discharge from vessels), the spread of harmful algal blooms or red tides, and the large-scale proliferation of macro-algae or green tides (caused by over-enrichment, up-welling) result in contamination of fishery products, human health hazards and loss of income.

b) Managing habitat protection, restoration and conserving marine biodiversity

The seas of East Asia are very rich in marine biodiversity. In fact, at least two of the six Large Marine Ecosystems form an important part of the Coral Triangle which sustains more than 76% of coral species, 37% of coral fish species and 53% of world coral reefs. The region also sustains more than 30% of world mangroves. The seas of East Asia support more than 40% of world fish production and more than 80% of world aquaculture production (PEMSEA, 2007). However, many of the coral reefs, mangroves and sea grass beds in the seas of East Asia have been largely destroyed, and the need to protect, conserve and restore these natural habitats has become a primary function of coastal management.

The challenge in rapid coastal land reclamation lies in the wisdom, policy, and commitment of local and national political leadership in understanding the economic trade-offs between losing natural defences against hazards, ecosystem services and genetic resources and short-term economic gains. A greater challenge is that most of these issues have transboundary and cross-boundary implications, such as affecting larval flow, spawning and nursery grounds.

With rapid coastal urbanisation, conservation of urban biodiversity has become a new challenge as well as an incentive for urban managers. Greening of urban landscapes has been increasingly adopted in many urban centres. This, of course, will enable the retention of biodiversity within urban areas even though many species are secondary and may be brought in from other parts of the country. In some urban cities, efforts are being made to transform green landscapes so that they also function as watersheds, such as in Singapore. In Japan, cities built within national parks have strict regulations on landscape development. Coastal biodiversity can continue to prosper if biodiversity conservation is included in government economic agendas.

c) Managing nutrient pollution and waste disposal

A major challenge in marine pollution is the large quantity of untreated domestic waste and agricultural fertilisers discharged into river systems, and flowing into estuaries and coastal seas. This pollution has enriched nutrients in estuaries and coastal seas primarily in the form of nitrogen (N) and phosphorus (P), resulting in eutrophication of the coastal waters. Nutrient-rich water promotes rapid growth of phytoplankton which also increases the zooplankton biomass. The immediate positive impact is the increase in fish stock and hence a better fish catch. However, continued and unabated nutrient influx changes the composition of phytoplankton and results in outbreaks of harmful algal blooms which produce toxic substances that cause mass fish mortality and food poisoning in human consumers.

Large-scale euthrophication can also result in areas deficient in oxygen. In semi-enclosed bays or inland seas, such as the Bohai Sea in China and the Seto Inland Sea in Japan where stratification usually occurs, the phytoplankton in the surface water column die, fall to the bottom and decompose. This, along with removal of dissolved oxygen in the water column, results in a layer of water low in oxygen at the bottom. When the amount of oxygen falls below 2 ml/L, very few fish and benthic organisms can survive, thus creating an oxygen-deficient or "dead zone" (Diaz and Rossenberg, 2008). In recent years, dead zones have been spotted in several coastal waters off the Changjiang estuary and the mouth of the Pearl River (Chan et al., 2008; Rabouklle et al., 2008). The number of dead zones around the world is said to be increasing, from about 100 in the 90s to 408 in 2008 (Diaz and Rossenberg, 2008). The size of dead zones has also increased, reaching more than 30,000 km^2 in the Gulf of Mexico. The growing global population and coastal urbanisation are considered to be the main policy challenges to be addressed to effectively eradicate large-scale eutrophication (Forsberg, 1998).

Of equal concern is the amount of solid waste generated, especially by densely populated urban coastal cities. Much of this waste finds its way into rivers and coastal seas as marine litter. While there are national efforts to build solid waste disposal and treatment facilities, current regional capacity to effectively manage solid wastes and their disposal in coastal seas is grossly inadequate and requires policy, legislative and public support at all levels of government and society. National and international regulatory controls need to be stepped up to curb the transfer of waste, especially the transfer of hazardous wastes from developed to developing nations, and the transport and spread of exotic species through ballast water.

In addition to national and international efforts, local government plays a very significant and important role in reducing the discharge of nutrients and solid wastes into rivers and coastal seas. Effective management of nutrients and solid wastes needs to take a broader and long-term perspective. In addition to regulatory control and financial investment, the community, as both the generator and victim of waste, should be brought centre stage in the solution equation.

d) Managing water supply, use and water resources

Less than 3% of planet earth's water is fresh. The rest is sea water. Of this 3% only 0.5% is available for human use and this is located mainly in aquifers, reservoirs, lakes, rivers and streams. Some freshwater comes from rainfall and melting snow. A large proportion of drinking water comes from aquifers. A substantial amount of freshwater is allocated to industries and irrigation. As such, freshwater is a very precious commodity for mankind. With modern desalination technology, freshwater can be extracted from sea water by the reverse osmosis process, but the cost of production is still high.

An increasing number of coastal urban centres lack sufficient freshwater to supply the demands of growing populations and industries (PEMSEA, 2007). In countries where water is supposedly abundant, such as those with a high annual rainfall, contamination of freshwater sources, including rivers, tributaries and aquifers, has raised the cost of drinking water.

Management of freshwater resources is considered here as part of coastal management, as freshwater is the lifeline of coastal urbanisation. Without adequate supplies of freshwater, coastal urbanisation cannot prosper. Major challenges are how to protect water sources from contamination, how to supply drinking water to large populations in urban centres, as well as how to provide water for sanitation services.

Ensuring food security and livelihoods

A substantial number of coastal populations bordering the seas of East Asia depend on fish and other marine resources for protein in their diets and for their livelihoods. The per capita consumption of fish globally is about16 kg/person/yr but FAO estimates this will rise to an average of 24 kg/person/yr by 2030 (Ye, 1999). In many countries in East and Southeast Asia the consumption of fish is higher than in countries outside the region. In Japan, RO Korea and Malaysia consumption is between 52 and 66 kg/person/yr, while in most of Southeast Asia consumption ranges between 18 and 32 kg/person/yr (NOAA, 2002). To increase fish supplies, water bodies such as lakes and reservoirs, as well as estuaries and coastal seas, are being heavily utilised for fish farming.

Indiscriminate harvesting of fish using various fishing methods has depleted many fishing grounds and caused fish catches to dwindle in many coastal seas in the region. Very few fisheries are managed within the maximum sustainable yield limit. Over-capitalisation of fishing gear pushes indiscriminate exploitation further down in the food chain (Pauly et al., 1998). Conversion of inland and coastal wetlands for fish farming has destroyed natural habitats, while over-use or misuse of antibiotic and other drugs in aquaculture, and poor post-harvest practices contaminate fishery products and render them unsafe for human consumption. The livelihoods of small-scale fishers are at stake as they depend very much on fishing for their livelihoods and, in many developing coastal nations, they are among the under-privileged coastal poor.

Solutions to these issues require combined efforts by both national and local governments, and stakeholders. At the national level, policy and legislative support is essential but science-based solutions are equally important. This will certainly need national effort to provide the knowledge base for risk assessment, particularly in identifying the root causes, the socio-economic impacts, and policy and management implications. Local government is the key implementing authority and will need to consider available policy and management options, and to translate them into management action.

The various issues identified above are closely interconnected. The best way to address them is to consider them holistically in an integrated manner within the administrative boundaries of local governments. Solutions will depend on the severity and priority of the types of risks in the areas concerned. While each responsible line agency can address specific issues within their mandate, the integrated management approach requires them to undertake comprehensive, interagency planning so as to resolve cross-cutting issues in overlapping jurisdictions.

Demonstrating the applicability and effectiveness of ICM

A major thrust of PEMSEA is to demonstrate the applicability and effectiveness of ICM in addressing issues that affect economic as well as environmental sustainability within a common governance framework (Chua, 2008). Xiamen Municipality, a city on the southern coast of China, and Batangas Bay, a coastal bay bordering several municipalities in Batangas Province in the Philippines, became PEMSEA's first two ICM demonstration sites. Both started in 1994 and used the same ICM framework and processes. Coastal management in both sites was based on a clearly defined development vision, a governance framework within a defined local coastal policy, and a participatory coordinating mechanism for implementing a long-term strategic action plan developed through appropriate horizontal and spatial scoping of the management areas and risk assessment processes. The two sites set priorities for the various environmental and sustainable development concerns, and implemented them within the limits of their human and financial resources. Despite marginal support of limited duration from GEF, both sites have continued implementing ICM over the last 16 years. The outputs and outcomes of the two demonstration projects were thoroughly analyzed and published (PEMSEA, 2006b, 2006c), including the cost-benefits of ICM (PEMSEA, 2006a) and a comparison of the effectiveness of ICM practices operating in two different political, socio-economic environments (Chua, 2008).

The success and sustainability of the two demonstration projects beyond the project phase fully showed that: (1) the governance framework, and especially the integrated planning and management processes, are indispensable components of ICM practice; (2) a coordinating mechanism with multi-agency representation and representatives from concerned stakeholders is essential to reduce policy, institutional

Photo: Mats Lannerstad

and legislative conflicts and overlapping functions; (3) building confidence and trust among line agencies and stakeholders is a continuous effort; and (4) wise application of the dynamics of ICM determines the level of maturity in ICM driving forces – vision building, forging partnerships, consensus building, public awareness – and strengthens the implementation of policy and management measures.

Replicating and scaling up ICM

Based on the experience of the first two demonstration sites, six more ICM sites were established in Cambodia, DP Korea, Indonesia, Malaysia, Thailand and Vietnam during the second phase of PEMSEA from 1997 to 2007. The participating sites gradually increased their annual contributions to implementing their strategic action plans and were able to sustain their own efforts before the end of the first ICM cycle. The willingness of local governments to duplicate ICM models has led to the establishment of 18 more parallel ICM sites throughout the region.

These efforts have further verified the applicability of ICM and laid a strong foundation for scaling up ICM practices across geographical and administrative boundaries. One form of scaling up is the duplication of the integrated bay management approach and practices by different coastal municipalities in other bays, gulfs and lagoons. Another is functional scaling up by extending integrated management from downstream municipalities to cover municipalities in upstream areas of river basins, such as in the case of the Juilong River in Xiamen. The latter effectively integrates the management of the river basin with that of the downstream estuary and coastal seas.

Another PEMSEA effort is to encourage the integrated management approach in larger bays, gulfs and inland seas within national jurisdictions (e.g. Manila Bay, Jakarta Bay and Bohai Sea). These large water bodies are often bordered by several provinces and large cities with large populations and diversified and complex economic activities. The challenge here was to expand the scope of ICM using the same governance framework even though the environmental sustainability challenges were (and still are) greater. The management experiences of Chesapeake Bay and the Seto Inland Sea provided useful insights in terms of building cross-boundary cooperation and partnerships, controlling pollution loads, reducing nutrients and applying policy and management options. These efforts are continuing.

Developing and implementing a Sustainable Development Strategy for the Seas of East Asia (SDS-SEA)

PEMSEA adopts a long-term, incremental approach to securing the seas of East Asia. This regional sea has a total coastline of 234,000 km, a sea area covering 7 million km^2 and receives drainage from more than 8.6 km^2 of watersheds through a network of major river basins such as the Yangtze, Yellow, Red and Mekong basins. It is influenced by the Kuroshio Current in the north, and the North and South Equatorial Currents, as well as the Java Current, in the south. Based on its hydrographic, bathymetric, productivity and trophic characteristics, the sub-regional seas of East Asia can be grouped into six Large Marine Ecosystems, the Yellow Sea, East China Sea, South China Sea, Gulf of Thailand, Sulu-Celebes Sea and the Indonesian Sea. A large part of the seas of East Asia sits on the relatively shallow Sunda Shelf, making the regional sea one of the richest in terms of marine biodiversity, fisheries, and oil and mineral resources (Figure 3).

Regional efforts to prepare a marine strategy to address many of the common environmental and sustainable development issues began in 2000 and involved a long process of consultations and technical workshops (Chua, 2008). The Strategy integrates several existing international marine and environment-related conventions, protocols and agreements which countries have ratified with other national and regional action plans for sub-regional and regional seas developed over the years by national and international projects, programmes or organisations. The Strategy sets out a common vision and a series of action programmes to address marine biodiversity, marine pollution, natural and man-made hazards, and freshwater resources in coastal areas, in addition to fisheries, aquaculture and other food security issues that affect human and ecosystem health, and lives and properties. The 227 action programmes were grouped under six implementing strategies: protect, conserve, sustain, develop, implement and communicate.

The SDS-SEA was finally adopted through the Putrajaya Declaration at the first Ministerial Forum held in Malaysia. PEMSEA uses the Strategy to promote regional collaboration. By upgrading the skills of local officials, non-governmental organisations (NGOs) and academics, PEMSEA has assisted the development and implementation of the Strategy. It also promoted the involvement of the private sector to assist local governments in implementing ICM programmes, and initiated public-private sector partnerships in developing nutrient reduction facilities. PEMSEA was given the mandate to coordinate the implementation of the SDS-SEA through the Haikou Declaration of 2006 signed by ministers of the participating countries (Bernad et al., 2006). The GEF followed up with financial support to enhance implementation during the third phase of PEMSEA (2007-2010).

Major commitments, though not legally binding, of the Haikou Declaration of 2006, are to scale up ICM practices to cover at least 20% of the regional coastline and for 70% of the countries in the region to develop coastal/ocean policy, legislation or strategies in support of the implementation of the SDS-SEA. Countries in the region have made significant progress towards this end.

Promoting policy and legislative support for integrated management

Realising the important contributions of coasts and oceans to national economies, several countries in the region have developed appropriate coastal and ocean policies and ICM legislation, and have issued presidential decrees to support management measures. The RO Korea enacted ICM legislation as early as 1999 and revised it in 2009, while Indonesia promulgated the Coastal and Island Management Act in 2007. The Philippines and Vietnam promulgated Executive Orders (2006) and a Prime Minister's Decision (2007) respectively to mandate the implementation of ICM throughout their coastlines. China legislated sea space utilisation in 2002, and national legislation on island management is being developed. Japan, in addition to its Ocean 21 agenda, has passed a national law on comprehensive management of the coasts and oceans (2007). All these legal and policy measures strengthen integrated management at all levels of the government.

Photo: Digital Vision

Consolidating ICM

Another major thrust of PEMSEA is to consolidate the working modality of ICM to ensure uniformity in administration of management interventions. The ICM approach has evolved over the years and frameworks, platforms, processes and mechanisms have been refined into an ICM system. The system includes a governance component for decision-making and management intervention processes: in identifying and administering policy and management options; in defining institutional arrangements for coordinating and implementing the development of strategies and action plans; in determining financial allocation for management interventions; in promoting public awareness for involvement of stakeholders; and in development of institutional and leadership capacity at all levels of the government. The system incorporates the application of science and technology in planning land and sea use, and risk assessments in determining priorities for management actions.

Another major component of the ICM system is the collective implementation of prioritised management actions to reduce risks to human and ecosystem health, and to ensure human security. The types and levels of management interventions depend on the severity and frequency of damage to lives and property from natural and man-made disasters, the level of habitat destruction and loss of ecosystem services, the types and levels of pollution, the availability of safe drinking water, and the challenges to food security and livelihoods. The priority of each management action largely depends on conditions in the particular area.

The ICM system is equipped with a management monitoring and reporting mechanism through the State of the Coast Reporting system, thus enabling measurement of achievements based on fixed performance and impact indicators. The ICM system provides working frameworks, mechanisms and processes, thereby ensuring conformity, repeatability and accountability.

Adapting to and mitigating climate change

Adaptation to global warming and rises in sea level can be manifested through the application of ICM, especially at the local level. Through ICM, the appropriate policy and management fundamentals can be put in place to reduce and mitigate the predicted impacts of rises in sea level, submergence of coastal lowlands, saline intrusions into agricultural land, contamination of aquifers, destruction to coral reefs and mangrove habitats, changes in biodiversity, changes in nursery or spawning grounds, loss of fish stock, and loss or changes in fishing grounds.

ICM prepares local governments to take precautionary measures, educate the public in the possible consequences, increase their resilience and prepare for any environmental eventualities.

Building a permanent regional mechanism for coastal and ocean governance

PEMSEA takes a long-term view to forging regional cooperation and implementation of the SDS-SEA and is transforming PEMSEA from a short-term project into a self-sustaining regional organisation focusing on coastal and ocean governance. Towards this end, eight countries (Cambodia, China, DPR Korea, Indonesia, Laos, Philippines, RO Korea and Timor Leste) signed a formal international agreement on 26 November 2009 formally recognising the international legal status of PEMSEA. On the same day, an agreement was signed between PEMSEA and the Government of the Philippines thereby: providing the diplomatic privileges accorded to international organisations; strengthening the leadership and managerial capacity of local governments to implement and scale up ICM practices through a series of long-term and short-term training programmes; and building a strong regional network of local governments practicing ICM so that the region will be more prepared for new challenges in coastal areas (Figure 3).

The evolution of PEMSEA into a knowledge-based regional organisation with international legal status took 16 years. Project achievements in building legitimacy, confidence and partnerships among country and non-country partners are significant considering the political and socio-economic complexity, and diverse capacity in the region. It was a long process to build regional consensus through three ministerial declarations and agreements, the Putrajaya Declaration (2003), Haikou Agreement (2006) and the Manila Declaration (2009), to promote national coastal and ocean policy and legislation, build marine stewardships, and to increase public awareness and strengthen national capacity. The new organisation provides a two-tier decision-making mechanism through the Partnership Council which involves non-country partners – including NGOs, scientific and educational institutions, and the private sector – in implementing the regional marine strategy (SDS-SEA) along with their government counterparts. An exclusive inter-governmental session on policy matters is also part of the mechanism. The two-tier decision-making process is unique in PEMSEA and is very different from operational mechanisms of other regional seas institutions. The activities of PEMSEA are coordinated and implemented through the PEMSEA Resource Facility (PRF) which provides secretariat services to the Partnership Council and technical services to implementing projects or programmes funded from various sources (Figure 2). However, the effectiveness and sustainability of the new organisation has yet to be proven.

Conclusion

PEMSEA takes a holistic approach to securing waters in coastal areas. The term "water" denotes both fresh and marine waters, including groundwater and water in aquifers. In securing waters in coastal areas, PEMSEA's two-pronged approach (top-down and bottom-up) has proved effective in a region marked by immense political, socio-economic, cultural and capacity diversity. PEMSEA has tested, demonstrated and replicated the ICM system over the last 16 years. PEMSEA provides a much needed working modality and visible demonstration of outputs and outcomes on the ground – key catalysts for the rapid replication of ICM practices.

The strategy of building national support through national ICM legislation, national coastal or ocean policy, or executive orders, is instrumental in implementing ICM nationwide, especially in Indonesia, the Philippines and Vietnam. Application of the ICM system or the implementation of the SDS-SEA is often a reminder of the need to adopt the main principles of sustainable development which allow flexibility and the application of the precautionary principle in cases of scientific and environmental uncertainty.

There is no absolute formula for security of waters in coastal areas. Coastal managers often have to make their decisions based on the trade-offs available to them. In such cases, efforts should concentrate on ensuring the availability of wise options. ■

References

- Asian Development Bank (2003) Integrated Coastal Resource Management Project, Philippines. Final Report, Vol. 1: Main Report. Manila, Philippines: Asian Development Bank, Tetra Tech, EM Inc. and PRIMEX.
- Bernad, S.R., Gallardo, K.R. and Chua, T-E. (2006) Regional arrangement for the implementation of the SDS-SEA. A partnership approach. *Tropical Coasts* 13(1): 57–65.
- Cicin-Sain, B. and Knecht, R.W. (1998) *Integrated Coastal and Ocean Management.* Washington, DC: Island Press.
- Chan, F., Barth, J.A., Lubchenco, J., Kirincich, A., Weeks, H., Peterson, W.T. and Menge, B.A. (2008) Emergence of anoxia in the California Current Large Marine Ecosystem. *Science* 319(5865), p. 920.
- Chua, T-E. (1998) Lessons learned from practising ICM in Southeast Asia. *Ambio* 27: 579–600.

PEMSEA Office Building, Manila

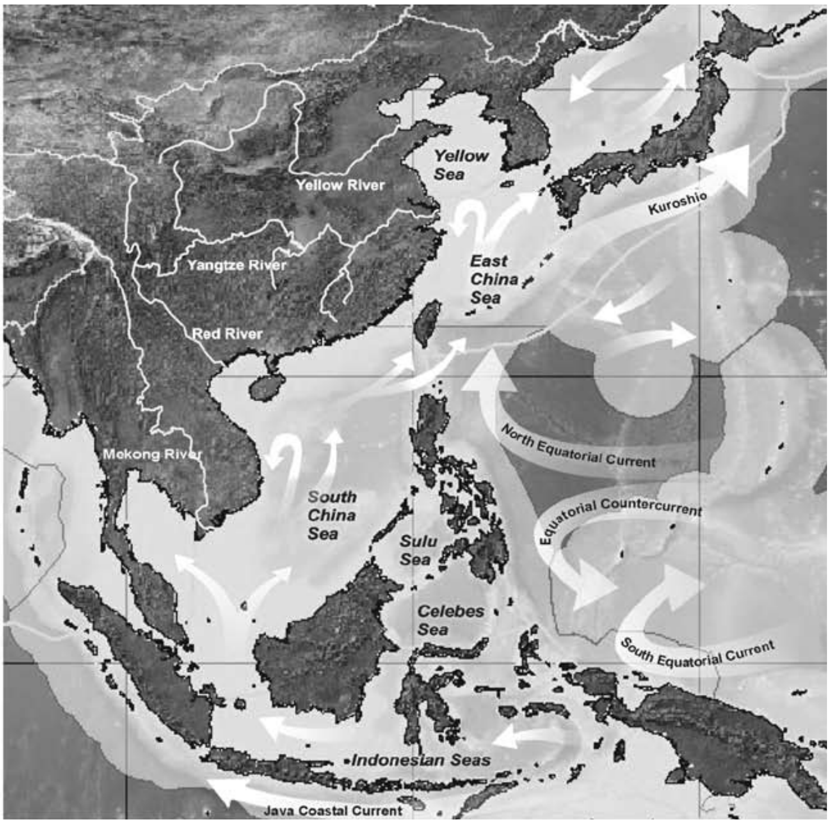


Figure 3. The seas of East Asia

- Chua, T-E., Bonga, D. A. and Bermas, N. (2006) The dynamics of integrated coastal management: PEMSEA's experience. *Coastal Management* 34(3): 303–322.
- Chua, T-E. (2006) *The dynamics of integrated coastal management: Practical applications in sustainable coastal development in East Asia.* Quezon City, Philippines: GEF/UNDP/IMO Regional Programme on Building Partnerships in the Environmental Management for the Seas of East Asia. 468 p.
- Chua, T-E. (2008) Coastal governance: A reflection of integrated coastal management (ICM) initiatives with special reference to the East Asian Seas Region. In *Securing the oceans: Essays on ocean governance--Global and regional perspectives* (Eds. Chua, T-E., Kullenberg, G. and Bonga, D.) pp. 371–402. Quezon City, Philippines: Global Environmental Facility/United Nations Development Programme/International Maritime Organization Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) and the Nippon Foundation. 770 p.
- Chua, T-E, Bonga, D. and Bernad, R.S. (2008) The evolving partnership model in coastal and ocean governance in the Seas of East Asia Region--PEMSEA's role. In *Securing the oceans: Essays on ocean governance--Global and regional perspectives* (Eds. Chua, T-E., Kullenberg, G. and Bonga, D.) pp. 597–628. Quezon City, Philippines: Global Environmental Facility/United Nations Development Programme/International Maritime Organization Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) and the Nippon Foundation. 770 p.
- Diaz, R.J. and Rossenberg, R. (2008) Spreading dead zones and consequences for marine ecosystems. *Science* 321: 926–929.
- Fisheries and Oceans Canada (2002) *Canada's Ocean Strategy: Policy and operational framework for integrated management of estuaries, coastal and marine environments in Canada.* Ottawa, Canada: Fisheries and Oceans Canada Ocean Directorate. 37 p.
- Forsberg, C. (1998) Which policies can stop large scale eutrophication? *Water Science and Technology* 37(3): 193–200.
- Helsinki Commission (2003) The Helsinki Commission: Lessons learned in ICZM. *Tropical Coasts* 10(1): 10–15.
- Jonch-Clausen, T. (2004) *Integrated water resources management (IWRM) and water efficiency plans by 2005. Why, what and how?* Stockholm, Sweden: Global Water Partnership, TEC Background Paper No. 10. 45 p.
- Kimball, L.A. (2003) Developments in the implementation of UNCLOS provisions on regional cooperation. *Tropical Coasts* 10(1): 4–9.
- Krishnamurthy, R.R., Kannen, A., Ramanathan, A.L., Tinti, S., Glavovic, B.C., Green, D.R., Han, Z. and Agudy, T.S. (Eds.) (2009) *Integrated Coastal Zone Management – The global challenges.* Singapore: Research Publishing Services. 775 p.
- Melvasalo, T. (2008) Perspectives and experience of the UNEP Regional Seas Programme. In *Securing the oceans: Essays on ocean governance--Global and regional perspectives* (Eds. Chua, T-E., Kullenberg, G. and Bonga, D.) pp. 229–249. Quezon City, Philippines: Global Environmental Facility/United Nations Development Programme/International Maritime Organization Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) and the Nippon Foundation. 770 p.
- Mario Soares Foundation (2008) *Lisbon Statement on Ocean Governance for the 21st Century. Commemorative Session on the 10th* Anniversary of the Lisbon Declaration, 1998. Lisbon, Portugal: Mario Soares Foundation. 3 p.
- NOAA (2002) *Annual per capita consumption of fish and shellfish for human food- by region and country, 1997–99 average (revised)*. National Oceanic and Atmospheric Administration.
- Pauly, D., Christensen, V., Dalsgaard, J., Froese R., Francisco, T. Jr. (1998) Fishing down the food chain. *Science* 279: 860–863.
- PEMSEA (2006a) *A perspective on the environmental and socio-economic benefits and costs of ICM: The case of Xiamen, PR China.* PEMSEA Technical Report No. 17. Quezon City, Philippines: GEF/UNDP/IMO Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia. 106 p.
- PEMSEA (2006b) *Securing the future through ICM: The case of the Batangas Bay Region.* PEMSEA Technical Report No. 19. Quezon City, Philippines: GEF/UNDP/IMO Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia. 84 p.
- PEMSEA (2006c) *Xiamen: An ICM journey.* PEMSEA Technical Report No. 18. Quezon City, Philippines: GEF/UNDP/IMO Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia. 93 p.
- PEMSEA (2007) PEMSEA: *Partnerships in Environmental Management of the Seas of East Asia (1994-2010). A regional mechanism facilitating sustainable environmental benefits in river basins, coasts, islands and seas.* PEMSEA IEC Material 2. Quezon City, Philippines: Global Environment Facility/United Nations Development Programme/International Maritime Organization Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia (PEMSEA). 80 p.
- Rabouklle, C., Conley, D.J., Dai, M.H., Cat, W-J., Chen, C.T.A., Lansard, B., Green, R., Yin, K., Harrison, P.J., Dagg, M. and McKee, B. (2008) Comparison of hypoxia among four river-dominated ocean margins: The Changjiang (Yangtze), Mississippi, Pearl and Rhone rivers. *Continental Shelf Research* 28: 1527–1537.
- Rogers, P. and Hall, A.W. (2003) *Effective water governance.* Global Water Partnership TEC Background Paper No. 7. Stockholm, Sweden: Global Water Partnership. 44 p.
- Rees, J.A. (2002) *Risk and integrated water management.* Global Water Partnership, TEC Background paper No. 6. Stockholm, Sweden: Global Water Partnership. 48 p.
- Tropical Coasts (2009) *The marine economy in times of change.* July issue. Quezon City, Philippines: PEMSEA. 80 p.
- Sorensen, J. (2002) *Baseline 2000. Background Report. The status of integrated coastal management as an international practice.* Second iteration 26 August 2002. Boston, USA.
- Scura, L.F., Chua, T-E., Pido, M.D. and Paw, J.N. (1992) Lessons for integrated coastal zone management: The ASEAN experience. In *Integrated framework and methods for coastal area management* (Eds. Chua, T-E and Scura, L.F.). ICLARM Conference Proceedings 37. Manila, Philippines. 169 p.
- Ye, Yimin (1999) *Historical consumption and future demand for fish and fishery products: Exploratory calculations for the year 2015/2030.* FAO Fishery Circular No. 946. Rome, Italy. 32 p.


Mr. Alain Vidal
Program Director, CGIAR Challenge Program on Water and Food
a.vidal@cgiar.org


Ms. Barbara van Koppen
Rural Sociologist & Gender Expert, International Water Management Institute
B.VanKoppen@cgiar.org


Mr. David Blake
Research Student, School of International Development, University of East Anglia
d.blake@uea.ac.uk

The green-to-blue water continuum: An approach to improve agricultural systems' resilience to water scarcity

This paper explores two examples from the CGIAR Challenge Program on Water and Food research on resilience along the green-to-blue water continuum. A threatened floodplain wetland of the Mekong Basin has been shown to provide many direct and indirect benefits and services that are more resilient and less vulnerable to shocks than externally introduced agricultural systems of various types and intensity occupying the same land–water interface. Multiple-use water systems (MUS) assessed in five large basins show that, wherever water is available, people use water for greater resilience, domestic and productive purposes, including livestock watering, horticulture, irrigation, tree growing or small-scale enterprise.
Keywords: water productivity, wetlands, multiple-use water systems, resilience, green water, blue water

Introduction

All around the world, agricultural systems have never been strictly rainfed or irrigated. The history of Mesopotamia teaches us that even if farmers were mastering some level of irrigation technology, they were not operating under full irrigation, nor were they cultivating using just rainwater. Between irrigated and rainfed agriculture, farmers' reality has been that they simply have never grown any crop without water which they have stored, mobilised and applied to plants through a variety of different methods depending on the nature of the resource available. Irrigated systems typically also use green as well as blue water, and rainfed systems sometimes also use blue as well as green water, even in the absence of formal irrigation systems. In a nutshell, farmers' coping strategies worldwide have always been to deal with a green-to-blue water continuum. Their dependency on this continuum has inspired them to innovate, and to extract the best productive value, not only from crops, but also from aquatic resources, livestock, and many other productive water uses.

Following this long history of combined rainfed and irrigated agriculture, more recent historical paradigms have emphasised a stronger opposition between rainfed and irrigated agricultures. The global surface area under irrigation has dramatically increased since the 1960s, practically doubling from 160 to 300 million hectares. Most policies have kept rainfed and irrigated agricultures distinct from one another, hence trying to negate the existence of this continuum. However a large majority of "new" irrigation farmers – those who were given land to irrigate and crop after the green revolution – were historically rainfed farmers, if not breeders (e.g. in Morocco), or their parents and relatives were. In other words, half of today's irrigated surface is cultivated by farmers who traditionally practised rainfed systems. Figure 1 shows the overall dominance of green-water use in agriculture, with a few exceptions in the arid and semi-arid areas where irrigation has expanded over the last 50 years (and significantly left Africa and South America relatively sparsely irrigated).

The CGIAR Challenge Program on Water and Food (CPWF) initially aimed to increase water productivity and to ensure more equitable use of water among users and the environment. However, and in common with resilience "science", it has considered agricultural and natural resource systems as coupled to social ecological systems, thus emphasising not only the dynamics in each domain, but also the nature and dynamics of the linkages between the two. Therefore, most of the

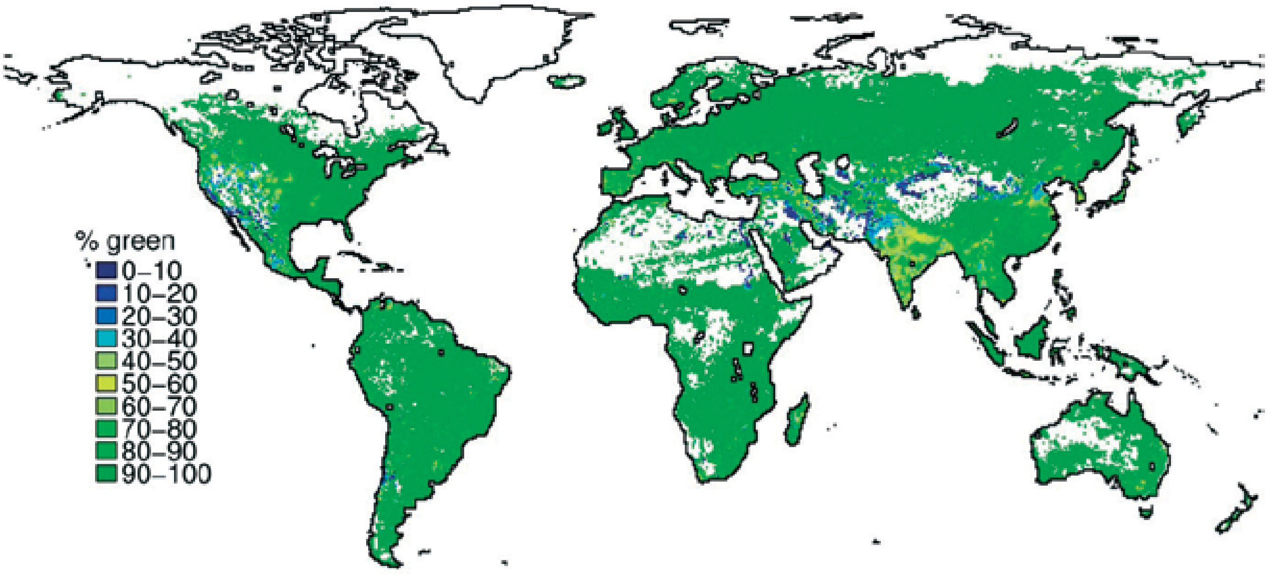


Figure 1. Share of green water in agriculture
Source: Hoff and Rockström (2008)

CPWF Phase 1 projects (2003–2008) have tried to bring greater resilience to the livelihoods of the rural poor who are the ultimate research beneficiaries, as are the natural resource systems upon which they depend. The present paper reviews results from two of these projects: one developed in a "green-water dominated" system, namely a threatened wetland of the lower Mekong Basin; and one developed in "blue-water dominated" systems, looking at multiple-use water systems (MUS) in the Andean, Nile, Limpopo, Ganges and Mekong Basins.

The paper aims to demonstrate that increasing water productivity and improving farmers' livelihoods should be done alongside, and in recognition of, the existing green-to-blue water continuum, and that significant progress can be achieved by learning from the resilience of various systems along this continuum.

The resilience concept and its linkages with agricultural water productivity

In ecology, resilience has long been defined as "a measure of the ability of systems to absorb changes of state variables, driving variables, and parameters, and still persist". It has since broadened to include people, emphasising not only the dynamics in the ecological and social domains, but also the nature and dynamics of the linkages between the two. Walker and Meyers (2004) provided a widely cited definition of the resilience of a social–ecological system as "the capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks". Alternatively, it is "the ability of the system to maintain its identity in the face of internal change and external shocks and disturbances" (Cumming et al., 2005). These resilience concepts have to be applied in the context of enhancing, or at least maintaining, the multiple economic, social and environmental benefits that societies derive from natural resource systems.

The Walker and Meyers (2004) paper identifies three attributes of a system that constitute an overall resilience approach: (1) resilience, in the sense of persistence, (2) adaptability, the capacity to manage resilience, and (3) transformability, the capacity to transform into a different kind of system. The essential point about resilience has to do with limits, or thresholds, to change. If a system follows linear dynamics, it is always smoothly reversible within current technology and resource constraints. If a mistake is made, or the managers change their minds, there is no fundamental difficulty in moving to another state of the system. In systems with non-linear dynamics, however, the likelihood of alternate system regimes is high. A shift (intended or unintended) from one to the other can be irreversible or very hard to reverse.

Conventional natural resource management policy and management institutions have tended to assume that ecosystems, agro-ecosystems and social–ecological systems are predictable and controllable, and follow smooth and linear trajectories (i.e., they don't exhibit discontinuous changes). Management has focused on average conditions and on particular time and space scales. Such an assumption is represented in Figure 2, showing what most agricultural and irrigation engineers imagine as a continuous transition from a green-water dominated rainfed system to a blue-water dominated irrigated system.

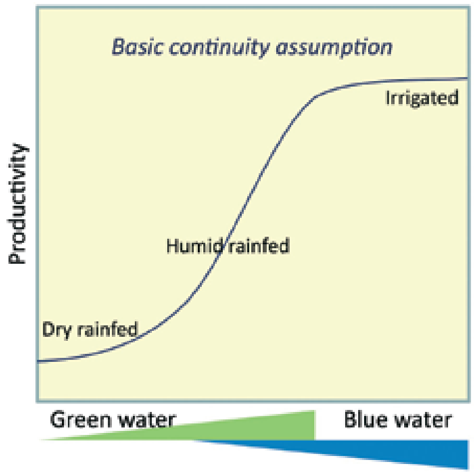


Figure 2. A theoretical " engineering" vision of the green-to-blue water continuum based on the assumption that water productivity of agricultural systems increases continuously when evolving from dry rainfed to humid rainfed, then to irrigated.

In contrast, a resilience approach to management assumes that social–ecological systems can exhibit threshold-type changes, which may move them towards some new state. Examples occur in agricultural, forestry and fisheries systems which are able to recover after being changed by human use and natural disturbances, but beyond some critical level of change can no longer recover. The existence (and the likelihood) of alternate stable states is what makes the concept of resilience so important. The bigger the difference between the levels of the two states, and the bigger the hysteresis effect (i.e., the more the controlling variable needs to be reversed before the state of the system "flips" back), the greater is the significance of that particular aspect of resilience.

The present paper assumes that, under water-scarce conditions, such alternate stable states exist along the green-to-blue water continuum, and correspond to quite high and stable water productivities made possible through better water management, be it green, blue or a combination of both (i.e. respectively left, right or centre of the X-axis in Figure 2).

In the following, water productivities will be approached through the estimated or measured income of poor households generated through the system considered (be it based on agriculture, livestock, fisheries or other productive water uses). Incomes per household are indeed strongly related to income per cubic metre of water (a strict measure of water productivity). And since higher incomes provide the rural poor with a buffer against market, environmental and climatic variations, they logically make them more resilient; hence household income can be considered as a good resilience indicator.

Lessons learnt from two CPWF projects

A wetlands ecosystem and resilience in the lower Nam Songkhram River Basin, Thailand

The Nam Songkhram Basin in Northeast Thailand is a medium-sized (13,128 km^2) sub-basin of the Mekong Basin encompassing a wide range of agro-ecological zones, from forests in the upper watershed to vast floodplain wetlands that experience a three to four month period of annual flooding in the lower basin. The total area of inundation varies from year to year, but averages at approximately 960 km^2, doubling in area during a one in fifty year flood (Blake et al., 2009). Annual rainfall varies within the basin from 1,200 to 2,800 mm, with 90% falling in the wet season. The natural eco-hydrological pattern of the lower Nam Songkhram Basin is complex and mirrors that of the better-known Cambodian Tonle Sap system's annual "flood pulse" phenomenon (Lambert, 2008), albeit on a much reduced scale. Studies have shown that these wetlands are strongly influenced in the wet season by the hydrology of the Mekong River, including occasional backflow events in July–August when Mekong waters may spill over onto the floodplain up to 100 km upstream from the confluence (Sarkkula et al., 2006). In the dry season, water levels fall by around 12 m from their peak and the floodplain reverts to a mixed habitat wetlands complex, dotted with permanent water bodies (natural and artificial), and interspersed by a mosaic pattern of remnant natural forest stands, land converted to agriculture (mostly rice paddy) and, increasingly, industrial tree species (e.g. rubber and eucalyptus) monoculture. In the 1980s and early 1990s, large areas of forested land were cleared of natural vegetation for cash crop plantations (e.g. tomatoes, sweetcorn and sunflowers) by several influential agribusiness companies, most of which failed commercially following the 1997 Asian economic crash and have subsequently been abandoned (Blake and Pitakthepsombut, 2006b).

Figure 3. Capture fisheries in the Nam Songkhram Basin wetland represent an average catch of 207 kg/household/annum, generating a household income of around US$1,100 per annum.

Local livelihoods are closely tied to the floodplain wetland ecosystem and traditionally relied heavily on the harvest of wetland products, including both terrestrial and aquatic biodiversity (Blake and Pitakthepsombut, 2006a). In particular, there has long been an important freshwater capture fishery, which targets both non-migratory and migratory species using a wide variety of gear. In a recent study, capture fisheries were estimated to involve up to 93% of households with an average catch of 207 kg/household/annum (Hortle and Suntornratana, 2008). Non-fish wetland biodiversity harvested by villagers for local consumption and sale include numerous species of edible and medicinal plants, fungi, insects, birds, mammals, amphibians, crustaceans, molluscs and reptiles, as well as a wide range of non-consumptive plant and animal products. Relatively few detailed socio-economic studies of the ecosystem values for Northeast Thailand have been conducted. A study found that the average gross economic benefits derived from wetland products per household in 2006–2007 was around US$1,100 and that approximately 92% of households participated in the collection of wetlands products (Pagdee, 2007).

Much of this natural biodiversity originates in the "paa boong paa thaam", or seasonally-flooded forest, a highly biodiverse and ecologically productive wetland habitat according to multi-disciplinary research conducted under the Mekong Wetlands Biodiversity Conservation and Sustainable Use Programme (MWBP) between 2003 and 2006 (Blake et al., 2009). The annual flood pulse is recognised to be the principal driver of the immense aquatic and terrestrial productivity of the Mekong wetlands floodplain ecosystem, as observed in other major lowland tropical river systems (Junk and Wantzen, 2004; Lambert, 2008). The paa boong paa thaam of the lower Nam Songkhram Basin has been steadily reduced in extent and quality over the past 50 years of modern "development". A study estimated that between 2001 and 2005 alone, the remaining paa boong paa thaam reduced in size from 89.6 km^2 to 73.2 km^2 due to various kinds of human encroachment (Suwanwerakamtorn et al., 2007). A number of ongoing threats to the integrity of the wetlands ecosystem have been identified (Blake and Pitakthepsombut, 2006a), including:

- Construction of large-scale water infrastructure projects, particularly irrigation schemes, including transboundary/basin transfer plans e.g. a proposed "water grid" project,
- Intensification of agriculture, including greater agrichemical inputs, large-scale agribusiness model application, and industrial tree monocrop plantations,
- Use of unsustainable fishing gear and methods,
- Expansion of existing salt and proposed potash-extraction activities,
- Industrialisation and urbanisation with associated local over-abstraction and water pollution,
- Release and spread of alien and potentially destructive plant and animal species,
- Changes in hydrology and sediment transfer from upstream Mekong mainstream and tributary dam construction, adversely impacting the flood pulse regime.

These factors have added to a general decline in the water productivity and resilience of paa boong paa thaam, reflected in numerous reports of reduced aquatic organism catches and other wetland product harvests (Blake and Pitakthepsombut, 2006a and 2006b), which have a low associated opportunity cost compared with agriculture. Research by Pagdee (2007) showed that the relative proportion of net economic benefit from harvesting wetlands products was 82.65% compared with 14.70% for rice cultivation. If protected and left undisturbed, paa boong paa thaam has the potential to provide high direct and indirect economic benefits from provisioning, supporting and providing cultural ecosystem services, which have rarely been considered by regional policymakers and planners.

As the paa boong *paa thaam* is essentially a common property resource, reliant on a complex eco-hydrological regime partially independent of in-basin run-off patterns, then its resilience to changes in water and land use patterns (both within the sub-basin and wider Mekong Basin) can be called into question. To date, a few remnant forested patches remain intact due to local protection measures and have shown a degree of resilience to some external shocks (e.g. rapid regrowth of bamboo forest post-clearance for rice fields) but not to others (e.g. severe physical and chemical forest clearance by agribusiness companies), suggesting highly uneven resilience at the local level. Also, the future resilience of these wetlands is as much dependent on future hydrological scenarios for the Mekong mainstream as much as it is on in-basin developments. On the one hand, blue water is now nominally more available due to the construction of numerous shallow reservoirs on the floodplain, but paradoxically there is little evidence that these sources are being used for agricultural purposes, and irrigation systems cover only 5% of total land area. On the other hand, natural seasonal flooding (green water) limits agriculture to a greater extent than absolute water scarcity, yet is simultaneously the main driver of natural wetland product diversity and abundance.

At the promotion peak of the Nam Songkhram Project in the mid 1990s, rural people were steadily migrating out of the locale, partly because of natural resource degradation and loss of wetland productivity, but also because of better wage earning opportunities elsewhere. Around the same period, it was estimated that 80% of total cash income was earned off-farm in Northeast Thailand, including 43% from wage work in cities (Blake et al., 2009), which cannot be considered as a resilient evolution. Hence, given the continual attempts by certain state agencies, private interests and Mekong regional water resources planners to overcome a perceived regional water scarcity and control floods (often termed "natural disasters") through engineering approaches, there is an urgent need to re-evaluate the present value and ecosystem services of existing natural and artificial wetlands, while recognising issues of equity and rights in common property regimes. Figure 4 below graphically indicates the likely shift in water productivity that may occur when a "tipping point" is reached in terms of ecosystem stability through external shocks such as vegetation clearance or hydrological changes resulting from a dam.

In summary, the paa boong paa thaam wetland production ecosystem may provide many direct and indirect benefits and services that are

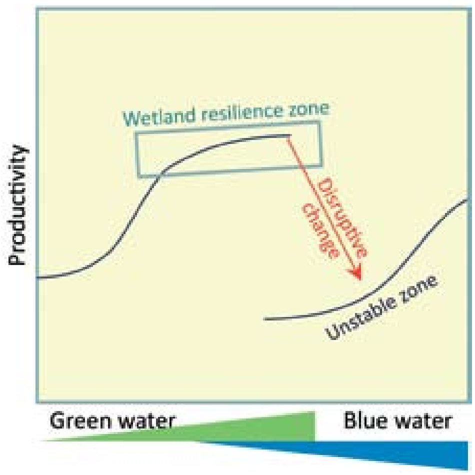


Figure 4. Schematic evolution of water productivity along the green-to-blue water continuum of a productive wetland of the Mekong Basin, and its likely evolution (red arrow) as already observed in past attempts to regulate floods and water flows through infrastructure or massive agricultural land conversion and enclosure schemes.

more resilient and less vulnerable to shocks than agricultural systems of various types and intensity occupying the same land–water interface, partly because it is fully adapted to and a product of the local ecological conditions related to the flood pulse phenomenon. However, the ecosystem is nevertheless vulnerable to external shocks such as changes to the flood pulse itself (for example, by built and planned Mekong mainstream dams in China) or wholesale forest clearance for agriculture, and thus its long-term resilience is limited in the face of multiple threats. At the same time, it should be noted that smaller-scale, farmer managed and controlled irrigation systems have proven more resilient over the last few decades to external socio-economic and ecological shocks than the larger state or private controlled irrigation systems, which in many cases have been abandoned within a decade. Whether the remaining fragments of paa boong paa thaam can be saved for the benefit of future generations in the face of environmental threats, stakeholder conflict and ongoing waterscape transformation, is a matter that Thai society is currently wrestling with.

MUS – multiple-use water systems

The multiple-use water systems (MUS) (sometimes referred to as multiple-use water services) project explored the resilience of humans and of natural resource systems, and, above all, their interfaces (Mikhail and Yoder 2008; Van Koppen et al., 2009). This broader conceptualisation opened up a new practical approach to water services by governments, NGOs, international water and rural development agencies and the private sector: "multiple-use water systems" (MUS). The project realised that water users are invariably quick to transform any system designed for a single use into multiple-use schemes, whether this causes damage and is illegal, or not. As conceptualised by the project, MUS moves beyond the fragmented interventions of single-use sub-sectors: either domestic, or green water, or blue water, or livestock watering, or fisheries, etc. It anticipates and plans for such multiple needs, including domestic water uses, which are often the priority of poor men and women, and mainstreams this priority across the water sector. Thus, MUS takes people's multiple water needs as the starting point of a water intervention. The project pioneered the implementation and scaling-up of this new approach, and found all evidence for its hypothesis that MUS is significantly more effective than conventional sector-based single-use interventions for sustainable rural and peri-urban poverty alleviation.

Photo credit: MUS project

Figure 5. Developing multiple water use systems in Nepal at household and community levels has empowered villagers, especially women, and generated additional income

The merits of MUS lie primarily in the fact that MUS strengthens resilience, both from a people's and a resource perspective. MUS boosts resilience in people's livelihoods by concurrently meeting multiple domestic and productive water needs, and thus simultaneously contributing to health, dignity, food, income and freedom from the drudgery of water fetching, to mention the most important dimensions of wellbeing. The combination of these livelihood benefits strengthens resilience against shocks and extreme events even more than the sum of each dimension. Health enables higher water productivity; more income allows more spending on health care; women can use the time saved for productive activities or rest; and girls can attend school which tends to increase marriage age, income and family welfare, thus breaking intergenerational poverty traps. Indeed, MUS triggers virtuous circles out of poverty, especially in peri-urban and rural settings in low- and middle-income countries where people's agrarian livelihoods are diversified and depend in many ways upon water.

From a resource perspective, MUS combines green and blue water and considers all forms in which water comes at the interface with society. Water is available for humans as multiple interlinked, conjunctively used water sources of rainfall, surface streams and storage, groundwater, and wetlands. Infrastructure, which brings the right quantities of water of the right quality at the right time to the right place, is the single most important trigger for a higher level of equilibrium in which many more water needs of many more people can be met. Water infrastructure development underpins the economic growth of high-income countries. The use and re-use of, and protection from combined natural and human-made water sources are key to resilience in the ecosystem of humans and natural resources as a whole. Significantly, since time immemorial, this is the way in which rural communities themselves have developed infrastructure and managed multiple water sources for multiple water needs, mitigating variability, unpredictability and extreme drought and flooding in often harsh ecological conditions.

The MUS project applied these new opportunities for enhanced resilience to the implementation and scaling-up of two models of MUS: homestead-scale MUS and community-scale MUS. Led by the International Water Management Institute, the project was implemented in 30 sites in eight countries in five basins of the Challenge Program on Water and Food: Andes (Bolivia and Colombia), Indus-Ganges (India and Nepal), Limpopo (South Africa and Zimbabwe), Mekong (Thailand), and Nile (Ethiopia). In each country, the lessons learnt on the ground were scaled up among intermediate and national level water service providers, through learning alliances which encompassed a total of 150 institutions. Advocacy at the global level was undertaken in collaboration with the global MUS Group (www.musgroup.net). The project's ultimate aim of scaling-up MUS was to contribute to providing all people with the water services they need.

For homestead-scale MUS, the project found that the water services ladder commonly used in the domestic sector failed to match reality in peri-urban and rural areas in low- and middle-income countries. Unlike the domestic sector's assumption that people use up to 100 litres per capita per day near to homesteads for domestic uses only, the project found that wherever water is available, people use water for productive purposes as well, including livestock watering, horticulture, irrigation, tree growing or small-scale enterprise. In Northeast Thailand, up to nine water sources were found to be used for intensive use- and re-use of water and nutrients at homesteads for economic self-sufficiency. Ample and flexible choice among homestead-based activities accommodates volatile environments. Moreover, for women, the land-poor, and the sick, the homestead is often the only site where they can use water productively.

The project estimated that these productive activities brought food and additional annual incomes in the order of US$300–500 per household, which is significant for poor households living on one U.S. dollar per person per day. Renwick (2007) found similar amounts and calculated that this income often allows full repayment of investments in the required infrastructure within a half to three years. So, in principle, homestead-scale MUS allows even the poorest to pay for water and cross-subsidise domestic water uses.

Hence, the project recommends replacing the domestic sector's water ladder with a more realistic "multiple-use water ladder" in poor rural and peri-urban areas (Van Koppen et al., 2009). Accordingly, water services policies should allow the poor to "climb the water ladder" by increasing service levels to an "intermediate level" MUS of 50–100 litres per capita per day, or even to more than 100 litres for "high level" MUS. Out of these quantities, 3–5 litres should be safe for drinking and cooking. In this way, homestead-scale MUS contributes cost-effectively to all the Millennium Development Goals, and creates a more productive and stable resilience zone when compared with the instability associated with single-use designed systems, as depicted in Figure 6.

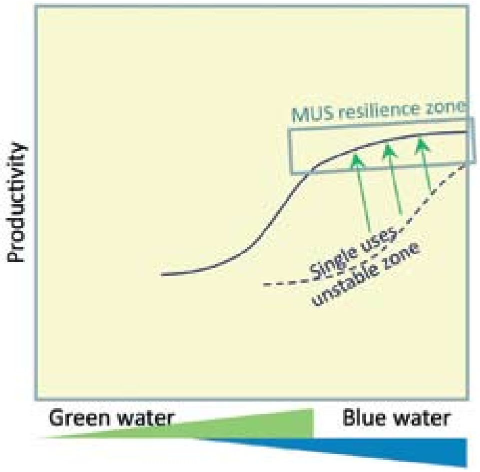


Figure 6. Schematic evolution of water productivity along the green-to-blue water continuum between single-use and multiple-use water systems (MUS), observed in many basins targeted by the Challenge Program on Water and Food

Photo: Mats Lannerstad, SIWI

Conclusions

The two cases reviewed above can be grouped into the same graph (Figure 7) to illustrate how the green-to-blue water continuum can be used to better guide interventions on improved productive water use and management, depending on actual conditions. Different trajectories may hence be drawn according to the productive systems considered: humid rainfed, like in the lower Mekong Basin, or blue-water dominated, like in many places around the world where water infrastructure has been significantly developed.

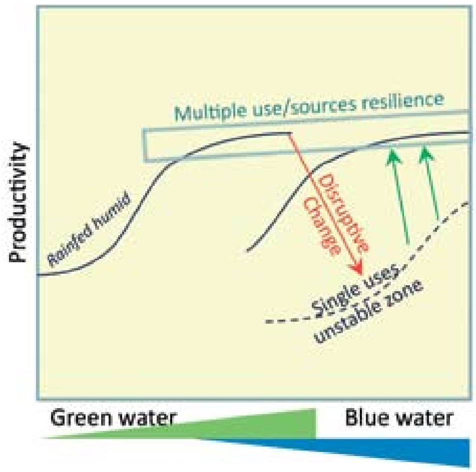


Figure 7. Schematic evolutions of water productivity along the green-to-blue water continuum according to the different productive systems considered by the CGIAR Challenge Program on Water and Food from the two cases described.

Experience from these two CPWF projects shows that, for each system, there is a state of higher household income related to higher water productivity, considered to be more resilient, which is ensured by a combination of multiple water uses, techniques and/or sources, together with a resulting (or accompanying) community organisation. It also shows that neglecting the green-to-blue water continuum creates unaffordable disruptive changes, depicted by the red arrow on Figure 7.

These two examples clearly show that, when increasing water productivity and improving farmers' livelihoods is done along the existing green-to-blue water continuum, more resilient states can be identified, maintained, created or restored by combining multiple water sources and uses. This paper hence suggests a change of paradigm in food production systems where green water is still too often placed in opposition to blue water in a sense that implies that more productive and resilient states are achieved only thanks to well-mastered blue water. ■

References

- Blake, D.J.H. and Pitakthepsombut, R. (2006a) *Situation Analysis: Lower Songkhram River Basin, Thailand.* Bangkok, Thailand: Mekong Wetlands Biodiversity Conservation and Sustainable Use Programme.
- Blake, D.J.H. and Pitakthepsombut, R. (2006b) The Songkhram River wetlands of Northeast Thailand and participatory resource research initiatives. In *Knowledge, Culture and Livelihood: The Struggle for Water and People's Everyday Resistances* (Ed. Li, K.Y.). Asian Exchange 21(2)/22(1), 1996. Asian Regional Exchange for New Alternatives, Hong Kong/Seoul.
- Blake, D.J.H., Friend, R. and Promphakping, B. (2009) The Nam Songkhram River Basin landscape transformations and new approaches to wetlands management. In *Contested Waterscapes in the Mekong Region: Hydropower, Livelihoods and Governance* (Eds. Molle, F.F.T. and Käkönen, M.) pp. 173–202. London, UK: Earthscan Publications.
- Cumming, G.S., Barnes, G., Perz, S., Schmink, M., Sieving, K.E., Southworth, J., Binford, M., Holt, R.D., Stickler, C., and Van Holt, T. (2005) An exploratory framework for the empirical measurement of resilience. *Ecosystems* 8:975–987
- Hoff H., Rockström, J. (2008) Global Drivers of Change. In CGIAR Challenge Program on Water and Food, *2nd International Forum on Water and Food,* Addis Ababa, Ethiopia, 10—14 November 2008 : Website publication http://ifwf2.org/addons/resources_downlaod_keynote_presentations.php?ksp_id=1002
- Hortle, K.G. and Suntornratana, U. (2008) *Socio-economics of the fisheries of the Lower Songkhram River Basin, Northeast Thailand.* MRC Technical Paper No. 17. Vientiane, Laos: Mekong River Commission.
- Junk, W.J. and Wantzen, K.M. (2004) The Flood Pulse Concept: New aspects, approaches and applications – an update. In *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries* (Eds. Welcomme, R.L. and Petr, T.) Vol. 2. pp. 117–140. Bangkok, Thailand: Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific.
- Lambert, D. (2008) Little impact, much damage: the consequences of Mekong river flow alterations for the Tonle Sap ecosystem. In *Modern Myths of the Mekong* (Eds. Kummu, M., Keskinen, M., Varis, O. and Suojanen, I.). Water and Development Publications, Helsinki University of Technology TKK-WD-002 (EN): Website publication http://www.water.tkk.fi/global/publications.
- Mikhail, M. and Yoder, R. (2008) *Multiple Use Water Service Implementation in Nepal and India: Experience and Lessons for Scale-up. Lakewood,* USA: International Development Enterprises, Challenge Programme on Water and Food, and International Water Management Institute.
- Pagdee, A. (2007) *Economic Valuation of Ecosystem Goods and Services in the Lower Songkhram River Basin.* Bangkok, Thailand: Mekong Biodiversity Conservation and Sustainable Use Programme. August 2007. Unpublished report. 49 pp. (in Thai).
- Renwick, M. (2007) *Multiple-use Water Services for the Poor: Assessing the State of Knowledge.* Winrock International, IRC Water and Sanitation Centre, International Water Management Institute. Arlington, VA, USA: Winrock International: Website publication http://www.winrockwater.org/docs/Final%20Report%20Multiple%20Use%20Water%20Services%20Final%20report%20feb%2008.pdf.
- Sarkkula J., Koponen, J., Keskinen, M., Kummu, M., Lauri, H., Rasphone, A., Souksakoun, K., and Veijaleinen, N. (2006) *Nam Songkhram model applications.* Working Paper No. 5, WUP-FIN Phase II – Hydrological, Environmental and Socio-economical Modelling Tools for the Lower Mekong Basin Impact Assessment. Mekong River Commission and Finnish Environment Institute Consultancy Consortium, Vientiane, Lao PDR. 71 pp.
- Suwanwerakamtorn, R., Ratcharoen, A. and Salakkham, E. (2007) The Seasonally-flooded Forest Change in the Lower Songkhram River Basin. *Journal of Remote Sensing and GIS Association in Thailand* 8(2): 36-47 (in Thai): Website publication http://www.gistda.or.th/resga.
- Van Koppen, B., Smits, S., Moriarty, P., Penning de Vries, F., Mikhail, M. and Boelee, E. (2009) *Climbing the water ladder: Multiple-use water services for poverty reduction.* Technical Paper Series 52. The Hague, the Netherlands: IRC International Water and Sanitation Centre and International Water Management Institute and Challenge Program on Water and Food: Website publication http://www.irc.nl/page/49660.
- Walker, B. and Meyers, J.A. (2004) Thresholds in Ecological and Social–ecological Systems: A Developing Database. *Ecology and Society* 9(2): 3: Website publication http://www.ecologyandsociety.org/vol9/iss2/art3.

Photo: David Molden

Prof. Junguo Liu
Professor, School of Nature Conservation, Beijing Forestry University
water21water@yahoo.com

Mr. Stuart Orr
Freshwater Manager, WWF International
sorr@wwfint.org

Water footprint overview in the governmental, public policy, and corporate contexts

Water footprints have evolved from the quantification of virtual water theory and have been linked to advocacy, awareness, measurement for baselines and, now, to water management decision-making. To date, the role of water footprints in water policy has been limited to a few examples in the government and the corporate contexts. In this article, we show how both the government in China and one particular brewery company (SABMiller) have used the water footprint concept. In China, a sharp increase in the per capita water footprint has been reported, mainly due to diet shifts in recent decades. Partly in response to this change, the Chinese government has promoted the strategy of a "water-saving society development" to enhance water use efficiency and reduce the national water footprint. Similarly, SABMiller have used the water footprint method to estimate water reliance in their supply chain and overlay this information with business risks in the value chain. We conclude that the evolvement of the water footprint concept from basic quantitative studies to a powerful advocacy tool can help support policy development, decision-making and business risk awareness for efficient water use.

Keywords: water footprint, policy, China, SABMiller

Introduction

Development of the water footprint concept

The water footprint concept was first introduced in 2002 by Arjen Hoekstra at the International Expert Meeting on Virtual Water Trade, held in Delft, The Netherlands (Hoekstra, 2003). The concept builds on work by Allan (1993) related to the virtual water trade. The water footprint takes the theory of virtual water trade and quantifies the amounts of water used in various processes. This defines the water footprint of an individual, community or business as the total volume of freshwater used to produce the goods and services consumed by the individual or community or produced by the business (Hoekstra and Chapagain, 2008). Prior to the quantification of virtual water, the relationship between water and food was mainly studied from the supply side. This concept has led to a focus on the studies on water–food relations by considering food consumption patterns, and by linking this consumption to production sites.

The water footprint concept generated interest soon after it was introduced, mainly because it was understandable as an advocacy tool and was an easily communicated message to stakeholders. The concept has been discussed at water-related conferences, such as the 3rd World Water Forum in Japan in 2003, the expert meeting on "virtual water trade" in Bonn in 2005, the 4th World Water Forum in Mexico City in 2006 and at the World Water Weeks in Stockholm in Sweden in 2008 and 2009. In October of 2008, the Water Footprint Network (WFN) was formally established in Enschede, The Netherlands, and aims to accelerate the research, applications and discussions on water footprints. In particular, the business community has frequent conferences and meetings on water footprints, such as the Corporate Water Footprinting Conferences in 2008/2009 in San Francisco, London, Brussels and Miami, as well as sessions at the 5th World Water Forum in Istanbul.

This paper looks into both public and private sector uses and advancements of the water footprint concept, with an example from China and one from the global brewery firm, SABMiller.

Review of water footprint research

A water footprint can be assessed for a well-defined region or product. At the global scale, Hoekstra and Chapagain (2007) quantified the water footprints of nations as a first attempt at quantifying the volume of water needed for the production of the goods and services consumed by humanity. At the national level, water footprints have been assessed for China (Liu and Savenije, 2008; Liu et al., 2008), India (Kampman et al., 2008), Spain (Aldaya et al., 2008) and the UK (Chapagain and Orr, 2008). Although most efforts have concentrated on the water footprint assessment of countries, spatial and temporal analyses of the water footprint below the national level have also been published (Chapagain and Orr, 2008; Aldaya and Llamas, 2009) to illustrate the refinement of the numbers at regional and even catchment levels.

A water footprint can also be calculated for a specific activity, good or service. For example, Chapagain et al. (2006) elaborated the water footprint of cotton; Chapagain and Hoekstra (2007) assessed the water footprint of coffee and tea; Gerbens-Leenes et al. (2009) and Yang et al. (2009) estimated the water footprint of primary energy carriers, while Jongschaap et al. (2009) discussed the water footprint of bioenergy from the crop jatropha. The water footprint concept has also been used to assess water use in businesses and other organisations (WBCSD, 2006; Gerbens-Leenes and Hoekstra, 2008). A detailed overview of this water footprint-related research has been described by Hoekstra (2009).

A review of water footprint applications in formulating policies

During the last part of the 1990s there was some effort to include virtual water considerations in policy frameworks. However, this met with strong resistance from water managers and economists who did not value the maturity of this concept in water policy formulation. But, while official policy may have omitted conscious decision-making on water comparative advantages, this was already the practice of a number of countries, whether explicitly stated or not. As Allan (1999) has shown from the Middle East and North Africa (MENA) region, those countries with poor water endowments were indeed huge importers of water intensive foodstuffs. Published works on water quality, and particularly the virtual water trade implications, have also been explored (Dabrowski et al., 2009) for the context of South Africa; this has direct links to grey water accounting in water footprints.

As water footprints evolved, there have been links to water management decision-making, yet to date the role of water footprint methods in water policy is limited to a few river basins. Work in Spain around the Guadiana basin (Aldaya and Llamas, 2009) has resulted in an economic assessment of water footprints that have now been captured as part of the Water Framework Directive assessments in that country. The interest and relevance of virtual water trading for future food security concerns, and the introduction of water footprint assessments of economic activities in basins, may lead to explicit policy making at national levels with regard to the use of water resources especially for higher value uses.

In the business world, the water footprint concept has helped to shed light on business water-related risk. It is perhaps through this lens that the water footprint is beginning to influence business strategies, which, in turn, may come to bear in formulating water policy that is coherent and consistent for business sectors.

Water footprint overview in the governmental context

Water footprint in China – a historical overview

The per capita water footprint is calculated by multiplying the food consumption per food item by the virtual water content (VWC) of the corresponding food item and then summing the results for the food categories. The VWC indicates the amount of water used to produce a unit food item (Liu et al., 2007). In this section, two major categories are used – animal products and vegetal products. Animal products include eight food items – beef, pork, poultry, mutton and goat meat, fish and seafood, eggs, milk and animal fats. Vegetal products include 10 food items – four cereals (rice, wheat, maize and other cereals), starchy roots, sugar and sweeteners, soybeans and other oil crops, vegetable oils, vegetables and fruits. The VWC of each food item is obtained from Liu and Savenije (2008), while food consumption patterns in each year are obtained from the FAO (2006). We assume VWC values remain the same for the same food item in different years, as the values of the VWC are not available for all years. Although the VWC fluctuates with different levels of technology, our assumption should not influence the analysis presented in this study, as its main objective is to demonstrate the effect of consumption patterns alone on a per capita water footprint, while holding all other variables constant.
The per capita water footprint in China has increased significantly

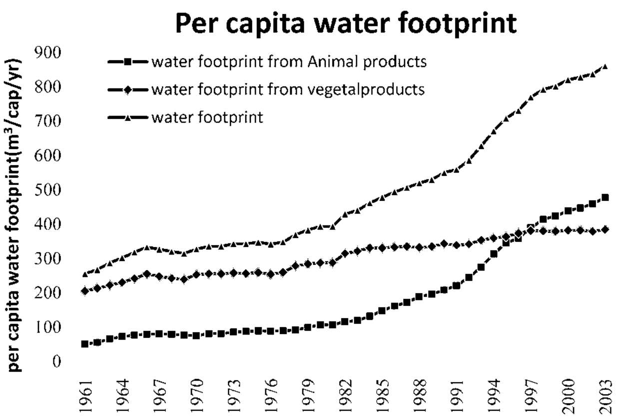


Figure 1. Per capita water footprint from 1961 to 2003 in China.

from below 300 m³/cap/yr in the early 1960s to 868 m³/cap/yr today (Figure 1). The changes are closely related to the shifts in food consumption patterns, which are associated with economic growth, increasing living standards and adjustments of agricultural policies in China. In 1961, the last year of the so-called "three bad years", contained a series of calamities resulting directly in the deaths of tens of millions from starvation. This period was characterised by very low food consumption due to food shortages. The average total cereal consumption was around 120 kg/cap/yr while the consumption of ani-

Photo: Gety Images

mal products was only 12 kg/cap/yr. People relied heavily on starchy roots to meet their basic caloric energy intake. The consumption of starchy roots was 112 kg/cap/yr, almost the same as the consumption of cereals. Given the low food consumption level and the dominance of vegetal product consumption, the water footprint was very low.

In 1961, the Chinese government started to introduce a series of new economic policies to boost agricultural production. These policies took effect and resulted in rising food consumption, particularly for wheat and rice. However, these policies only lasted for a few years before the Cultural Revolution occurred (between 1966 and 1976). The Cultural Revolution involved devastating social turmoil and adverse effects on agricultural production. Over this period, food consumption barely changed, leading to stagnation of the water footprint.

After the Cultural Revolution, China abandoned collective agriculture and, in 1978, assigned most agricultural land to families under the household responsibility system. The adoption of this system stimulated the farmers' enthusiasm for food production, largely enhancing the domestic food supply and consequently helping increase the level of food consumption. Between 1978 and 1984, the steady rise in the per capita water footprint was largely a result of the higher consumption of cereals, starchy roots and animal products. After 1984, the consumption of cereals and starchy roots started to decline slightly, while the consumption of animal products, vegetal oils, and vegetables and fruits continued to increase, leading to continuous growth of the per capita water footprint.

Since the 1990s, the consumption of animal products has grown markedly from 49 kg/cap/yr in the 1990s to 116 kg/cap/yr in 2003. The consumption of vegetables and fruits more than doubled from 116 kg/cap/yr to 320 kg/cap/yr, while the consumption of cereals and starchy roots declined slightly. The VWC of animal products is much higher than that of vegetal products. For example, the VWC of beef is around 13 m^3/kg; much larger than that of wheat at around 1 m^3/kg. The rise in the consumption of animal products was the very reason for the increase in the per capita water footprint in the 1990s and into the new Millennium.

Diet shifts have led to obvious changes in the proportion of the water footprint from animal products, accounting for over half of the water footprint since 1997 (Figure 1). In the 1960s and 1970s, the water footprint from animal products was very small compared with that from vegetal products (Figure 1). This is a reflection of the low living standards of the Chinese in these periods. Since the 1980s, with economic growth increasing and urbanisation spreading, the consumption of animal products has gradually increased, leading to the growth in the water footprint from animal products. In contrast, the water footprint from vegetal products has barely changed. As a result of these diet shifts, the water footprint from animal products has exceeded that of vegetal products from 1997 on. In 2003, it accounted for 55% of the total water footprint.

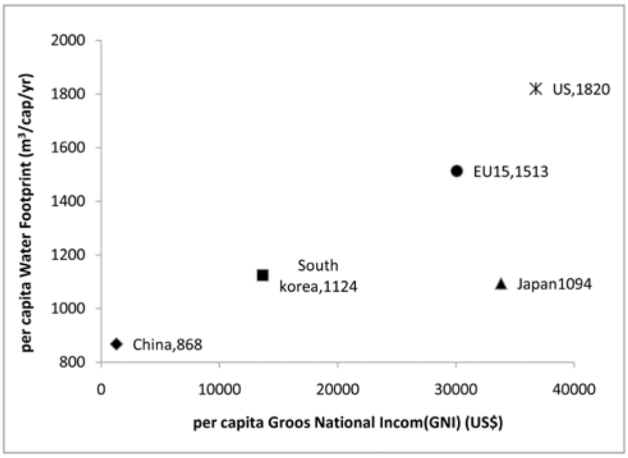


Figure 2. Per capita water footprint vs. gross national income (GNI).

national income (GNI) in a country. In general, a higher level of per capita GNI corresponds to a higher level of per capita water footprint (Figure 2). The USA and the EU15 (the 15 member countries of the EU prior to the accession of candidate countries on 1 May 2004) have a much higher level of per capita GNI. As can be seen, they both have a much higher level of per capita water footprint. Two Asian countries, Japan and South Korea, also have higher levels of both per capita GNI and water footprint. China's water footprint is still well below that of many developed countries and is indeed less than half the water footprint of the United States. It is likely that the per capita water footprint of China will further increase in the future as the economic situation continues to change. A larger water footprint will further pose greater pressure on the looming water scarcity crisis in China, particularly in the northern part of China where water scarcity is the most serious, and agricultural production is high.

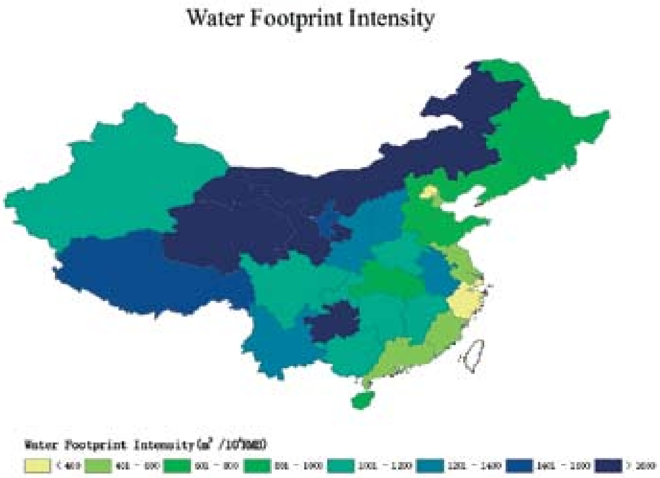


Figure 4. Spatial distribution of the water footprint intensity in China

Spatial distribution of the water footprint in China

The northern part of China has a generally higher per capita water footprint than in the south (Figure 3). This is explained in part by the higher meat consumption in the north. Low precipitation together with low temperatures leads to harsh conditions for crop production in several provinces in the north, e.g. Inner Mongolia and Qinghai province. Instead, farmers raise a large number of animals on extensive pasture areas. Traditionally, residents relied heavily on animal products for their daily food consumption, leading to a high per capita water footprint. It is no wonder that Inner Mongolia and Qinghai province are the two provinces with the highest per capita water footprint. Besides the dietary pattern, the dry weather and high potential evapo-transpiration may also contribute to the higher water footprint in the north. There is also a trend for the eastern provinces to have a relatively higher per capita water footprint than the western provinces. This may be caused by the different levels in the standard of living. The per capita income is much higher for those in the coastal areas than those in the western regions. Guangxi province turns out to be the province with the lowest per capita water footprint.

The water footprint intensity, defined as the ratio of the per capita water footprint to the per capita GDP, has a very clear trend: a low water footprint intensity in the eastern provinces and a high water footprint intensity in the western provinces. This trend is a result of a higher standard of living in the east and a lower standard of living in the west. This is also a reflection of rich regions that have the capacity to develop more water-saving methods to conserve water resources.

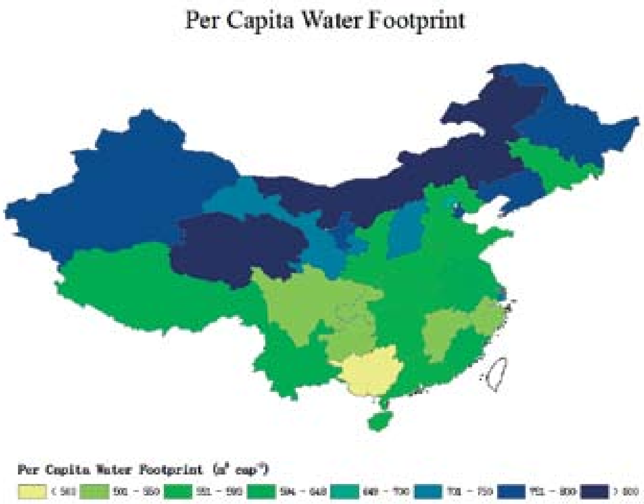


Figure 3. Spatial distribution of the water footprint in China

Long et al. (2006) studied the factors influencing the total water footprints in provinces in China. They concluded that (1) population is the major driving force influencing the magnitude of the total water footprint; (2) richness (in terms of per capita GDP) has a significant positive influence on the water footprint; and (3) climatic conditions (in terms of potential evaporation) also have significant influences on the water footprint. From these conclusions, we can see that the water footprint of China will further increase in the next 20 years with population growth and economic development. The impacts of climate change on water footprints are not yet clear. However, climate change is expected to play a less important role in influencing China's water footprint than the population and dietary change associated with continued economic development.

Government perspective on water footprints: water-saving society development

The continuous growth of the water footprint has imposed a higher pressure on scarce water resources in China. Water scarcity has become a serious constraint for future economic and societal development. The Chinese government has realised the seriousness of this problem and in response has promoted the strategy of a "water-saving society development".

The Chinese government started to promote the idea of a "water-saving society" in 2000. The essence of this is to establish a water resources management system on the basis of water rights and water market theory. The government provides guidance to society and formulates policies for the market. The objectives are (1) to increase water use efficiency, (2) to reduce the per capita water footprint and water footprint intensity as much as possible and (3) to promote "harmonious development" of the economy, resources and the environment.

In 2002, a revised water law came into effect. The Water Law of the People's Republic of China was adopted at the 24th meeting of the Standing Committee of the Sixth National People's Congress on 21

January 1988. It was revised at the 29th meeting of the Standing Committee on 29 August 2002. In Article 8 of this revised law, it is clearly stated that "the state shall strictly carry out water saving and devote major efforts to implementing water-saving measures, popularise new water-saving technologies and processes and develop water-saving industries, agriculture and services, and establish a water-saving society". For the first time, the formulation of a water-saving society was written into China's water law.

In 2005, a policy document entitled the "China Water Conservation Technology Policy Outline" was published. This document provides guidance for the development and application of water conservation technologies. It also gives targets for this development between 2005 and 2010. For example, industrial water use will remain in "micro-growth", agricultural water use will remain at "zero-growth" and water footprint intensity in cities will have to show a gradual reduction.

In 2007, the 11th Five-year Plan for a Water-saving Society Establishment was published. This document makes clear the targets and tasks of water-saving society development. According to this document, from 2005 to 2010, the blue water footprint intensity should be reduced by 20%, irrigation water efficiency should be improved from 0.45 to 0.5, and the blue water footprint per added value in industry should be reduced by 30%. The seepage rate in urban water supply pipelines should not exceed 15% by 2010.

Water footprint overview in the corporate contexts

In alignment with government awareness of water issues, there has also been a radical increase in media, public and business recognition of the importance of water from social, economic and ecological perspectives. This is due in part to a greater understanding of the pressures and risks associated with the world's freshwater resources. As a result, more progressive governments have begun to reform water policies and reassess their water-related priorities, and multinational companies have begun to assess the risks and uncertainties they face throughout their operations and supply chains (UN, 2009).

For companies, the multiple drivers that influence water availability and use interact with each other in ways that are often not well understood, predicted or managed. A major obstacle is properly evaluating water availability and reliance. Response from the private sector hinges on poorly coordinated methods for estimating water use and impacts at an operational level, and in the miscalculation of embedded water in supply chains. There also remains a large uncertainty and misunderstanding concerning interactions and the sometimes counter-balancing effects of water uses and responses to shortages.

The formulation of the Water Footprint Network (WFN) in 2009 was to address some of these issues and link with the recent uptake in business interests in water. While the CEO Water Mandate and World Economic Forum (WEF) processes provide frameworks and platforms for business discussions on water issues, the need for measurements of water use and impacts has been made clear. There is also now a large push for water disclosure following on from the success of the carbon disclosure project and Global Reporting Initiative (GRI), as well as investor and insurance concerns over capital outlays exposed to water risk issues.

SABMiller: a water footprint case study

A water footprint is only useful for companies when it informs better decision-making. In the context of a business, this means enabling the business to make better decisions regarding how it manages its plants, how it works with suppliers, or how it engages with governments on policy issues. In 2008 and 2009, SABMiller and the World Wide Fund for Nature (WWF) collaborated on research and a subsequent report to use the water footprint analysis for the company. The report discusses results in South Africa and the Czech Republic and what they mean for SABMiller's business and action plans in response to the findings. The objective was to look beyond the basic water footprint numbers into the context of SABMiller's water use, in particular by considering water use for different agricultural crops in specific water catchments.

Water-related business risks emanate from changes to the resource in terms of quality or quantity. Risks then manifest themselves in reputational impacts, costs, regulatory changes and, ultimately, the bottom line. Water is not only used at the primary manufacturing site, but, rather, touches the entire value chain with varying degrees of in-

Photo: Gety Images

tensity. Now, more than ever, there is a convincing case to be made for a comprehensive approach to water management that not only looks at internal processes, but also considers the supply chains that companies source from and the communities and ecosystems these activities interact with. Being aware of, and understanding, the water challenges they face undoubtedly allows businesses to make better management decisions and provides the platform to engage with a broader set of stakeholders to address issues outside their direct sphere of influence.

SABMiller has acknowledged these risks and has made water one of the company's top sustainable development priorities. They promote responsible water use throughout their operations, and encourage their suppliers to do the same. They have invested significant management time at the local and global levels in understanding the challenges of water scarcity and quality, and what these may mean for their business (SABMiller, 2009).

The water footprint study considered the results in the context of ecological risks and needs, business risks and needs and the broader water policy context. The footprints were used to develop a matrix of water risk for each business covering blue water, green water and grey water, and, in response, to develop local action plans to mitigate these risks. It is no surprise that agricultural water use was highlighted as the biggest risk area in the South African water footprint.

In the Czech Republic, SABMiller is considering projects to initiate in order to understand the risk of climate change on water availability and how this may impact crop growth in the future. In addition, it is reviewing how legislative risks may impact its crop growing areas, with particular reference to groundwater and nitrate limits, and engaging with suppliers in the process. The aggregate volumes of water provided an overall picture of green and blue water use in the value chain and presented a picture of risk and opportunity costs. The South African water footprint, in particular, highlighted that crop water use within the context of available resources was the most important element. However, even this number needs to be treated with care, because there is no simple answer as to what is an acceptable, fair or efficient use of water for a particular purpose. These questions always need to be answered in the context of local economic, social and environmental needs, government priorities, available technologies and the structure of the agriculture industry. In this sense, the water footprint links the total volumes and opportunity costs of water with regulations, policies, laws, allocations and discharges. In doing so, it has opened up new understanding within the company for long-term strategic planning.

The policy overlay in South Africa was the most telling, and provided a clear example of the benefits of obtaining a clear understanding of the likely risks and opportunities around water use, both at facility level and in the broader value chain. Four key policy issues were identified during the course of the South African study.

Water allocation and resource protection

The South African Water Act is perhaps one of the most progressive of its kind, providing specific allocations to protect the ecological integrity of water bodies and ensuring sufficient availability for domestic consumption before industrial water users are allocated water rights. To manage this process a comprehensive catchment management strategy has been established in the country, which governs licensing, water use efficiency and determination of illegal water use.

Water use efficiency

Of particular relevance in the drive for efficiency is the government's drive for geography-specific water conservation and demand management. The result of this is that there is a high likelihood of licensing and allocations being based on water use efficiency and a more focused look at water reuse and recycling.

Water use licensing and enforcement

This relates to where water rights and licenses are withheld for certain types of activity considered to have a detrimental impact on water resources and the monitoring and enforcement of these directives. An important impact of this is the move towards reducing the amount of water available to agriculture for example, in favour of other water users.

Economic instruments and pricing

Finally, the use of economic instruments to manage water will become more apparent in the future. This will include full cost pricing in relation to water infrastructure development, water charges related to efficiency of use of the resource and reviewing the structure of the polluter pays principle insofar as waste discharges are concerned. These elements of water policy can, potentially, significantly impact the management and use of water resources. By having a fuller understanding of the relevant policy frameworks, local managers are able to make informed investment decisions for the company.

Summary and conclusion

This article provides case studies on the assessment and application of this concept in the government, public policy and corporate contexts. The first case study shows a sharp increase in the per capita water footprint in China in the 1990s and into the new Millennium, largely due to dietary shifts from vegetal to animal products. Trends indicate that the future per capita water footprint will further increase in the next few decades, which will no doubt put high pressure on the limited water resources in China, particularly in the north. In response to this looming water pressure, the Chinese government has advocated the development of a "water saving society" to reduce the per capita water footprint and water footprint intensity. The water policies formulated are expected to help improve water use efficiencies and lead to consistent development of the economy, resources and the environment. However, it also needs to be pointed out that the current policies are mainly "blue" water biased. Future policies should take a more comprehensive approach and take "green" water into account to optimise the water footprint in China.

The business example exemplifies how the measurement and quantification of water in the value chain has brought new insights to a company seeking to understand their risks arising from water use. To what extent a detailed water footprint of a company is required, however, is debatable, as water-related risk is more aligned to regulatory, government and policy coherence where water is used. These issues require less knowledge of individual water uses than they do of the cumulative impacts. However, the basic understanding of water use for benchmarking, raising awareness inside the company and comparing with locally relevant information is highly desirable in a water-constrained world. From this perspective, water footprints allow companies to better grasp water issues and their relative contribution to local situations.

The water footprint concept has evolved from basic quantitative studies to a powerful advocacy tool, relevant policy support, business risk awareness and decision-making and now an assessment tool for policy processes. By itself, a water footprint does not solve complicated water management challenges, but it can be applied, as shown here, to support awareness and policy development and contribute to positive actions in watersheds. ■

References

- Aldaya, M.M. and Llamas, M.R. (2009) *Water Footprint Analysis (Hydrologic and Economic) of the Guadiana River Basin.* The United Nations World Water Assessment Programme. Scientific paper.
- Aldaya, M.M., Garrido, A., Llamas, M.R., Varela, C., Novo, P. and Rodriguez, R. (2008) The water footprint of Spain. *Sustainable Water Management* 2008-3: 15–20.
- Allan, J.A. (1993) Fortunately, there are substitutes for water otherwise our hydro-political futures would be impossible. In *Priorities for Water Resources Allocation and Management* pp. 13–26. London, UK: Overseas Development Administration.
- Allan, T. (1999) Productive Efficiency and Allocative Efficiency: Why Better Water Management May Never Solve the Problem. *Agricultural Water Management* 40(1): 71–5.
- Chapagain, A.K. and Hoekstra, A.Y. (2007) The Water Footprint of Coffee and Tea Consumption in the Netherlands. *Ecological Economics* 64(1): 109–118.
- Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G. and Gautam, R. (2006) The Water Footprint of Cotton Consumption: An Assessment of the Impact of Worldwide Consumption of Cotton Products on the Water Resources in the Cotton Producing Countries. *Ecological Economics* 60 (1): 186–203.
- Chapagain, A.K. and Orr, S. (2009) An improved Water Footprint Methodology Linking Global Consumption to Local Water Resources: A Case Study of Spanish Tomatoes. *Journal of Environmental Management* 90: 1219–1228.
- Chapagain, A.K. and Orr, S. (2008) *UK Water Footprint: the Impact of the UK's Food and Fibre Consumption on Global Water Resources, Volume 1.* Godalming, UK: WWF-UK.
- Dabrowski, J.M., Murray, K., Ashton, P.J. and Leaner, J.J. (2009) Agricultural Impacts on Water Quality and Implications for Virtual Water Trading Decisions. *Ecological Economics* 68: 1074–1082.
- FAO (Food and Agriculture Organization of the United Nations) (2006) *FAOSTAT: FAO statistical databases*. Rome, Italy: FAO.
- Gerbens-Leenes, P.W. and Hoekstra, A.Y. (2008). *Business water footprint accounting: a tool to assess how production of goods and services impacts on freshwater resources worldwide.* Value of Water Research Report Series No. 27. Delft, the Netherlands: UNESCO-IHE.
- Gerbens-Leenes, P.W., Hoekstra, A.Y. and Van der Meer, Th.H. (2009) The Water Footprint of Bioenergy. *Proceedings of the National Academy of Sciences of the United States of America* 106(25): 10219–10223.
- Hoekstra, A.Y. (Ed.) (2003). Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade, Delft, Netherlands, 12–13 December 2002, Value of Water Research Report Series No. 12. Delft, Netherlands: UNESCO-IHE.
- Hoekstra, A.Y. (2009). Human Appropriation of Natural Capital: a Comparison of Ecological Footprint and Water Footprint Analysis. *Ecological Economics* 68: 1963–1974.
- Hoekstra, A.Y. and Chapagain, A.K. (2007) Water Footprints of Nations: Water Use by People as a Function of their Consumption Pattern. *Water Resources Management* 21(1): 35–48.
- Hoekstra, A.Y. and Chapagain, A.K. (2008) *Globalization of Water: Sharing the Planet's Freshwater Resources.* Oxford, UK: Blackwell Publishing.
- Jongschaap, R.E.E., Belsgraaf, R.A.R. Gogaard, T.A. van Loo, E.N. and Savenije, H.H.G. (2009) The Water Footprint of Bioenergy from *Jatropha curcas L., Proceedings of the National Academy of Sciences of the United States of America* 106(35): E92.
- Kampman, D.A., Hoekstra, A.Y. and Krol, M.S. (2008) *The Water Footprint of India.* Value of Water Research Report Series No. 32. Delft, the Netherlands: UNESCO-IHE.
- Liu, J., Zehnder, A.J.B. and Yang, H. (2007). Historical Trends in China's virtual Water Trade. *Water International* 32(1): 78–90.
- Liu, J. and Savenije, H.H.G. (2008) Food Consumption Patterns and their Effect on Water Requirement in China. *Hydrology and Earth System Sciences* 12: 887–898.
- Liu, J., Yang, H. and Savenije, H.H.G. (2008) China's Move to Higher-Diet Hits Water Security. *Nature* 454(7203): 397.
- Long, A.H., Xu, Z.M., Wang, X.H. and Shang, H.Y. (2006) Impacts of Population, Affluence and Technology on Water Footprint in China. *Acta Ecologica Sinica* 26(10): 3358-3365. (In Chinese)
- SABMiller (2009) *Water Footprinting: Identifying and Addressing Water Risks in the Value Chain.* Woking, UK: SABMiller and Godalming, UK: WWF-UK.
- UN (United Nations) (2009) *From Footprint to Public Policy.* CEO Water Mandate document: Website publication: http://www.unglobalcompact.org/docs/issues_doc/Environment/ceo_water_mandate/From_Footprint_to_Public_Policy.pdf.
- WBCSD (World Business Council for Sustainable Development) (2006) *Business in the World of Water: WBCSD Scenarios to 2025.* Conches-Geneva, Switzerland: WBCSD.
- Yang, H., Zhou, Y. and Liu, J. (2009) Land and Water Requirements of Biofuel and Implications for Food Supply and the Environment in China. *Energy Policy* 37: 1876–1885.

Mr. Shilp Verma
PhD student, UNESCO-IHE
Institute for Water Education
s.verma@unesco-ihe.org

Understanding interstate virtual water trade and its determinants in India

Based on recent estimates, this paper discusses the nature of and factors affecting domestic virtual water trade in India against the backdrop of an ambitious US$120 billion interbasin water transfer plan of the Government of India. Our analysis shows that differences in water endowments fail to fully explain virtual water trade flows. We argue that it is economic rather than physical water scarcity (or abundance) that explains trade flows. Non-water factors – such as per capita arable land – and public policy on agricultural inputs and access to agricultural markets explain the trade flows better. We therefore argue that these factors need to be taken into account for a more nuanced understanding of the virtual water trade and its policy interpretation.
Keywords: virtual water trade, India, comparative advantage, food policy, water policy

Virtual water in the Indian context

Allan (1993, 1994) coined the term "virtual water" while referring to the volume of water needed to produce agricultural commodities. The same has alternatively been referred to as "embedded water" (Allan, 2003), "exogenous water" (Haddadin, 2003) or "ultra-violet water" (Savenije, 2004). When a commodity (or service) is traded, the buyer essentially imports (virtual) water used in the production process of the commodity. In the context of international (food) trade, this concept has been applied in an attempt to optimise the flow of commodities with consideration to the water endowments of nations. Using the principles of international trade, it is argued that water-rich countries should produce and export water-intensive commodities to water-scarce countries, thereby enabling the water-scarce countries to divert their precious water resources to alternative, higher value uses.

The concept of virtual water trade has entered policy discussions across the world in recent years. It is increasingly seen as a useful approach to understand the influence of water uses beyond the boundaries of a river basin in the globalising world, and as an "alternative" approach to physical water transfers and water resources development, especially for water-scarce regions and countries. While largely discussed in the context of international food trade, the concept encounters ideological roadblocks when being discussed in countries such as India – given the long-standing, strategic policy of food self-sufficiency.

While the issue of food self-sufficiency has been a topic of active academic debate within as well as outside India, the Government of India does not seem eager to entertain any discussion on the topic, as food self-sufficiency seems to have become a matter of national pride. This is despite the fact that some experts have argued that national food self-sufficiency has little to do with food security of the poor. In his seminal work on poverty and famines, Sen (1981) argued that national food self-sufficiency does not ensure freedom from poverty and famines. Sen's study on the Bengal famine of 1943 noted that food production in the famine year was, in fact, higher than in some of the earlier non-famine years. With reference to Manning (1988), Hutagaol (2005) contends that "For many developing countries, food self-sufficiency programmes are not merely a way to increase food production, but, more importantly, a strategic instrument for creating and maintaining domestic political stability".

In Indonesia, on the other hand, it has been argued that dependence on the world food market is risky and that "maximising rice pro-

duction, even in excess of efficiency levels, was not without economic logic given a thin world market and a large, poor population that was heavily dependent on rice as the primary source of calories" (Stern, 2003). If there is any merit in this argument, it holds even more weight in the Indian context, since India has an even bigger number of poor people heavily dependent on food grains.

Economic arguments aside, the following quote from a senior official of the Government of India nicely sums up the dominant sentiment: "Surely a country growing at more than 8% per annum; a nuclear power and one of the leaders in space research; the world's largest democracy; a hub for the global IT and communications industry; arguably the biggest pool of skilled manpower; and vying desperately for a membership of the UN Security Council and the title of a world 'superpower' cannot depend on any other country to feed its people". Given such persistence of the policy of national food self-sufficiency, and the unlikelihood of any change in the near future, this paper deliberately side-steps the issue of using virtual water trade as a means to meet domestic food requirements in order to focus on the potential of domestic, interstate virtual water trade, within India.

The National River Linking Project

Perhaps guided by the pressure exerted on per capita water resources by India's ever growing population, Falkenmark (1997) contended that India will have to eventually give up its food self-sufficiency policy and depend on food (and virtual water) imports. Curiously, around the same time, the government unveiled its grand plans for an investment of US$120 billion, targeted almost exclusively at maintaining India's fragile national food security through the National River Linking Project (NRLP).

NRLP envisages linking 37 Himalayan and peninsular rivers. Doing this will form a gigantic South Asian water grid which will annually handle 178 x 109 m^3 of interbasin water transfer; involve the building of 12,500 km of canals; generate 34 Giga-watts of hydropower; add 35 million ha to India's irrigated areas; and generate inland navigation benefits (Figure 1; IWMI, 2003; NWDA, 2006). The prime motivation behind the grand plan is India's growing concern about the need to produce additional food for its large and rapidly increasing population. It has been projected that India will require about 450 million tonnes of food grains per annum to feed a population of 1.5 billion in the year 2050 (NCIWRD, 1999) and in order to meet this requirement, it needs to expand its irrigation potential. Considering that large parts of the Ganga-Brahmaputra-Meghna (GBM) Basin face recurring floods and a number of western and peninsular states face severe droughts, it has been argued that "one of the most effective ways to increase the irrigation potential for increasing food grain production, mitigate floods and droughts and reduce regional imbalance in the availability of water is the Inter Basin Water Transfer (IBWT) from the surplus rivers to deficit areas" (NWDA, 2006).

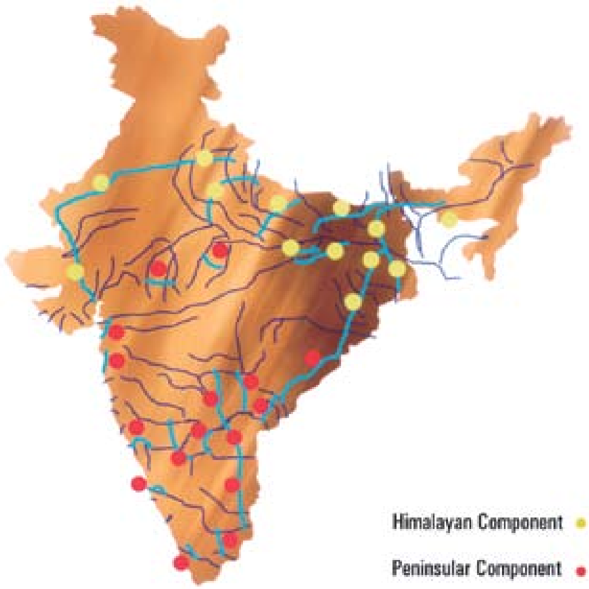


Figure 1. Proposed links under the National River Linking Project (NRLP)
Source: IWMI (2003)

The NRLP proposes to transfer excess flood waters from the rain-rich eastern Indian states to the drought-prone regions of north, western and peninsular India which produce the bulk of India's food grains. However, representatives from civil society, media and academia have strongly criticised this plan (Iyer, 2002; Vombatkere, 2003; Vaidyanathan, 2003; Bandyopadhyay and Perveen, 2004; Patkar, 2004). Besides voicing concerns about the potential negative environmental impacts of the mega-project, critics have argued that the decision to go ahead with the plan has been hasty. They argue that the NRLP is only one of the ways to ensure India's food and water security, and that alternative – local, cheaper and greener – options should have been given more serious consideration.

While a number of the suggested "alternatives" to the NRLP seem plausible, all of them require further exploration and scientific study before any of them (or a group of them together) can form a formidable answer to India's impending water crisis. The lack of such analysis led to a highly polarised national debate on the NRLP (Verma and Phansalkar, 2007). One such "alternative" to NRLP that has been discussed is "domestic virtual water trade". Proponents of this alternative have argued that instead of physically transferring large quantities of water from the flood-prone east to the water-scarce west and south, it would be desirable to transfer virtual water in the form of food grains.

Interstate virtual water flows in India

Kampman (2007) estimated that the virtual water flow as a result of interstate crop trade in India is 106 × 109 m^3/yr or 13% of total water use. This estimate covers virtual water flows as a result of trade in 16 primary crops which represent 87% of the total water use, 69% of the total production value and 86% of the total land use. Verma (2007) estimated that at the current level of production and consumption, milk and milk products are unlikely to significantly add to the interstate virtual water flows; India as a whole has a surplus of milk and consumption levels in states that produce the least milk are much below the prescribed standards for nutritional security. However, considering a hypothetical nutritional security scenario (where minimum nutritional standards are met in every state), we can expect interregional virtual water flows of the order of 40 × 109 m^3/yr.

Kampman (2007) also estimated the mean annual import (or export) of virtual water between states and between regions. As per these estimates, the states of Punjab, Uttar Pradesh and Haryana are the largest exporters of virtual water, while Bihar, Kerala, Jharkhand and Orissa are the largest importers (Figure 2). Aggregating the flows at the regional level, eastern India, India's wettest region, prone to annual floods, imports large quantities of virtual water not only from the northern, western and southern Indian states, but also from the rest of the world (Figure 3).

The key virtual water importers – Bihar, Jharkhand and Orissa – lie in rain-rich eastern India. These are also the states which are proposed as the key donor states in the interbasin water transfer plans of the Government of India. Thus, while physical water transfers are being planned to originate from these water-surplus states, significant quantities of virtual water continues to flow into these states. It is interesting to note that a similar trend was observed in China with respect to the south–north water transfer project (Ma et al., 2006; Liu et al., 2008).

The per capita and per hectare (gross sown area) water resource endowment (Table 1) in the key virtual water-exporting states is significantly lower than the same in the water-importing states. The key virtual water exporters (Punjab, Uttar Pradesh and Haryana) are the food grain baskets of India. Punjab alone, for instance, contributed roughly 52% and 48% respectively to the total wheat and rice procurement in the country in 2002–2003. A significant proportion of the remainder comes from Haryana and Uttar Pradesh (IndiaStat, n.d.).

Determinants of interstate virtual water trade in India

Why do water-rich states import even more water (in virtual form) from relatively water-scarce states? What is the relationship between the water endowment of a state and its net virtual water import? Figure 4 (a–d) presents net virtual water imports (or exports) against: (a) per capita green water availability; (b) per capita internal blue water availability; (c) per capita total blue water availability; and (d) per capita total (internal blue + external blue + [internal] green) water availability as estimated by Kampman (2007). We use Figure 2 as a starting point but omit states with net inflow or outflow less than 2 × 109 m^3/yr, given the approximate nature of Kampman's (2007) estimates.

If water endowments were to influence virtual water trade as hypothesised by the virtual-water logic, we would expect that as we move along the plots from left to right, moving from the largest exporters to the largest importers, the water resource endowments would show a

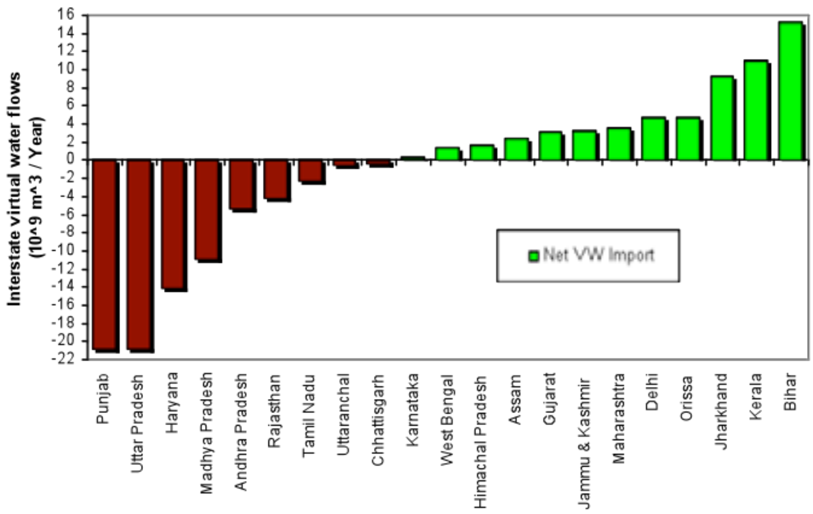


Figure 3. Interregional virtual water flows (109 m^3/yr), as estimated by Kampman (2007)
Source: Verma et al. (2009)

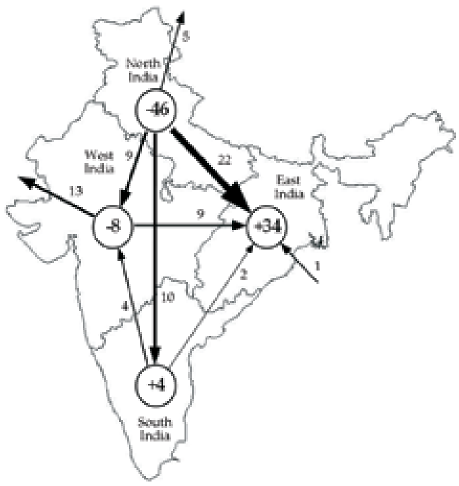


Figure 2. Interstate virtual water flows (109 m^3/yr), as estimated by Kampman (2007)
Source: Verma et al. (2009)

States	Population (million)	Gross sown area (million ha)	Water resource endowment			Net virtual water import	Per capita net virtual water import
			Total water resources	Water resources per ha gross sown area	Per capita water resources		
			109 m^3/yr	m^3 /ha	m^3/capita/yr	109 m^3/yr	106 m^3/capita/yr
Major virtual water exporters							
Punjab	23.68	8.04	84	10,445	3,554	-20.9	-882.6
Uttar Pradesh	161.56	26.52	472	17,797	2,922	-20.8	-128.7
Haryana	20.55	6.14	45	7,325	2,176	-14.1	-686.0
Major virtual water importers							
Bihar	80.68	10.01	557	55,633	6,898	15.3	189.6
Jharkhand	26.19	2.24	121	54,139	4,580	9.3	355.0
Orissa	35.78	8.65	311	35,975	8,710	4.8	134.2

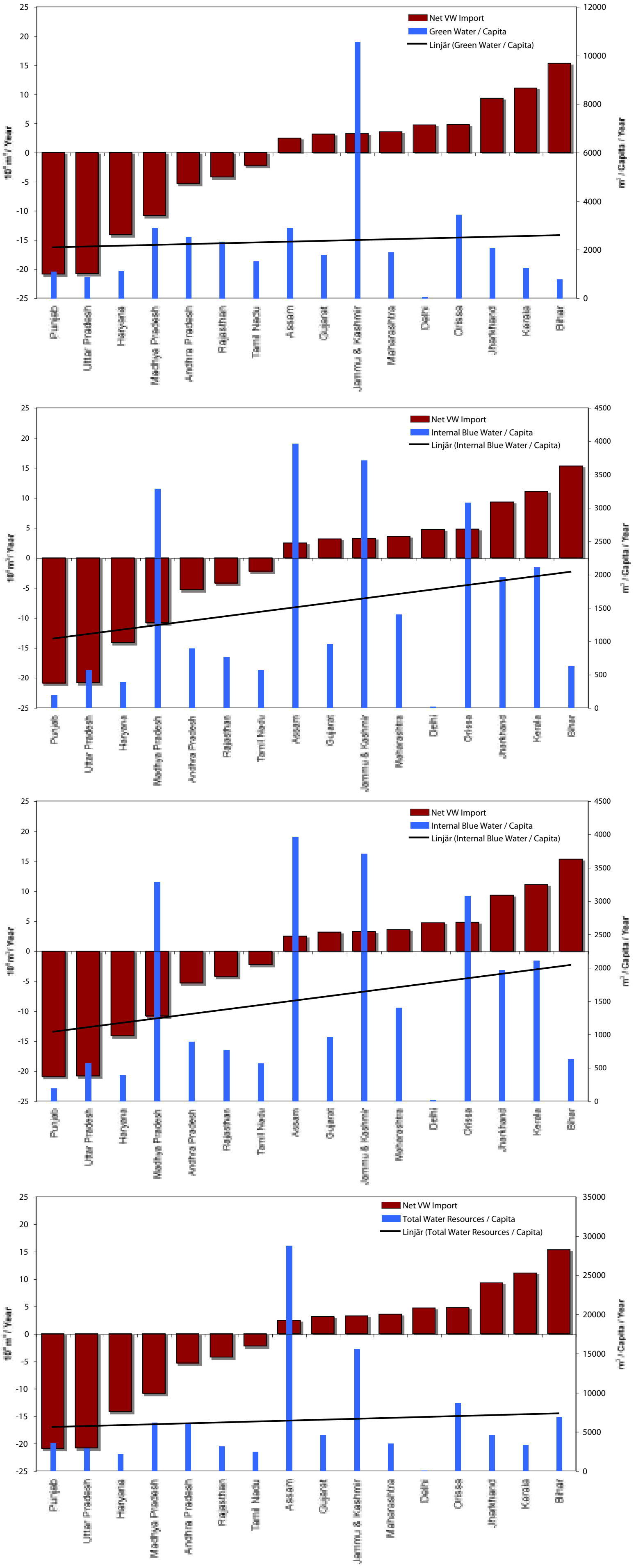
Table 1. Virtual water trade balances and water endowments
Data source: Kampman (2007), IndiaStat (n.d.)

declining trend. In other words, states with lower water endowments would be virtual water importers and states with higher water endowments would export virtual water. However, none of the four plots depict strong correlations (R2 in the range of 0.004 to 0.058); nor do they point to any such trend. Thus, higher water endowment does not lead to higher virtual water exports.

It may also be argued that very high water endowments, leading to serious flood problems, might reduce the comparative advantage of water-rich regions. Perhaps there is an optimal level of water resource endowments that offers the ideal conditions for exploiting water resources for agricultural production. This is, to an extent, true in the case of Bihar where annual flooding in the monsoon season renders low-lying areas useless for anything other than low-input paddy cultivation. However, this does not explain the low productivity of post-monsoon agriculture in Bihar when abundant shallow groundwater resources are available for irrigation. We discuss this further below.

Trade in agricultural commodities depends on a lot more factors than merely differences in water scarcity in the trading nations. Such factors include differences in availability of land, labour, knowledge and capital and differences in economic productivities in various sec-

Photo: OME Images



tors. Furthermore, the existence of domestic subsidies, export subsidies or import taxes in the trading nations may influence the trade pattern. As a consequence, international virtual water transfers cannot fully be explained by relative water abundances or shortages (De Fraiture et al., 2004; Wichelns, 2004). Yang et al. (2003) demonstrated that only below a certain threshold in water availability can an inverse relationship be established between a country's cereal import and its per capita renewable water resources. As shown here, trade in agricultural commodities between Indian states is not governed by water scarcity differences between the states.

If it is not water endowment that determines the direction of virtual water flow, then what is it? Analysing data for 146 countries, Kumar and Singh (2005) have also argued that a country's virtual water surplus or deficit is not determined by its water situation. They concluded that no correlation exists between relative water availability in a country and the virtual water trade. Several water-rich countries, including Japan, Portugal and Indonesia, recorded high net virtual water imports. From a further analysis of 131 countries, Kumar and Singh also argue that "access to arable land" can be a key driver of virtual water trade.

When we tested this "access to arable land" hypothesis using per capita gross cropped area (GCA) data for the Indian states, we found that our results were in agreement. States with higher per capita GCA are net exporters of virtual water, and vice versa (Figure 5). We also found that "access to secure markets", represented by the proxy variable of "percentage of rice production procured by the Food Corporation of India" correlates well with net virtual water exports. Almost all the virtual water-exporting states have a significant proportion of their rice production procured centrally by the Food Corporation of India (FCI), at a minimum support price usually higher than the market price. This offers them a secured market for their produce, which acts as an incentive to grow paddy despite growing water scarcity. Virtual water-importing states, on the other hand, have little or no FCI procurement (Figure 6).

Figure 4. Virtual water trade and (a) per capita green water availability (R2 = 0.004); (b) per capita internal blue water availability (R2 = 0.058); (c) per capital total blue water availability (R2 = 0.004); and (d) per capita total water resources availability (R2 = 0.006).
Source: Verma et al. (2009)

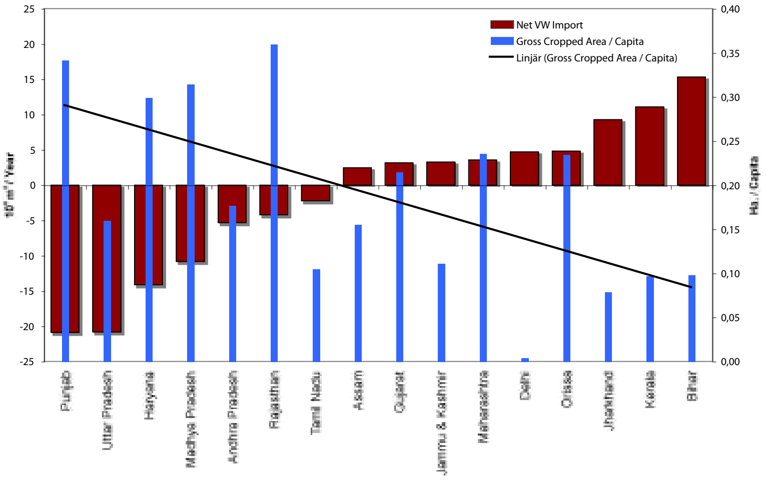


Figure 5. Virtual water trade and per capita gross cropped area (GCA)
Source: Verma et al. (2009)

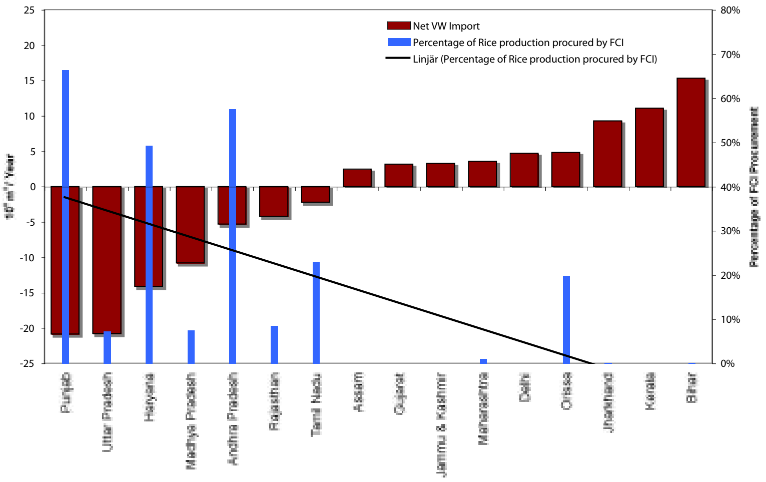


Figure 6. Virtual water trade and percentage of rice production procured by the Food Corporation of India
Source: Verma et al. (2009)

Discussion

Hoekstra (2003), referring to Wichelns (2001), observed "the economic argument behind virtual water trade is that, according to international trade theory, nations should export products in which they possess a relative or comparative advantage in production, while they should import products in which they possess a comparative disadvantage." Thus the logic of virtual water trade follows Ricardo's Theory of Comparative Advantage which focuses on trade based on differences in production technologies and factor endowments. It states that each country should specialise in the production, and export to other countries, of goods and services in the production of which they enjoy a comparative advantage by virtue of their factor endowments.

Developed by Eli Heckscher and Bertil Ohlin, the Heckscher-Ohlin (H-O) Model builds on Ricardo's theory to predict patterns of trade and production based on factor endowments of trading entities. Broadly, the model states that countries (or more generally, trading entities) will export products that require high quantities of abundant resources, and import products that require high quantities of scarce resources. Thus, a capital-rich (and relatively labour-scarce) country would be expected to export capital-intensive products and import labour-intensive products or services and vice versa (IESC, 2007; Antras, 2007; Davis, 2007).

However, the H-O Model has been found wanting in terms of empirical evidence to support its logic. In 1954, Prof. W.W. Leontief attempted to test the H-O Model by studying trade patterns between countries. To his surprise, he found that the U.S., perhaps the most capital-abundant country in the world, exported labour-intensive commodities and imported capital-intensive commodities. This was seen to be in contradiction to the H-O Model and came to be known as the Leontief Paradox. Interstate virtual water flows in India represent the water sector's equivalent of the Leontief Paradox. Several economists have attempted to resolve this paradox.

Doubtful water centrality of virtual water trade

Virtual water trade theorists argue that water-abundant countries (or regions) enjoy a comparative advantage in the production of water-intensive commodities. However, the patterns of interstate virtual water trade in India, as well as global food trade trends (De Fraiture et al., 2004; Kumar and Singh, 2005), show that water endowments alone are unable to explain the direction and magnitude of trade. An implicit assumption behind measuring every commodity by its virtual water content is that water is the most critical resource input that determines production, surplus (or deficit) and trade. But, this assumption does not always hold true and this is acknowledged in virtual-water literature. There are several key inputs that go into the production of food, and these other "factors of production" might tilt the balance of decisions against the logic of virtual water, which dictates water saving through trade as the sole criterion.

The virtual-water logic can, in theory, work to efficiently allocate water resources if water resources constitute the most critical resource in the production process. If, on the other hand, another resource such as land becomes the critical constraint, efficient allocation will optimise land use and not water use. By importing food grains from a land-rich state, a land-scarce region is economising on its land use. Following the virtual-water trade logic, this can be termed as "virtual land trade" (see Würtenberger et al., 2006). A land-scarce region (such as Bihar) would import crops from regions where land productivity is higher (for instance, Punjab). In order to produce the same amount of food in Bihar, Bihar would have to employ more land than Punjab (Aggarwal et al., 2000). If, and as long as, land is the critical constraining resource, Bihar would need to economise on its land use, even at the cost of inefficient or incomplete utilisation of its abundant water resources. This perhaps explains why per capita land availability correlates better than water endowments to virtual water deficits and surpluses (Figure 5).

Ignoring the Linder effect

In 1961, Staffan Burenstam Linder proposed the Linder Hypothesis as a possible resolution to the Leontief Paradox. Linder argued that demand, rather than comparative advantage, is the key determinant of trade. According to him, countries (or entities) with similar demands will develop similar industries, irrespective of factor endowments; and these countries would then trade with each other in similar but differentiated goods. For example, both the U.S. and Germany are capital-rich economies with significant demand for capital goods such as cars. Rather than one country dominating the car industry, both countries produce and trade different brands of cars between them. This has also been observed in subsequent examinations as well, but it does not account for the entire pattern of world trade (see Linder, 1961; Bergstrand, 1990).

Kampman (2007) estimated trade (import or export) as equal to the difference between production and consumption: only surplus states export and only deficit states import. Such an estimation procedure implicitly assumes that all traded agricultural goods are undifferentiated commodities. But we know that products such as basmati rice, branded dairy products and other or branded agricultural commodities negate this assumption. However, in comparison to the total volume of virtual water traded, the proportion of virtual water embedded in branded products is perhaps small.

Insights from the new trade theory

Proponents of the new trade theory (Paul Krugman, Robert Solow and others) argue that factors other than resource endowments determine trade. New trade theorists base international trade on imperfect competition and economies of scale – both of which are realistic but assumed away in the H–O Model. Gains from increasing returns to scale at the entity level are understood intuitively, but gains from industry level scale economies (external economies of scale) often get ignored. Such gains are particularly important in the case of agriculture where the scale of production of an individual farmer is very small compared to the size of the market. Several factors, such as the agricultural extension services, specialised machinery markets and fertilizer markets and marketing channels for outputs, etc. contribute significantly in determining where agricultural commodities are produced.

That these insights are useful in understanding interstate virtual water trade is clear from Figure 6. Farmers in states which have access to assured and lucrative output markets (in the form of FCI procurement) are more likely to grow food grains and export them to other states.

Physical versus economic water scarcity

Another reason why the H-O Model fails to apply in real life is that it assumes pre-trade factor prices to be in line with natural factor endowments. In the case of water, this does not happen, especially at the farm level. Compared to water-scarce states like Punjab, farmers in water-rich states like Bihar face a much steeper price for using water for irrigation. This can be attributed to the public policy biases in favour of states like Punjab.

Punjab's status as India's food grain provider has come at a price and Punjab today faces a groundwater stress caused mainly by excessive withdrawal for irrigation. Bihar, on the other hand, enjoys one of the best per capita water endowments in the country. Yet, owing to a number of factors, Bihar is unable to produce enough food even to fulfil its own consumption needs, let alone export virtual water to water-scarce regions. Table 2 compares the two states on some basic statistics.

Particulars		Units	Punjab	Bihar
Population density		People / km^2	470	857
Total (internal) green water resources		109 m^3 / year	26	64
Total (internal) blue water resources		109 m^3 / year	5	51
Total (external) blue water resources		109 m^3 / year	54	442
Per capita total (blue + green) water resources		m^3 / capita / year	3,554	6,898
Water resources per ha of gross cropped area		m^3 / hectare GCA	10,445	55,633
Per capita blue water footprint		m^3 / capita / year	438	198
Milled rice (1997–2001)	Production	'000 tonnes / year	8475	5337
	Consumption	'000 tonnes / year	775	7066
	Surplus	'000 tonnes / year	7700	-2070
	Production	'000 tonnes / year	14462	4508
	Consumption	'000 tonnes / year	2694	6396
	Surplus	'000 tonnes / year	10168	-2387
Net virtual water export		**m^3 / year**	**20874**	**-15302**

Table 2. Water endowments, food grain production and consumption in Punjab and Bihar Source: Verma (2007); Kampman (2007)

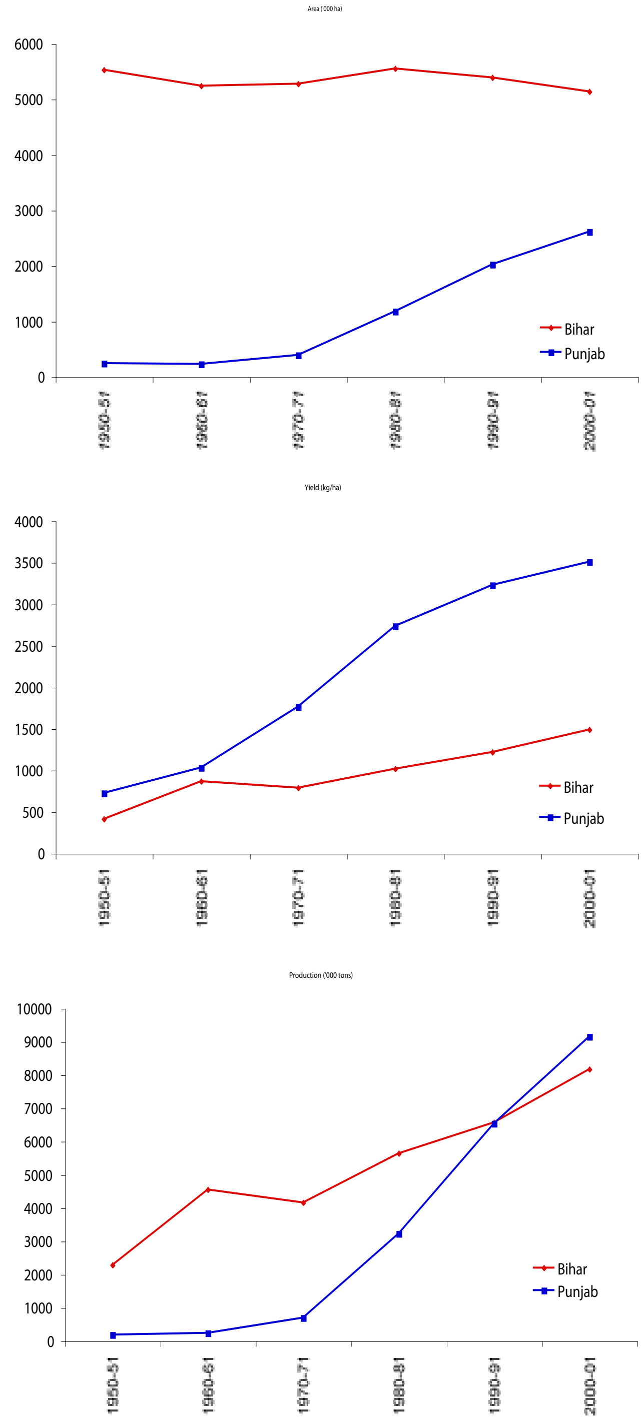


Figure 7 shows how rice area, yield and production have changed since independence in Bihar and Punjab. Rice was not traditionally grown in Punjab and it was only after the late 1960s that rice cultivation started increasing in Punjab as a result of the policy push under the green revolution.

Figure 7. Area, yield and production of rice in Punjab and Bihar
Source: Verma (2007)

In spite of a poor and deteriorating water situation, and in contradiction to the logic of water saving through virtual water trade, Punjab continues to be a leader in food grain production in India. What led to such a situation and why does it persist despite water scarcity? We look at the historical growth in the production of rice in water-scarce Punjab vis-à-vis Bihar which enjoys a natural comparative advantage over Punjab in terms of water endowments. We discuss the case of rice not only because it is a very water-intensive crop, but also because traditionally, rice was not grown in Punjab and Punjab exports more than 90% of the rice produced within its borders (Table 2).

In 1960–61, rice yields in Punjab were only marginally higher than those in Bihar. This difference has been attributed to the climatic and biophysical conditions prevailing in the state. Studies carried out by the Indian Agricultural Research Institute (IARI) and the Rice–Wheat Consortium have confirmed that maximum potential yields of rice and wheat are indeed higher in the north-western parts (Punjab) of the Indo-Gangetic Basin (IGB) compared to the eastern parts (Bihar) (Aggarwal et al., 2000). In the late 1960s and early 1970s, when India was striving hard to attain the cherished dream of food self-sufficiency, the north-western Indo-Gangetic plains offered the most promising potential for attaining this goal in the least amount of time. It is no wonder, therefore, that Punjab and neighbouring Haryana were chosen by the Government of India for heavy investment in agricultural development and to act as India's grain bowls.

Natural water endowments are heavily tilted in favour of Bihar. Owing to climatic conditions and abundant green water availability, irrigation requirement is also lower. Furthermore, groundwater levels are shallower vis-à-vis Punjab and therefore it is a lot easier to extract and apply groundwater for irrigation. However, at the level of the individual farmer, the reality is completely different. Punjab farmers benefit from huge investments in surface irrigation systems made by the government and receive highly subsidised irrigation water for their crops through gravity flow and abundant canal-induced groundwater recharge. Bihar has a lot less area under surface irrigation systems and the systems are poorly performing and maintained. Even in the absence of surface irrigation, farmers in Punjab are able to extract groundwater at zero marginal cost owing to a free supply of farm electricity. In Bihar, on the other hand, groundwater irrigation is largely dependent on diesel pumps because rural electrification is low. With the increase in the price of diesel in recent years, the groundwater irrigation economy has shrunk (Shah, 2007). Even with higher water resource availability, Bihar farmers face economic water scarcity, leading them to under-irrigate and over-economise on blue water use.

Thus, the factor of price for the individual farmer, who is the decision-maker on what to produce and where, does not relate to the physical resource availability. The state-level water scarcity or abundance does not get reflected in farmers' crop choice due to the mismatch between physical and economic scarcity created by public policy.

Conclusions and implications for India's river linking project

Mean annual interstate virtual water trade in India has been estimated to be 106 × 109 m³ per year (Kampman, 2007). While these estimates are neither precise nor comprehensive, they do illustrate that the quantum of interstate virtual water trade is comparable to the proposed interbasin water transfers proposed under the NRLP (178 × 109 m³/yr). Significantly, the estimates also show that the direction of virtual water trade runs opposite to the proposed physical transfers. While physical water transfers are proposed from "water surplus" to "water deficit" basins – from eastern India to the rest of the country – interstate virtual water flows from relatively water-scarce to water-rich regions in eastern India.

According to international trade theory, there are five basic reasons why trade takes place between two entities: (1) differences in technological abilities, as explained by the Ricardian model of comparative advantage; (2) differences in resource endowments, as explained by the H–O Model; (3) differences in demand, which partly explain trade between surplus entities, as explained by the Linder effect; (4) the existence of economies of scale, as enumerated by the new trade theory; and (5) the existence of government policies which might create new comparative advantages and disadvantages that are different from natural advantages and disadvantages (Suranovic, 2007). Much of the literature on virtual water trade has focused on understanding differences caused by water endowments, or on the Ricardian logic of trade. However, this paper argues that in order to have a comprehensive understanding of the behaviour of agents in trade, all other reasons including endowments of non-water factors of production (such as land) and the impact of government policies need to be taken into consideration.

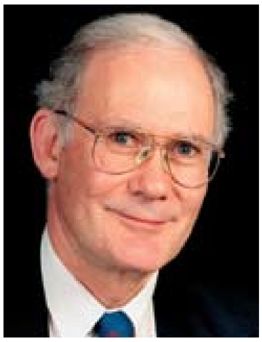
Finally, we have presented a case study where virtual water concepts are applied within a country at the regional and sub-regional level. The existing pattern of virtual water trade is exacerbating water scarcities and, rather than being dictated by water endowments, trade patterns are influenced by factors such as per capita availability of arable land and, more importantly, by biases in food and agriculture policies. There is a need to align the physical water transfers planned under the NRLP with the existing virtual water trade. This can be done by focusing on improving the productivity of eastern India's agriculture through changes in food, energy and agricultural market policies. If understood and used correctly, virtual water trade can complement physical water transfer rather than work against it. ■

References

- Aggarwal, P.K., Talukdar, K.K. and Mall, R.K. (2000) *Potential yields of rice-wheat system in the Indo-Gangetic plains of India.* Rice-Wheat Consortium Paper Series 10. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains, 16 pp.
- Allan, J.A. (1993) Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible. In *Priorities for water resources allocation and management* (Ed. ODA) pp. 13–26. London, UK: Overseas Development Administration (ODA).
- Allan, J.A. (1994) Overall perspectives on countries and regions. In *Water in the Arab World: Perspectives and Prognoses* (Eds. Rogers, P. and Lydon, P.) pp. 65-100. Cambridge, MA, USA: Harvard University Press.
- Allan, J.A. (2003) Virtual Water – the Water, Food, and Trade Nexus: Useful Concept or Misleading Metaphor? *Water International* 28(1): 106-113.
- Antras, P. (2007) Lecture Notes on International Economics I. MIT 14.581 (graduate), Spring 2007. Massachusetts Institute of Technology (MIT), Cambridge, MA: Website publication http://stellar.mit.edu/S/course/14/sp07/14.581/materials.html (last accessed: May 2007).
- Bandyopadhyay, J. and Perveen, S. (2004) *The doubtful science of interlinking.* India Together, February: Website publication http://www.indiatogether.org/2004/feb/envbadsci-p1.htm (last accessed: 7th October 2006).

Photo: BrandXPictures

- Bergstrand, J.H. (1990).The Heckscher-Ohlin-Samuelson Model, the Linder Hypothesis and the Determinants of Bilateral Intra-industry Trade. *Economic Journal* 100 (403): 1216–1229.
- Davis, D.R. (2007) Notes on Competitive Trade Theory. Lecture notes from Columbia University, New York: Website publication http://www.columbia.edu/~drd28/Text.pdf> (last accessed: May 2007).
- 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. Colombo, Sri Lanka: Comprehensive Assessment Secretariat.
- Falkenmark, M. (1997) Meeting Water Requirements of an Expanding World Population. *Philosophical Transactions of the Royal Society: Biological Sciences* 352(1356): 929–936.
- Haddadin, M.J. (2003) Exogenous water: A conduit to globalization of water resources. In *Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade* (Ed. Hoekstra, A.Y.). Value of Water Research Report Series No. 12. Delft, the Netherlands: UNESCO-IHE.
- Hoekstra, A.Y. (2003) Virtual water: An introduction. In Virtual water trade: *Proceedings of the International Expert Meeting on Virtual Water Trade* (Ed. Hoekstra, A.Y.). Value of Water Research Report Series No. 12. Delft, the Netherlands: UNESCO-IHE.
- Hutagaol, P. (2005) Are food self sufficiency programmes the only way? CGPRT Flash 3 (7), July. ISSN 1693–4636: Website publication http://www.uncapsa.org/Flash/flash0705.pdf (last accessed: March 2007).
- IESC (2007) Website of the International Economics Study Center (IESC): Website publication http://internationalecon.com/Trade/T-toc.php (last accessed: May 2007).
- IndiaStat (n.d.) IndiaStat web database for data and information on India. Access available on subscription: Website publication http://www.indiastat.com (last accessed: June 2010).
- IWMI (2003) *Strategic Analysis of India's National River Linking Project* (NRLP). Proposal submitted to the CGIAR Challenge Program on Water and Food: Website publication http://waterandfood.org/fileadmin/CPWF_Documents/Documents/First_call_projects/PN_48.pdf (last accessed: 9th October 2006).
- Iyer, R. (2002) Linking rivers: vision or mirage. Frontline 19 (25), 7th December: Website publication http://www.frontlineonnet.com/fl1925/stories/20021220001504900.htm (last accessed: 8th October 2006).
- Kampman, D.A. (2007) *Water Footprint of India: A Study on Water Use in Relation to the Consumption of Agricultural Goods in the Indian states.* Masters thesis. Enschede, the Netherlands: University of Twente.
- Kumar, M.D. and Singh, O.P. (2005) Virtual Water in Global Food and Water Policy Making: Is There a Need for Rethinking? *Water Resources Management* 19: 759–789.
- Linder, S.B. (1961) *An Essay on Trade and Transformation*. Stockholm, Sweden: Almqvist and Wiksell.
- Liu, J. and Savenije, H.H.G. (2008) Time to Break the Silence around Virtual-water Imports. Nature 453: 587.
- Ma, J., Hoekstra, A.Y., Wang, H., Chapagain, A.K. and Wang, D. (2006) Virtual versus Real Water Transfers within China. *Philosophical Transactions of the Royal Society* B 361: 835–842.
- NCIWRD (1999) *Integrated Water Resource Development: A Plan for Action.* Report of the National Commission for Integrated Water Resource Development (NCIWRD). Vol. I. New Dehli, India: Ministry of Water Resources, Government of India.
- NWDA (2006) *Inter Basin Water Transfer: The Need.* National Water Development Agency: Website publication http://nwda.gov.in/index2.asp?sublinkid=46&langid=1 (last accessed: 7th October 2006).
- Patkar, M. (Ed.) (2004) *River linking: A millennium folly?* Mumbai, India: National Alliance of Peoples' Movements (NAPM) and Initiative, 131 pp.
- Savenije, H.H.G. (2004) *The role of green water in food production in sub-Saharan Africa*. Article prepared for the Food and Agriculture Organization of the United Nations (FAO): Website publication http://www.wcainfonet.org/cds_upload/documents/1352.Role_of_green_water.pdf (last accessed: 7th October 2006).
- Sen, A. (1981) *Poverty and Famines: An Essay on Entitlement and Deprivation*. Oxford, UK: Oxford University Press, p. 257.
- Shah, T. (2007) Crop Per Drop of Diesel? Energy Squeeze on India's Smallholder Irrigation. *Economic and Political Weekly* 42(39): 4002–4009.
- Stern, J. (2003) *The rise and fall of the Indonesian economy.* Faculty Research Working Paper Series No. RWP03-030. John F. Kennedy School of Government, Harvard University: Website publication http://papers.ssrn.com/sol3/papers.cfm?abstract_id=421182 (last accessed: March 2007).
- Suranovic, S.M. (2007) *International Trade Theory and Policy.* Online textbook on International Trade, International Economics Study Center: Website publication http://internationalecon.com/Trade/tradehome.php (last accessed: April 2007),
- Vaidyanathan, A. (2003) Interlinking of Peninsular Rivers: A Critique. *Economic and Political Weekly,* 5th July, pp. 2865–2871.
- Verma, S. (2007) *Can H-O work for H2O? Interstate Virtual Water Trade as an Alternative to Inter Basin Water Transfers in India.* MSc thesis. Delft, the Netherlands: UNESCO-IHE, Institute for Water Education.
- Verma, S. and Phansalkar, S. J. (2007) India's Water Future 2050: Potential Deviations from 'Business-As-Usual'. *International Journal of Rural Management* 3(1): 149–179.
- Verma, S., Kampman, D. A., Van der Zaag, P. and Hoekstra, A. Y. (2009) Going against the Flow: A Critical Analysis of Inter-State Virtual Water Trade in the Context of India's National River Linking Program. *Journal of Physics and Chemistry of the Earth* 34(4-5): 261–269.
- Vombatkere, S.G. (2003) Interlinking: Salvation or folly? India Together, February: Website publication http://www.indiatogether.org/environment/water/wtrsgvintlink.htm (last accessed: 7th October 2006).
- Wichelns, D. (2001). The Role of 'Virtual Water' in Efforts to Achieve Food Security and Other National Goals, with an Example from Egypt. *Agricultural Water Management* 49: 131–151.
- Wichelns, D. (2004) The Policy Relevance of Virtual Water can be Enhanced by Considering Comparative Advantages. *Agricultural Water Management* 66(1): 49–63.
- Würtenberger, L., Koellner, T., Binder, C.R. (2006) Virtual Land Use and Agricultural Trade: Estimating Environmental and Socio-economic Impacts. *Ecological Economics* 57: 679–697.
- Yang, H., Reichert, P., Abbaspour, K.C. and Zehnder, A.J.B. (2003) A water resources threshold and its implications for food security. In Virtual water trade: *Proceedings of the International Expert Meeting on Virtual Water Trade* (Ed. Hoekstra, A.Y.). Value of Water Research Report Series No. 12 pp. 111–117. Delft, the Netherlands: UNESCO-IHE.



Prof. David J Bradley
Department of Zoology, University of Oxford and London School of Hygiene and Tropical Medicine, University of London
david.bradley@lshtm.ac.uk

Dr. Robert Bos
World Health Organization
bosr@who.int

Water storage: health risks at different scales

Water is stored to facilitate access, and at all scales from huge reservoirs to small pots within the household. But there are health hazards as well as benefits from water storage; these are explored here within the frameworks of geometry, process and functional classification of risk. Hazards depend upon ease of access of people and other biota and pathogens to the water. Insect vectors of disease may breed in the water. Risk tends to decrease in larger water bodies. Methods to reduce the health hazards of large dams are well studied, even if often ignored, but those for small dams are less clear, requiring a choice appropriate to the locally relevant pathogens, and further research attention. Measures against specific diseases will depend on the pre-existing levels of endemicity, and on how far alternative methods of treatment and prevention are available.

Keywords: water storage, health, malaria, schistosomiasis, reservoirs, vectors

Introduction

A key way to improve access to water for the common good is to store it, both to even out variation in availability and to have it closer to the point of use. Such deliberate storage, involving purposive human action, can take place at many scales, from the huge reservoir to the household jar and may be for one of various purposes, from human drinking to agriculture, or increasingly for multiple purposes. A reservoir may be used for both hydropower and irrigation water, a village pool for domestic use and livestock. Multipurpose use for both domestic and productive purposes is increasingly planned (Senzanje et al., 2008), and in practice unplanned types of use are added to those intended (Ensink et al., 2002).

There are more types of water storage than appear in engineering texts, and different types grade into each other rather than being simple categories. Several scales and types of water storage have been the subject of detailed research but others have been neglected.

Water storage not only has benefits, it may also bring disease to the users or to others nearby, and since human action is involved anyway, it may be possible for interventions to prevent or reduce these health hazards (White et al., 1972). For this group of reasons it may be useful to look at the whole range of water storage activities, the more so as multiple uses are increasingly favoured. All are subject to health hazards, many of which are focused on particular storage modalities although there is a continuum of sizes. Health research has been concentrated on specific types of water storage, such as very large dams, small dams in a few countries, and household water storage containers. The other scales both need attention and can benefit from cautious extrapolation from the existing data.

Water storage implies human action: that either some storage facility has been created by people, or else a natural system has been modified, for example by damming a stream, to make it more fit for storage purposes.

These issues make it desirable to review the health hazards of water storage as a whole, particularly seeking general lessons of use in assessing the likely health consequences of any intervention to store water, when at the planning phase. Two contemporary debates, one on the desirability of multiple use water development (Moriarty et al., 2004) and the other on the application of household-level water treatment (Mintz et al., 1995; Clasen 2008), make this review timely. The aim will be to move from a rather general analysis of water storage in terms of scale and geometry, process, types of health impact and problem management, towards specific comment on health hazards at certain scales. This will all be preceded by a discussion of types of water storage with special reference to areas often missed, and anomalous situations. The aim in this short paper is to convey the general approach and broad concepts. The topic is to be dealt with in detail in subsequent papers.

The boundary between man-made water storage and natural water sources, conduits, etc., is, of course, arbitrary although the category is self-evident in most cases. Problem examples are where water storage pools and irrigated rice fields are contiguous and have an unclear boundary; where a horse-drawn set of drums of water for sale act as both storage and distribution; and where a village "tank" or pond created for storage of water in Vietnam is also used for washing vegetables grown in fields irrigated with sewage, on their way to market. Moreover, it is common for a constructed village storage pond, created by a small earth dam, to become vegetated and in time to resemble a natural pool in biodiversity and most other respects. The key distinction remains that storage is constructed by human agency and could therefore have been done differently, in particular to decrease health hazards (Bradley, 1977a, 1977b).

Where water is stored for multiple purposes, ideally requiring water of different qualities, then subsequent treatment of the water for domestic use has to be considered. It is desirable to investigate use in some detail, even within the domestic category, to understand what is needed. For example, the Hima pastoralists of south west Uganda frequently use water from the same rural ponds (Figure 1) for both watering livestock and family domestic use. This is clearly of concern, but the Hima traditionally do not drink water, only milk (Jelliffe and Blackman, 1962), so the situation may not be as dire as may at first appear.

Historical background

Diseases have been associated with proximity to water bodies and their use since the time of Hippocrates. Concern for water quality is of similarly early origin, and demonstration of the water-borne transmission of cholera even precedes the microbiological era of the later 19th century (Snow, 1855). The major infectious disease hazards of water storage for drinking are the faecal-orally transmitted diseases, predominantly the diarrhoeal diseases and dysentery, but sometimes causing grave systemic illness in the case of typhoid and leptospirosis. Attempts were made a century ago in rich countries to exclude people and sometimes livestock from the catchment of drinking water reservoirs, but subsequently water treatment by filtration and chlorination has been increasingly relied on. Most problems were solved for temperate climates with relatively prosperous communities. However, users of surface storage in the rural tropics in particular continue to have major difficulties with supplies polluted by faeces, urine and wastewater. This has repeatedly led to the development and advocacy of methods for the household level treatment of water (Mintz et al., 2001), an important approach whose sustainability needs further data.

Historically, concern for the adverse health consequences of water resource developments increased in the mid 20th century. The damage done to health by thoughtless creation of very large dams became apparent (Stanley and Alpers, 1975), involved the increase of vector-borne diseases, displacement of local residents and disruption of livelihoods, and international development agencies became concerned.

The need to control malaria in the water developments of the Tennessee Valley Authority in the USA (USPHS and TVA, 1947), and schistosomiasis outbreaks in reservoirs funded by the World Bank, were particular driving forces. Key publications in the 1970s (e.g.

Photo: Michael Moorev

Stanley and Alpers, 1975) set out principles that are still valid today:

- man-made impoundments have hazards as well as benefits,
- ecological changes need to be monitored,
- lanning and implementation of impoundments require a scientific basis, co-ordinated inputs from many disciplines and substantial local data,
- impoundments should preferably be integrated into a regional development programme.

Human health needs to be specifically addressed in planning, construction, operation and use. Much experience has been gathered since then, chiefly around large impoundments, but only recently have issues of small impoundments for multiple use been addressed.

Boundaries and categories

To consider the variety of forms of water storage is to embark on both description and classification, and in several dimensions. Clearly, there is a huge range of sizes from high dams and their reservoirs (Jobin, 1999) through to small household jars and bottles (Table 1). Roughly parallel to size is the range of ownership, from large public corporations or the central government in the case of great reservoirs, down through medium-sized reservoirs belonging to a town or county, small reservoirs under the control of a group of villages (Figure 1C), community pools created for and sometimes by individual villages (Figure 1B), smaller pools owned by a syndicate of households or by a rich person, community level tanks in an urban block of flats, and then a great diversity of modes of household level storage (White et al., 1972; Thompson et al., 2001). These extend from farm scale household ponds (Figure 1A) which store water for both people and livestock in pastoral areas, through large concrete jar-shaped tanks in Thailand that have substantial storage for domestic use through the dry season, much smaller pots and jars, replenished daily throughout the year, underground and within-wall cisterns for older houses in urban Gujarat, India, metal household tanks within richer homes worldwide, and innumerable variations upon all these.

This table below illustrates the range of water storage "containers" in the broadest sense of the word. It does not attempt to be comprehensive. The statements of public access are the common ones for each item, but there are very many exceptions. Containers are open or closed by intention (there is clearly no "lid" on a large reservoir), but many of the "closed" items are leaky in one way or another in many instances. The form of governance will affect the ability to control access and so affect pollution and exposure.

Small multipurpose reservoirs and dams are probably collectively more important for health than are large dams, making up in numbers what they lose in capacity. In part of northern Nigeria, there were over 700 in a limited area. Worldwide, in 2001 it was estimated that there were 40,000 large dams and over 800,000 small reservoirs (Keiser et al., 2005a), although the last figure is probably a substantial underestimate. Multiple small reservoirs pose different problems from big dams. Formal control over them is weak, and is exerted at local level by local government and community pressure. The users need to be convinced if health measures are to be implemented and maintained. The various health risk issues have to be balanced against the different uses to which the water will be put. General rules are less applicable and flexible local inputs are needed. Resources are, however, much more limited and many small dams pose major health hazards. There are then other modes of storage where the usual concept of a container does not apply. Deliberate recharge of groundwater by pumping is one. Another is the form of some irrigation schemes where the canals are massively overdesigned to act as storage as well as being a conduit of water to the fields, as in the Gezira, Sudan.

1A. Farm pond made and owned by one household; 1B. Community-owned small dam used, as are the others, for watering livestock

Size range	Category	Description of size	Governance	Public access	Open or closed
Biggest					
Very large	Public	Large dam	Government or special authority	Restricted in some societies	Open
Large		Medium reservoir	Government	Yes	Open
Large		Small/medium reservoir	Local government	Yes	Open
Medium	Community	Small dam	Community	Yes	Open
Medium		Small pools	Society	Restricted	Open
Medium		Small pools	Individual	Conditional	Open
Small		Storage tanks on roof of flats	Society	Restricted	Closed
Small	Household	Small ponds	Household	No	Open
Small		Storage tanks, roof catchments	Household	No	Closed
Small		Household tanks	Household	No	Closed
Very small	Inside home	Containers, planned	Household	No	Closed
Very small		Containers, informal	Household	No	Vary
Smallest					

Table 1. Varied scales of water storage, indicating the great range of size, governance, access and consequent attributes of the storage containers*

Figure 1. Array of water storage in a water-scarce pastoral area of SW Uganda.

as well as people; surface covered by the floating fern Azolla which at high coverage prevents mosquito breeding; 1C. Parish-level impoundment, created and managed by the local government; 1D. Natural lake and the water source of last resort in drought, lying within a national park under central government control.

A critical dichotomy is between open and closed storage. Clearly, the larger types of surface water storage are of necessity open. Many smaller storage containers, especially at household level, are closed in intention but not always in practice. They either have a complete top in the case of a metal or plastic tank, or a very narrow neck for some water storage jars. Both human unwashed hands and dippers, and also female mosquitoes seeking to lay eggs, need to be kept out. Ensuring that closed containers in fact live up to their name is one of the key health protective interventions.

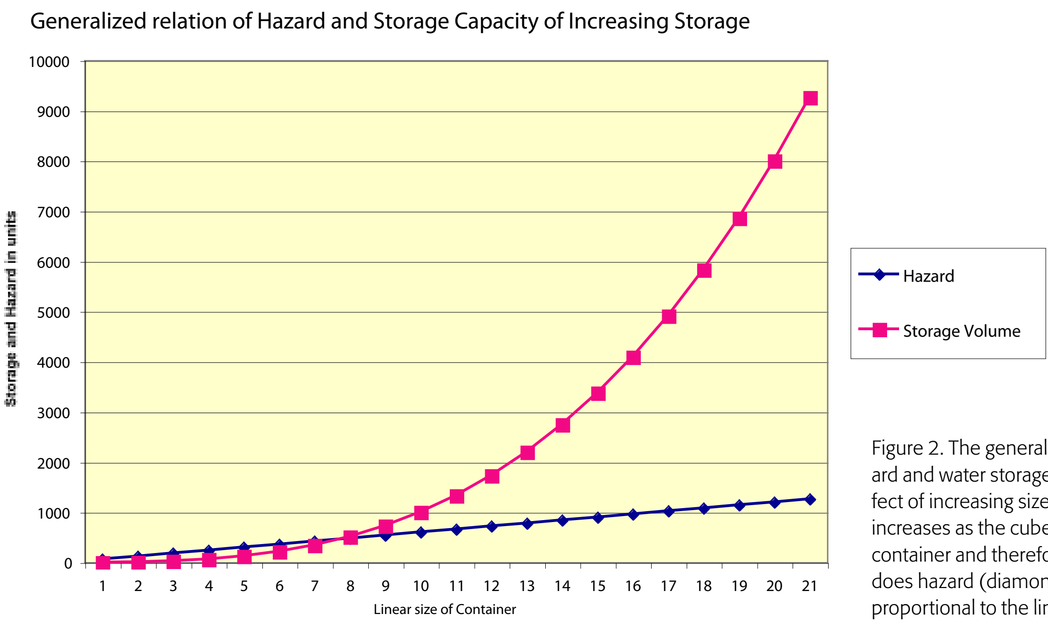


Figure 2. The generalised relation between hazard and water storage capacity, to show the effect of increasing size: storage (square symbols) increases as the cube of the linear breadth of the container and therefore much more rapidly than does hazard (diamond symbols), which is roughly proportional to the linear breadth.

Theoretical approaches

Geometry and scale

When considering storage "containers" varying from large reservoirs to household level containers, some general aspects of scale become apparent. The storage capacity of a hemispherical storage container will vary as the cube of its radius since its volume is 2 π r3 / 3. However, its surface area will be π r2, and, more important for many determinants of disease transmission, the rather small peripheral area close to the shore, where most human water contact occurs, will tend to increase as a function of r (Figure 2). This last piece of shallow water we may conveniently call "the water's edge", and it is where the majority of aquatic insect vectors of disease breed, and where simple polluting activities by people and livestock will be concentrated. People will be in contact with water there and may collect water supplies from the edge. So if storage capacity is a function of r3, and health hazards are closer to a function of r1, then it follows that as storage volume increases, the health hazard per unit of storage will rapidly decrease.

To give an extreme example of this effect, consider two ways to store a cubic kilometre of water: the first as part of the Volta Lake, a reservoir in Ghana, and the second as a series of ponds of the type found in Nigeria and most other places. Each pond may have a surface area of two hectares and mean depth of 2 m, and a volume of 40,000 m^3, this will require 25,000 ponds for the cubic kilometre of water, whereas the whole of Lake Volta contains 148 km^3 of water. The perimeter involved, which is key to disease transmission, as explained above, would be 12,500 km for the ponds and 35.1 km for Lake Volta, a ratio between them of 356 times. In this very simple model, the benefits of large capacity storage for diminishing health hazards of storage are clearly seen. Of course, the real world is much more complex and, at the lower scales of storage, the whole water body may be viewed as "periphery" or "water's edge". Nevertheless, there are real advantages to large-scale storage, but not at the expense of increasing the journey to water. Large-scale storage requires a distribution network.

Process

The infectious disease hazards of water storage may be viewed as a problem in pathogen population dynamics. Water enters the storage facility, and leaves it with a certain load of pathogens. It may also act as a breeding site for disease vectors in warm climates. The difference between the entry and exit hazard will depend on the transit time of the water and the specific pathogens involved, but most particularly on whether pathogens or vectors can gain access to the stored water: that is, whether it is open or closed storage (in fact, rather than just in intention). Attempts to keep storage closed often fail; examples include the commonly reported increase in bacterial pollution of water stored in the household, as compared with when it was collected from a source (Wright et al., 2004). Some of this increase may have been in drawing the water at source and in transit, but much may be from people removing water from the storage vessel, while children and animals may access and contaminate open household storage.

Another example of the open/closed category underlies the epidemiology of malaria in the city of Mumbai, India. Here there live strains of the vector mosquito Anopheles stephensi which have become adapted to breeding in the roof water storage tanks of urban blocks of flats. The air vents of these tanks, in theory covered in metal gauze, are often not tightly covered and the female mosquitoes gain access, lay their eggs, and mosquito larvae develop in the tanks, escaping, when the new adults emerge, by the same route through which their mother entered.

The dynamics of pathogens will depend on temperature, substances in the water and on the surfaces of the container, whether the pathogens simply die off exponentially or in some other survival profile, whether they are able to multiply in the right circumstances, as is the case with some pathogenic bacteria and some usually free-living amoebae, and whether those circumstances are present. In the case of pathogens able to cross the human skin, such as schistosomes and leptospires, contact of people with infective water is sufficient to cause infection. Death rates of most faecal-oral pathogens in water tend to lead to a log-linear decrease with time, so that after a time the number of organisms consumed by drinking a usual amount of water has fallen below the usually infective dose. The parameters of die-off are highly species-specific.

Functional classification of hazards in epidemiology and control

What then are the communicable disease hazards of water storage? As with all water-related diseases (White et al., 1972; Bradley, 2009), they fall into five broad categories (Table 2). Water-borne infections are transmitted by ingestion of organisms in the water and are therefore a problem of domestic water use. Their relation to storage depends on the quality of water being put into storage and on the access of further contamination to the water being stored. Unless the water contains small quantities of nutrients and the pathogenic micro-organisms are able to multiply in the stored water, which is not usually the case, the hazards will decay over time as the bacteria die and viruses become less infectious. The well-studied theme of improving the microbiological quality of water to be used for drinking, food preparation and other domestic uses which will lead to pathogens being ingested, will be familiar to readers.

Photo: BrandXpictures

Main category	Sub-category	Key diseases	Relation to water storage
WATER-BORNE	Classical	Cholera, dysentery	These may persist through storage; the latter may provide an opportunity to reduce their transmission. Water treatment or filtration will reduce risk.
	Other	Some diarrhoeal diseases	
WATER-WASHED	Intestinal tract	Diarrhoeal diseases	These diseases will tend to be reduced by the better access to water; need concomitant hygiene education and available soap.
	Skin & eyes	Trachoma, skin infections	
WATER-BASED	Percutaneous	Schistosomiases, developing in aquatic snail intermediate hosts	Proliferate in snails in open storage pools that are subject to both contamination and water contact. Reducing that water contact is effective in prevention.
	Oral	Dracunculiasis	Poor sources rather than storage but may persist in stored water. Control possible by altering well design.
WATER-RELATED INSECT VECTORS	Breeding in water	Mosquitoes, midges, spread malaria, filariasis, arboviruses	The edges of open pools and puddles around them provide breeding habitats, habitats highly species-specific. Alterations to habitat may stop breeding.
	Biting near water	Tsetse flies (some)	Not relevant to storage of water.
WATER-AEROSOL	Aerosol from water	Legionella	Multiply in biofilms of storage and distribution systems, especially of warm water.

Table 2. Disease transmission and water storage. This elaborates the system from Bradley (2009) in relation to the communicable disease hazards of water storage.

A key aspect of safe storage for domestic use is for smaller artificial containers not to allow people's hands to contact the stored water. So household tanks need taps to control outflow and, if simple vessels are used, the necks of the jar should be too narrow for hands to pass through. The use of simple dipping cups to take water from storage in the household, which almost inevitably leads to immersion of hands in the water, is to be avoided. Treatment of contaminated (especially surface) water as near to the point of use as possible, whether by filtration, chlorination, or other chemical treatment (Clasen et al., 2007a, 2007b; Lantagne et al., 2007; Lule et al., 2005), is logically preferable if reliable chlorination of the whole supply is not possible, although some doubts about sustainability remain.

The second group of diseases, those washed away by an adequate supply of water for personal cleanliness, benefit from the easy access which is the primary object of water storage, and the actual microbiological quality of this water is less critical than for drinking water. If the water-washed disease hazards are to be reduced substantially, it is essential that effective health education should ensure that washing, especially of hands, takes place at the critical times and that soap is available and made use of (Curtis and Cairncross, 2003; Parker et al., 2006; O'Reilly et al., 2006). Water-washed transmission affects many faecal-orally transmitted diarrhoeal diseases, from cholera to dysentery, also many skin and eye infections, including the potentially blinding trachoma.

The third, "water-based", and fourth, "water-related insect vectors", categories of water-related transmission are most closely associated with open surface water storage. The chief water-based disease group, the schistosomiases, require double contact with the stored water body for transmission, first to contaminate it with eggs of schistosomes in the human excreta (and animal excreta in the case of Schistosoma japonicum) and then, after the parasites have developed in water-snails and emerged into the water as infective cercarial larvae, direct skin contact with the infected water. Hence its importance in reservoirs with gently sloping edges and much emergent vegetation that are used for laundry, bathing and as sources of domestic water to be carried home.

Of the water-related insect vectors of disease, the mosquitoes are by far the most important, widely distributed, and intractable. Whilst mosquito larvae develop in many sorts of fresh and brackish water, they tend to be in smaller and shallow water bodies or the edges of large reservoirs. Although there are very many species (over 3,000) of mosquitoes, the majority have relatively specific habitat requirements and also have a restricted geographical range, so that the number of potentially hazardous species occurring near a given water-storage body will be quite limited. To make a rather gross simplification of a complex topic, there are three groups of mosquitoes of particular importance in relation to water storage. The genus Anopheles includes all the species able to transmit malaria. They tend to breed in unpolluted water from larger pools, the edges of reservoirs, down to puddles. They also to some degree transmit filariasis (elephantiasis) and a few virus fevers. At the other habitat extreme is the genus Aedes, which are container-breeding mosquitoes. In the wild they may breed in tree-holes, but close to man in flower vases and vessels used to store water at the household level. They transmit insect-borne viruses, of which there are very many, the most important being yellow fever and dengue. Dengue is now the most important arbovirus infection of people and its main vector, Aedes aegypti, is primarily urban and a hazard of household-level water storage there. The highly invasive Aedes albopictus is rather less associated with deliberate water storage. A third group of mosquitoes of the genus Culex lies rather between in habitat preference. Some Culex species prefer heavily polluted waters and hence are very prevalent in urban areas but not particularly in stored water; others are floodwater zone mosquitoes with hardy eggs that may persist between floods and produce large numbers of mosquitoes when one comes. Constructed water storage and treatment ponds and wetlands may provide a sequence of habitats which will provide breeding sites for a series of different potential vectors of disease.

The implications for prevention of disease are that prior to any changes in water storage an assessment of the likely hazards and their vectors should be made, that should give a short list on the basis of which a limited number of modifications can be made to minimise health risks. The most widespread of these risks is malaria.

The benefits that reducing mosquito numbers will have upon malaria in people are highly dependent upon the baseline of malaria endemicity in the area. Under conditions of very intense pre-existing malaria, the increase of vectors that may result from water storage developments may have a trivial effect on the frequency of human disease, as in these circumstances malaria is regulated by human acquired immunity much more than by changes in the level of malaria transmission. By contrast, where malaria endemicity is relatively low, and the area is subject to occasional malaria epidemics, construction of storage reservoirs in the tropics may greatly increase malaria risk. In well-controlled studies of micro-dams for livestock in northern Ethiopia, malaria incidence within three kilometres of the storage reservoirs was raised between five-fold and 8.7-fold at different altitudes, by dam construction (Ghebreyesus et al., 1999).

Estimating burden and risk of disease

The infectious and communicable disease burden due to water resource development has been assessed for several key vector-borne diseases, primarily in relation to the larger dams and reservoirs (and to irrigation schemes, which are not considered here). Malaria and schistosomiasis are greatly affected by surface water storage; other diseases are more affected by the uses to which the stored water is eventually put, so that, for example, irrigated agriculture has a large effect on disease burden and water with faecal contamination will have a much larger effect if actually consumed as water than when used for other purposes.

The effect will also vary very much with the baseline endemicity and local vector species, so that, for example, four times larger a percentage of schistosomiasis incidence can be ascribed to dams in Southeast Asia than in Africa, though the actual number of people involved is far greater in Africa south of the Sahara. Meticulous calculations have been made by Kaiser, Utzinger and colleagues in a series of systematic reviews of the key vector-borne diseases, and the results are summarised in Table 3, for big dams in the case of malaria and schistosomiasis. Globally it appears that some 42 million people are at risk of schistosomiasis from big water storage dams, of whom 10 million are infected (Steinmann et al., 2006), while 18 million are at risk of malaria as a consequence of water storage in large dams (Keiser et al., 2005a). Of the two other major vector-borne diseases affected by agricultural water resource developments, Japanese encephalitis (Keiser et al., 2005b) is mainly transmitted by mosquitoes breeding in flooded rice fields and less affected by water storage, and there is very little relevant data on filariasis (elephantiasis). Because several mosquitoes that can act as vectors are differentially affected by water storage, the effect is not clear-cut (Erlanger et al., 2005).

Interventions

Among specific interventions that are of value in reducing health hazards of water storage, two have received most attention, at opposite ends of the scale of size. In the pre-1939 golden period of environmental management for vector control, particular attention was paid to varying the water level of reservoirs in a controlled way, especially in the USA, deriving from the experience of the Tennessee Valley Authority in malaria prevention on impounded waters (USPHS and TVA, 1947). The water level in medium-scale reservoirs can be rapidly lowered either by manual control of the sluice gates or by an automatic siphon device. By careful manipulation of series of dams on a watercourse, it was possible raise the water level transiently to flood height, so stranding flotsam and floating vegetation that tended to harbour vector mosquito larvae. Subsequently, rapid dropping of the water level was able to strand the larvae of Anopheles quadrimaculatus, the local malaria vector, and marshy areas dried out. This was highly successful in malaria control there, and the approach has also been used against An. culicifacies in South Asia. However, as with most environmental control methods, this is species-specific. Any attempt to use it against puddle-breeding mosquitoes in the tropics, around large dams with very shallow sloping edges, would be worse than useless: the rate of water level fall would be slow and generate extensive breeding sites for An. gambiae, the world's most effective malaria vector, and do more harm than good.

At the other end of the scale, household storage, as discussed above, in the poorest communities often involves not only initially polluted water but means of transport that further increase contamination. The source may have been shared with livestock. Point-of-use treatment has been thoroughly explored recently (Clasen et al., 2007a, 2007b).

	SCHISTOSOMIASES			MALARIA	
	At risk from big dams	% of total risk from big dams	Estimated infected from big dams	Number of big dams	People at risk from big dams
WHO	*millions*	*%*	*millions*	*number*	*millions*
Region					
Africa S. of Sahara	28.71	5.1	9.62	525	3.07
Latin America	1.22	3.4	0.06	1449	0.48
Middle E. & N. Africa	2.35	1.7	0.29	812	2.46
S.E. Asia & W. Pacific	10.09	21.7	0.23	6405	12.33
World	**42.36**	**5.4**	**10.20**	**9191**	**18.34**

Table 3. Schistosomiasis and malaria risk from water storage in large dam reservoirs. The data are derived from Keiser et al. (2005a) and Steinmann et al. (2006).

Photo: Mats Lannerstad

Much is known about pathogen survival in water (Feachem et al., 1983) and particular storage regimes can be developed to destroy schistosome cercariae, etc. Indeed, there is sufficient knowledge to propose interventions against many pathogens and vectors but, as with most control by environmental means, interventions need to be appropriate for the local organisms and human activities and also maintained scrupulously, which is operationally not easy.

Measures to control the health hazards of small dams are site-specific, but may include avoiding the need to enter the water, by provision of pumps, cattle troughs (but with adequately drained surrounds), sites for laundry and canoe landing stages. These will reduce schistosomiasis risk. Fencing may be used to prevent access of livestock and consequent pollution, and steep edges to the pool deter emergent vegetation and reduce mosquito breeding (although they may create a drowning risk to children unless fenced), while stocking with appropriate small fish may reduce mosquitoes further. The floating fern Azolla will also deter mosquito breeding (especially of anophelines) once surface coverage exceeds 90%, which may or may not be acceptable to users. It is difficult to prevent all pollution of surface waters and some form of post-storage treatment is, if possible, needed for drinking water. In the tropics, sanitation is best directed towards pathogen reduction, rather than relying on water treatment to achieve this.

Interventions over time: chronotones

There is now much published work on the health hazards of major water storage reservoirs (Stanley and Alpers, 1975; Jobin, 1999). Planning (stage 1) to construct a dam, and even the rumour that this might happen, will lead to a set of social and environmental changes with health consequences of an unplanned as well as intended nature. The construction phase (stage 2) will greatly intensify these, as there will be immigration of workers, of those hoping to provide services for the workers, and often the beginnings of a health infrastructure. The health problems of transient labour predominate: trauma, sexually transmitted and respiratory infections, and outbreaks of locally endemic diseases if the workers are from a non-endemic area. Funds for infrastructure may enable good facilities for the longer term. The local people displaced from the inundated area almost invariably suffer from inadequate support and lack of planned movement to a suitable site. These indirect health consequences of creating water storage matter, and also provide health opportunities.

The early period after filling the reservoir (stage 3) may see complex biological changes such as rotting forests, explosions of insects, fish, fishermen, and shoreline vegetation with vector habitats being created, leading to outbreaks of schistosomiasis and malaria (in areas of previously low transmission), with gradual progression to a steady state (stage 4) which may or may not include a higher level of health hazards than before. Stages 1–3 comprise a key period or "chronotone" lying between the original state of the landscape and the final relatively steady state of the mature dam and reservoir (Bradley, 2004). The terminology is by analogy with the term ecotone, which is the area in space that lies between two types of ecosystem, whereas the chronotone is an equivalent interval in time rather than space. It includes the structures, water and adjacent land, the ecology, settlement, use and social conditions. Many of the changes that occur during the chronotone are predictable, others not, so there is a need both to plan the management of expected health hazards and to monitor the situation. It is a key time to invest effort in order to reap long-term reductions in health hazards. While this is also true of small impoundments, the strategy needed is different from that appropriate for large reservoirs. For a big dam, such as that for the Volta Lake, Ghana, the chronotone may last for around two decades.

Conclusion

Thus, while there are many particular and detailed measures to be taken to reduce the health hazards associated with any specific modality of water storage, there are some general principles that are widely applicable across the scales and types of storage container.

It is helpful to consider the continuum of storage containers, varying from the almost natural, with a little human intervention, through to the wholly artificial. There is a particular need to consider those containers of surface water that do not fit tidily into the engineers' categories, but which may be used by the poor and by those with unusual livelihoods. With the increased perception of multiple use sources and storage, there needs to come a more comprehensive view of the implications for nature and a diversity of health hazards and a means for their prevention. There needs to be a focus on an operational effectiveness of means to reduce hazards for specific multiple uses, and not just on idealised solutions.

While the methodology for reducing transmission of truly waterborne infections is now well understood, the location and extent of water treatment that can be maintained sustainably and at minimal cost still needs more work. The general view that multiple-use storage necessitates, under limited resources, an increase in household water treatment, has not yet been fully matched by operational programmes.

Similarly, we have a good understanding of the ecology and epidemiology of many water-based diseases and of those with water-related insect vectors. However, insufficient attention is given to the local variations in vector ecology so that findings are transferred across regions or across vector species but without sufficient care. Local research and understanding are needed if the disease risks are to be minimised at reasonable cost. Adequate attention must be paid to the endemic levels of specific disease transmission in predicting consequences of new water storage, and hence the allocation of resources for prevention. Whilst the insect-transmitted viral diseases (arboviruses) are a particular concern because of the lack of vaccines against many of them and the limited potential of chemotherapy, molecular methodology for their study and diagnosis in people and the environment is much more powerful than in the past.

Research has been concentrated on health hazards of large dams, but in spite of some excellent local studies, work on smaller water storage dams is relatively neglected. More work is needed on these problems, not only in relation to health but also into linked aspects of agriculture, livestock watering and conservation.

Whatever the scale of water storage, planning for health hazard reduction needs to be undertaken well before the development and construction of new storage. The chronotone, or period of rapid change around the development that is crucial for effective long-term action, is a period of great opportunity to improve health.

Acknowledgements

The underlying work received support from the World Health Organization, and was begun while DB held a Leverhulme Trust Emeritus Fellowship. Tamsin Bradley provided invaluable clerical assistance. This forms part of a larger WHO endeavour to address the health aspects of water storage as a whole. However, the contents are the views of the authors and are not a statement of WHO policy. ■

References

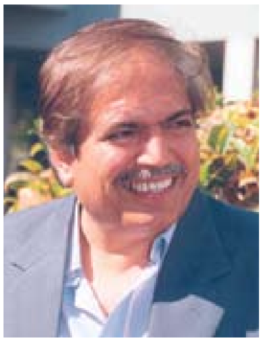
- Bradley, D.J. (1977a) Health Aspects of Water Supplies in Tropical Countries. In *Water, Wastes and Health in Hot Climates* (Eds. Feachem, R.G., McGarry, M.G. and Mara, D.) pp. 3–17. New York, USA: Wiley.
- Bradley, D.J. (1977b) The Health Implications of Irrigation Schemes and Man-made Lakes in Tropical Environments. In *Water, Wastes and*

Photo: Mats Lannerstad

Health in Hot Climates (Eds. Feachem, R.G., McGarry, M.G. and Mara, D.) pp. 18–29. New York, USA: Wiley.

- Bradley, D.J. (2004) An Exploration of Chronotones: A Concept for Understanding the Health Processes of Changing Ecosystems. *Ecohealth* 1(2): 165–171.
- Bradley, D.J. (2009) The Spectrum of Water-related Disease Transmission Processes. In *Global Issues in Water, Sanitation, and Health* (Ed. Institute of Medicine) pp. 60–73. Washington, DC, USA: The National Academies Press.
- Clasen, T.F. (2008) *Scaling Up Household Water Treatment: Looking Back, Seeing Forward.* Geneva, Switzerland: World Health Organization.
- Clasen, T., Haller, L., Walker, D., Bartram, J. and Cairncross, S. (2007a) Cost-effectiveness of Water Quality Interventions for Preventing Diarrhoeal Disease in Developing Countries. *Journal of Water and Health* 5(4): 599–608.
- Clasen, T., Schmidt, W.-P., Rabie, T., Roberts, I. and Cairncross, S. (2007b) Interventions to Improve Water Quality for Preventing Diarrhoea: Systematic Review and Meta-analysis. *British Medical Journal* 334(7597): 782.
- Curtis, V. and Cairncross, S. (2003) Effect of Washing Hands with Soap on Diarrhoea Risk in the Community: A Systematic Review. *Lancet Infectious Diseases* 3(5): 275–281.
- Ensink, J.H.J., Aslam, M.R., Konradsen, F., Jensen, P.K. and van der Hoek, W. (2002) *Linkages between irrigation and drinking water in Pakistan.* Working Paper No. 46. Colombo, Sri Lanka: International Water Management Institute.
- Erlanger, T.E., Keiser, J., Castro, M.C., Bos, R., Singer, B.H., Tanner, M. and Utzinger, J. (2005) Effect of Water Resource Development and Management on Lymphatic Filariasis, and Estimates of Populations at Risk. *American Journal of Tropical Medicine and Hygiene* 73: 523–533.
- Feachem, R.G., Bradley, D.J., Garelick, H. and Mara, D.D. (1983) *Health Aspects of Excreta and Wastewater Management.* Chichester, UK: John Wiley.
- Ghebreyesus, T.A., Haile, M., Witten, K.H., Getachew, A., Yohannes, A.M., Yohannes, M., Teklehaimanot, H.D., Lindsay, S.W. and Byass, P. (1999) Incidence of Malaria among Children Living near Dams in Northern Ethiopia: Community Based Incidence Survey. *British Medical Journal* 319: 663–666.
- Jelliffe, D.B., and Blackman, V. (1962) Bahima Disease. Possible “Milk Anemia” in Late Childhood. *Journal of Pediatrics* 61: 774–779.
- Jobin, W. (1999) *Dams and Disease: Ecological Design and Health Impacts of Large Dams, Canals and Irrigation Systems.* London, UK: E & FN Spon.
- Keiser, J., Castro, M.C., Maltese, M.F., Bos, R., Tanner, M., Singer, B.H. and Utzinger, J. (2005) Effect of Irrigation and Large Dams on the Burden of Malaria on a Global and Regional Scale. *American Journal of Tropical Medicine and Hygiene* 72: 392–406.
- Keiser, J., Maltese, M.F., Erlanger, T.E., Bos, R., Tanner, M., Singer, B.H. and Utzinger, J. (2005) Effect of Irrigated Rice Agriculture on Japanese Encephalitis, including Challenges and Opportunities for Integrated Vector Management. *Acta Tropica* 95: 40–57.
- Lantagne, D., Quick, R. and Mintz, E.D. (2007) Household Water Treatment and Safe Storage Options in Developing Countries: A review of current implementation practices. In *Water Stories: Expanding Opportunities in Small-scale Water and Sanitation Projects* (Eds. Parker, M., Williams, A. and Youngblood, C.) Washington, DC, USA: Environmental Change and Security Program, Woodrow Wilson International Center.
- Lule, J.R., Mermin, J., Ekwaru, J., Malamba, S., Downing, R., Ransom, R., Nakanjako, D., Wafula, W., Hughes, R. Bunnell, R., Kaharuza, F., Coutinho, A., Kigozi, A. and Quick, R. (2005) Effect of Home Based Water Chlorination and Safe Storage on Diarrhea among Persons with Human Immunodeficiency Virus in Uganda. *American Journal of Tropical Medicine and Hygiene* 73(5): 926–933.
- Mintz, E.D., Reiff, F.M. and Tauxe, R.V. (1995) Safe Water Treatment and Storage in the Home: A Practical New Strategy to Prevent Waterborne Disease. *Journal of the American Medical Association* 273(12): 948–953.
- Mintz, E.D., Bartram, J., Lochery, P. and Wegelin, M. (2001) Not Just a Drop in the Bucket: Expanding Access to Point-of-use Water Treatment Systems. *American Journal of Public Health* 91(10): 1565–1570.
- Moriarty, P., Butterworth, J. and van Koppen, B. (2004) *Beyond domestic: case studies on poverty and productive uses of water at the household level.* Technical Paper Series No. 41. Delft, The Netherlands: IRC International Water and Sanitation Centre.
- O’Reilly, C.E., Freeman, M.C., Ravani, M., Migele, J., Mwaki, A., Ayalo, M., Ombeki, S., Hoekstra, R.M. and Quick, R. (2008) The Impact of a School-based Safe Water and Hygiene Programme on Knowledge and Practices of Students and their Parents: Nyanza Province, Western Kenya, 2006. *Epidemiology and Infection* 136(1): 80–91.
- Parker, A.A., Stephenson, R., Riley, P.L., Ombeki, S., Komolleh, C., Sibley, L. and Quick, R. (2006) Sustained High Levels of Stored Drinking Water Treatment and Retention of Hand-washing Knowledge in Rural Kenyan Households Following a Clinic-based Intervention. *Epidemiology and Infection* 134(5): 1029–1036.
- Senzanje, A., Boelee, E., and Rusere, S. (2008) Multiple Use of Water and Water Productivity of Communal Small Dams in the Limpopo Basin, Zimbabwe. *Irrigation and Drainage Systems* 22: 225–237.
- Snow, J. (1855) *On the mode of communication of cholera.* London: Churchill.
- Stanley, N.F. and Alpers, M.P. (1975) *Man-made Lakes and Human Health.* London, UK: Academic Press.
- Steinmann, P., Keiser, J., Bos, R., Tanner, M. and Utzinger, J. (2006) Schistosomiasis and Water Resources Development: Systematic Review, Meta-analysis, and Estimates of People at Risk. *Lancet Infectious Diseases* 6: 411–425.
- Thompson, J., Porras, I.T., Tumwine, J.K., Mujwahuzi, M.R., Katui-Katua, M., Johnstone, N. and Wood, L. (2001) *Drawers of Water II: 30 Years of Change in Domestic Water Use and Environmental Health in East Africa.* London, UK: International Institute for Environment and Development.
- USPHS and TVA Health and Safety Department (1947) *Malaria Control on Impounded Water.* Washington, DC, USA: U.S. Government Printing Office.
- White, G.F., Bradley, D.J. and White, A.U. (1972). *Drawers of Water: Domestic Water Use in East Africa.* Chicago, USA: University of Chicago Press.
- Wright, J., Gundry, S. and Conroy, R. (2004) Household Drinking Water in Developing Countries: A Systematic Review of Microbiological Contamination between Source and Point-of-use. *Tropical Medicine and International Health* 9(1): 106–117.

Dr. Aditi Mukherji
Researcher, International Water Management Institute
a.mukherji@cgiar.org



Mr. Tushaar Shah
Principal Researcher, International Water Management Institute
t.shah@cgiar.org

Mr. Shilp Verma
PhD Student, UNESCO-IHE
s.verma@unesco-ihe.org

Electricity reforms and their impact on ground water use in states of Gujarat, West Bengal and Uttarakhand, India

Managing the externalities of groundwater use by minimising the negative impacts of over-exploitation, while preserving the benefits from such use, has emerged as the key natural resources management challenge in South Asia. Direct regulation of groundwater is not a feasible option in the region given the large number of pumps (over 20 million or so) and the huge transactions costs involved. In this context, an indirect mechanism, such as the regulation of the electricity supply and changes in electricity pricing and subsidies, can provide an effective tool for governing groundwater use. The link between groundwater and electricity is rather straight forward – electricity is used for pumping groundwater from aquifers. This paper documents three such cases of electricity reforms that have had a profound impact on groundwater use in the Indian states of Gujarat and West Bengal.

Keywords: groundwater, electricity, reforms, subsidies, Gujarat, West Bengal

Introduction

Indian policy discourse on the most suitable form of agricultural electricity tariff has come full circle. Until the early 1970s, all state electricity boards (SEBs) charged their tubewell owners based on metered consumption, but, due to a whole range of administrative issues, this was later changed to a flat tariff in the early 1980s. However, the flat tariffs remained low over the years and the SEBs started making large losses. Low flat tariffs also led to the over-exploitation of groundwater in arid and semi-arid states of India. Therefore, recently, there has been a renewed interest in reforming the electricity sector. This has been triggered by the poor financial status of most SEBs. The main element of electricity sector reform has been the unbundling of services – that is, the separation of the electricity generation, transmission and distribution functions and the universal metering of all consumers. Almost 50% of India's pumps depend on electricity for pumping groundwater and hence, reforms in this sector profoundly affect the groundwater sector.

Given that both water resources and electricity are state concerns in India, individual states have chosen to implement power sector reforms differently, keeping in mind the political exigencies faced by these states. The states of West Bengal in the east and Uttarakhand in the north have embarked upon the path of universal metering of agricultural electricity consumers mainly because there are no strong farm lobbies in the state to oppose such a move. This shift from a flat rate tariff (signifying a zero marginal cost of pumping) to a pro-rata tariff, altered the cost and incentive structure for the pump owners and hence affected their pumping behaviour. In contrast, the government of Gujarat, in the face of strident opposition from farmers, decided not to meter tubewells. Instead, they separated agricultural feeders from non agricultural ones, improved the quality of the power supply and rationed the number of hours of electricity to agriculture to just 8 hours a day. This initiative of the government of Gujarat is called the Jyotirgram Yojana. Figure 1 shows the location of West Bengal, Uttarakhand and Bihar.

The purpose of this paper is to analyze the possible impacts of these reforms on the pumping behaviour of pump owners, on the informal groundwater markets through which water buyers would be impacted, and on the revenues of the state electricity boards. The paper is divided into five sections. After the first introductory section, the second section

Figure 1. Location of study states

describes the groundwater and electricity situations in the three states. The third section discusses the process and implementation of the power sector reforms in each of these states, while the fourth section analyses the impact of these on groundwater use and on groundwater markets.

Groundwater and electricity situation in West Bengal, Uttarakhand and Gujarat

West Bengal, an eastern state of India, receives an annual rainfall of around 2000 mm and has a groundwater potential of 31 billion cubic meters (BCM), most of which is available at shallow depths. Only 42% of the total available groundwater resources in the state have been utilised so far (WIDD, 2004). While West Bengal has plentiful groundwater resources that can be furthered developed, the state has, for various political reasons (Mukherji, 2006), adopted one of the most stringent groundwater regulations in India. For instance, procuring electricity connections for tubewells needs permission from multiple sources, such as the State Water Investigation Directorate (SWID) and village level bodies (panchayats) and the process is fraught with red tape and corruption. The result is that West Bengal has the lowest proportion of electric tubewells to total tubewells in India (GOI, 2003). The farmers in West Bengal, until 2007, also paid the highest flat tariff (Rs. 2160/HP/year, where HP = horse power) for electricity among all Indian states. Agricultural consumption of electricity accounted for only 6.1% of total electricity consumption (WBSEB, 2006) and unlike other states, where the electricity subsidy forms a major share of state fiscal deficits, in West Bengal this was negligible (Briscoe, 2005). The existence of a very high flat tariff, coupled with small land holdings and abundant groundwater resources had led to the emergence of competitive informal groundwater markets here, and small and marginal water buying farmers benefitted substantially through these markets (Mukherji, 2007). The main irrigated crop in the state is summer paddy, called boro paddy. Average annual pumping hours vary from 1500 to 2100 for centrifugal and submersible pumps respectively.

The state of Uttarakhand in the northern part of India was formed in 2001 – earlier it was a part of Uttar Pradesh state. Uttarakhand is a pre-dominantly hilly state with the bulk of its agricultural lands limited to the southern Terai parts of the state. The mean rainfall in the state is around 1500 mm. The state has an annual net available groundwater resource of 2.10 BCM, of which 66% is being utilised presently (CGWB, 2006). The depth to the water table depends on the sub-surface lithology and varies from less than 2 m in the Terai region to as deep as 50 m in the Bhabar zone. Agriculture uses only 12% of the total electricity consumed in the state, though nearly 70% of all tubewells run on electricity. Until 2007, Uttarakhand too had a high flat tariff (Rs. 1512/HP/year) compared with other Indian states. Though unlike West Bengal where tariff recovery is very high (more than 90%), in Uttarakhand it is as low as 25% (personal communication with an official of the SEB). One of the main reasons for such a low tariff recovery is the high tariff rate coupled with periodic waivers of electricity dues by the politicians, which lessens the incentive to pay bills in a timely manner. The main irrigated crop in the state is kharif (or monsoon) paddy and rabi (or winter) wheat. The average annual pumping hours are only 800 because the water requirement of the wheat crop is not extensive. Water markets are less developed than in West Bengal, mostly because of the larger land holding size, which makes it economical for farmers to invest in their own tubewells. Another reason is the wide prevalence of government tubewells; we found that almost every village had a government tubewell and they were functioning satisfactorily.

Gujarat, a western state of India, receives an average annual rainfall of 1243 mm, though with wide regional variations. South Gujarat receives the bulk of the rainfall, while western parts of the state (Saurashtra and Kutch) are distinctly arid. The state has an annual, replenishable groundwater potential of 15.81 BCM, of which 76% (11.49 BCM) is withdrawn every year. This is a state where groundwater is used intensively and 61% of the administrative blocks are over-exploited, critically or semi-critically as per the norms of the Central Groundwater Board (CGWB). North Gujarat, which on average receives 500–700 mm of rainfall in a year, has deep alluvial aquifers and is a prime example of the unsustainable use of groundwater. In many ways, the state of Gujarat epitomises the groundwater crisis in India. Yet, surprisingly, the state has been registering an agricultural growth rate of 10% for the last 7–8 years and this surpasses that of other states better endowed with water resources (Gulati et al., 2009). Here, farmers have also increasingly moved away from cereal crops to high value crops, such as Bt cotton, tobacco, dairy, orchard and commercial crops, so as to maximise value per drop of water. Gujarat also has strong farmers' lobbies that have, time and again, successfully thwarted any attempts to curtail their access to groundwater (Mukherji, 2006). Gujarat, until the recent reforms, had one of the highest electricity subsidies in India (Briscoe, 2005). Given the heavy losses sustained by the state electricity board, there was a rapid deterioration in the quality of the power supply in the state, thereby negatively affecting the quality of life in rural areas. Gujarat, like West Bengal, also supports a vibrant groundwater market. Indeed, groundwater markets in Gujarat pre-date those of other regions in India (Shah, 1993). Table 1 summarises the agricultural and groundwater situation in these three states.

Indicator	West Bengal	Uttarakhand	Gujarat	Source
Level of development of groundwater in 2004 (%)	42	66	76	CGWB, 2006
Number of over-exploited blocks in 2004 (and as a % of all blocks)	0 (0%)	2 (2.5%)	31 (16.8%)	CGWB, 2006
Normal average annual rainfall (mm)	2074	1523	1243	CGWB, 2006
Nature of aquifer	Alluvial	Alluvial	Alluvial & hard rock	CGWB, 2006
Percentage of electric tubewells to total tubewells (2001)	8.2	70	54.5	GOI, 2003
Agricultural electricity consumption (MkWh) in (2000–2001)	1360	5122	14507	Mukherjee, 2008 for West Bengal and Gujarat and ICICI, 2000
Share of agriculture to total electricity consumption (2001–2002) (%)	6.1	12.0	45.9	Planning Commission, 2002
Transmission and distribution losses (%)	25.9	34.2 (includes Uttar Pradesh)	28.5	Narendranath et al., 2005
Flat tariff (2007) (Rs/HP/year)	1760–2160	1512	850	Mukherji, 2008
Electricity subsidy as % of fiscal deficit (2000–2001)	0.8	10 (includes Uttar Pradesh)	56	Briscoe, 2005
Percentage of households reporting hiring irrigation services from others (1997–1998)	67.2	N.A., but groundwater markets are thin	N.A., but groundwater markets are all-pervasive	NSSO, 1999
Average hours of operation of electric tubewell in a year	1000–1500	600–800	1000–1200	Authors' fieldwork
Main crops grown	Paddy in monsoon and winter season	Paddy in monsoon and wheat in winter	Less than 50% of area devoted to cereal crops, rest to cotton and other high value crops	Authors' fieldwork

Table 1. State of groundwater, electricity and agriculture in West Bengal, Uttarakhand and Gujarat

The process of reform in three states

Metering in West Bengal and Uttarakhand

As already mentioned, both the states are in the process of metering their agricultural tubewells. While the aim of the metering is the same, namely, to facilitate the efficient use of groundwater through marginal cost pricing, better energy audits and smaller transmission and distribution losses, these two states have adopted entirely different processes of metering.

The Government of West Bengal (GoWB) has adopted a hi-tech approach to metering through the installation of remotely sensed, tamper-proof meters which operate on the Time of the Day (TOD) principle. TOD is a demand management tool whereby by differentiating the cost of electricity during different times of the day, consumers are discouraged from using pumps during peak evening hours, while they are encouraged to use them during the slack night hours. There are three metered tariff rates: the normal rate from 6 am to 5 pm (Rs. 1.37/kilowatt hour (kWh)), the peak rate from 5 pm to 11 pm (Rs. 4.75/kWh) and the off-peak rate from 11 pm to 6 am (Rs 0.75/kWh). On average, these rates translate to around Rs. 6/hour inclusive of Rs. 22/month as meter rent. The new meters use technologies such as GIS (geographic information systems) and GSM (Global System for Mobile Communications) and are read remotely (Figure 2). These new meters solve many of the traditional problems of metering, such as tampering, under-reporting and under-billing by the meter readers in collusion with the villagers, curbing the arbitrary power of the meter readers and the physical abuse that the meter readers were subject to at times at the hands of the irate villagers. Meters are now remotely read and the reading is transmitted

Photo: Mats Lannerstad

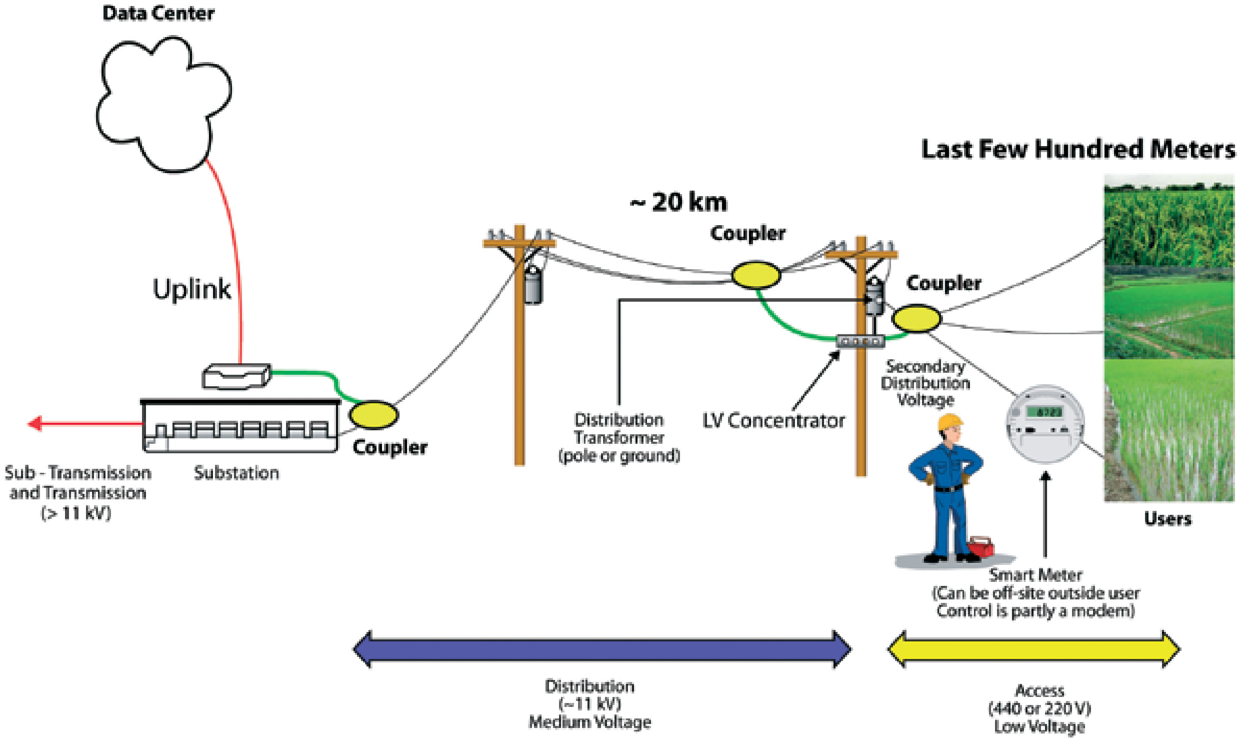


Figure 2. A schematic diagram of a generic IT Power Distribution System that is being used in West Bengal (LV = low voltage)
Source: Adapted from Tongia (2004)

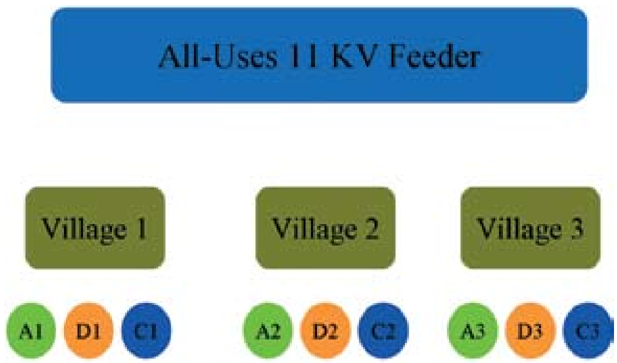
directly to the commercial office. The meter reader does not know and cannot tamper with the meter reading.

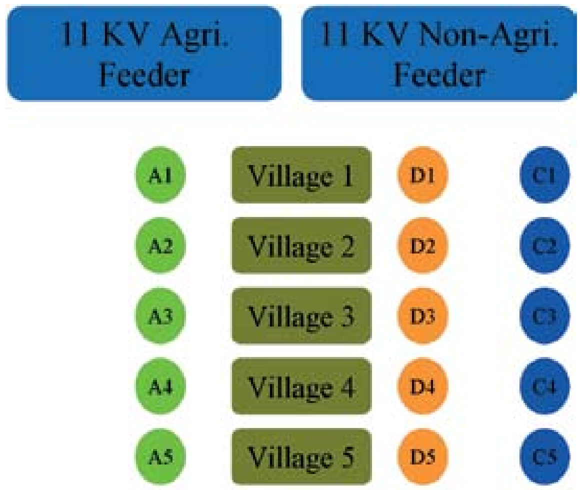
The Government of Uttarakhand (GoU) has installed electronic meters, but it has chosen the conventional form of billing which relies on manual billing by the meter readers. No TOD system has been adopted here and the metered tariff has been fixed at a low rate of Rs. 0.70/kWh, which is even lower than the lowest off-peak tariff in West Bengal. This works out to be even much lower than the current flat tariff rates of Rs. 126/HP/month. So far, meters have been installed for 70% of the agricultural tubewells. During our survey in 2008, we did not find a single instance where a farmer reported receiving bills based on the actual meter readings. The reason for this is the paucity of field staff in the electricity department and there are no chances that new meter readers will be recruited in the near future. The electricity department has undertaken some half-hearted efforts at involving village self-help groups for meter reading, but we did not gauge much enthusiasm for this among the villagers. On the whole, the farmer leaders and the villagers, as well as the electricity department officials, believe that metering in its current form is unlikely to succeed and that the government would go back to the flat tariff system, albeit at even lower rates than at present.

Decoupling agriculture from non-agricultural use of electricity: the Jyotirgram Yojana in Gujarat

In September 2003, the Government of Gujarat (GoG) pioneered a bold scheme – the Jyotirgram Scheme (JGS) – to separate agricultural feeders from non-agricultural ones. JGS was launched initially in eight

Photo: Gety Images





Figures 3a and b. Electricity network before and after the Jyotirgram Scheme (JGS)
A1, A2 etc refers to agricultural electricity connections; C1, C2 etc refers to commercial electricity connections; and D1, D2 etc refers to domestic electricity connections.

districts of Gujarat on a pilot basis. The early results were so encouraging that the scheme was extended to the entire state by 2004. By 2006 over 90% of Gujarat's 18,000 villages were covered under JGS and the total investment in the scheme amounted to Rs. 11,700 million. Feeders supplying agricultural connections were bifurcated from the supply to commercial and residential connections at the sub-station level and these feeders were metered to improve the accuracy of the energy accounting. Figures 3a and 3b show schematic diagrams of the electricity network before and after JGS.

Under the JGS, the villages began to be provided with a 24 hour power supply for domestic uses, and for schools, hospitals and village industries; and farmers began getting 8 hours of daily power supply, but at full voltage and on a pre-announced schedule. Every village is to get agricultural power during the day and night in alternate weeks that are pre-announced.

Impact of electricity reforms on groundwater use, water markets, quality of rural life

Impact of metering in West Bengal

In West Bengal, groundwater markets emerged in response to the high flat rate tariff, whereby the tubewell owners were under pressure to sell water just to recover the costs of the electricity bill, given their own land holding was not sufficiently large to justify the high electricity cost. This compulsion on the part of tubewell owners also meant that water buyers, who happen to be mostly small and marginal farmers, had sufficient bargaining power over the water seller. That this reasoning is correct is shown by the fact that while flat tariff rates increased around 10 fold from 1991 to 2006 (from Rs. 1100/year to Rs. 10,800/year), the price of water only rose 3 times, from Rs. 300/acre in 1991 to Rs. 1800/acre in 2006 for summer boro paddy (Mukherji, 2007).

However, metering the supply of electricity has changed the incentive structure and now the water sellers are no longer under a compulsion to sell water because they will pay only for as much as they pump. So, soon after metering, the pump owners increased the rates at which they sell water by 30–50%, even though, assuming the same hours of usage as under the earlier flat tariff, we found that they would have to pay a lower electricity bill under the metered tariff than before. The pump owners have, therefore, benefitted under the current meter tariff regime in two ways: (1) by having to pay a lower electricity bill than before for the same hours of use and (2) by being able to charge a higher water price than before and therefore increase their profit margins for selling water. It is to be noted that there are only 100,000 or so electric pump owners in the state and they constitute less than 2% of the total, farming households. It is this small group of wealthier farmers who have benefitted directly from metering.

In contrast, the water buyers have lost out in two ways: (1) by having to pay a higher water charge than before and (2) by having to face adverse terms and conditions for buying water (e.g. advance payments, not being able to get water at desired times, etc.). At the current tariff rates and assuming the same usage pattern, the SEB too will lose out in terms of revenues, but it may gain through a decrease in transmission and distribution (T&D) losses. The actual impact of metering on the size of the groundwater markets (i.e. whether they will expand, contract or remain the same) and the volume of groundwater extracted cannot be predicted a priori and has to be answered only empirically (Mukherji et al., 2009).

Impact of metering in Uttarakhand

In Uttarakhand, under the existing metered tariff rates, all tubewell owners will gain by having to pay less than one-third of the electricity bill that they would have paid under the flat tariff rates, but as we found, very few paid anyway. In this state, the main irrigated crops are kharif (monsoon) paddy which needs supplementary irrigation and rabi (winter) wheat which needs between 4 and 6 irrigations. As such, average annual hours of operation of a tubewell are only 600–800. Informal groundwater markets exist, but they are not as developed here as they are in West Bengal or in Gujarat. The main reason for the relatively small number of groundwater markets in Uttarakhand is that land holding sizes are relatively large and most farmers prefer to install their own tubewells than depend on other farmers for irrigation. Besides, almost every village has a government tubewell, most of them constructed after 2001 when the state was formed, and these function reasonably well and supply water to farmers at rates cheaper than private tubewells. In addition, the types of crops grown ensure that there is not a very large demand for water as is the case for summer paddy in

West Bengal. All these reasons explain why groundwater markets are relatively less developed in this state. Here, we found that the metering of tubewells has had no impact on water prices. Water was sold at a rate of Rs. 50/hour before metering, and the same rate continued even after metering. In Uttarakhand, similar to West Bengal, the state electricity utility would earn less revenue than before. Given the very low metered tariff rates, it is unlikely that there would be any impact on the volume of water pumped either (Mukherji et al. 2008).

Impact of JGS in Gujarat

Jyotirgram has radically improved the quality of village life, spurred non-farm economic enterprises, halved the power subsidy to agriculture and reduced the groundwater withdrawal. It has also offered some advantages, such as a high quality electricity supply, to medium and large farmers, but hit marginal farmers and the landless. These depend for their access to irrigation on water markets, which have shrunk post-Jyotirgram and water prices charged by tubewell owners have soared between 30% and 50%. Table 2 summarises the impact of the scheme on different groups of rural residents, including pump owners and water buyers.

Stakeholder group	Positive (+)/ Negative (-)
Rural housewives, domestic users	+++++
Students, teachers, patients, doctors	+++++
Non-farm trades, shops, cottage industries, rice mills, dairy co-ops, banks, co-operatives	+++++
Pump repair, motor rewinding, tubewell deepening, etc. (Pump mechanics)	- - - - -
Tubewell owners: quality and reliability of power supply	+++
Tubewell owners: number of hours of power supply	- - -
Water buyers, landless labourers, tenants	- - - - -
Groundwater irrigated area	- - -

Source: Shah and Verma (2009)

Table 2. Impacts of the Jyotirgram scheme on different stakeholder groups

Since over 90% of the groundwater withdrawal in Gujarat occurs through electrified tubewells, electricity consumption is an accurate surrogate for the aggregate groundwater withdrawal. Government figures suggest that farm power use on tubewells has fallen from over 15.7 billion kWh/year in 2001 to 9.9 billion kWh in 2006, a decline of approximately 37%. Unfortunately, pre-JGS figures for agricultural power use are residual figures, containing a portion of the T&D losses in other sectors, and therefore significantly inflate the extent of pre-JGS farm power use. However, even if we discount the 2001–2002 figures, there is still a very substantial decline in agricultural power use, and a halving of the aggregate farm power subsidy, from US$788 million in 2001–2002 to US$388 million in 2006–2007. From this, we can infer that annual groundwater use in Gujarat agriculture has declined significantly over the same period. True, some of the decline may be caused by two successive good monsoons in 2005 and 2006; but there is unmistakable evidence of tubewell irrigation shrinking.

Finally, the JGS has brought about an unprecedented improvement in the quality of life of rural people by creating a rural power-supply environment that is qualitatively identical to an urban one. The new era of a high quality, uninterrupted power supply in the countryside will, without doubt, unleash myriad impulses for socio-economic development and growth in non-farm livelihoods in rural areas.

However, JGS's impact on the farming community has been generally negative. The intensity of this negative impact depends on the size of the land holding and the nature of the aquifer. In the depleted alluvial aquifers of North Gujarat, farmers who can pump their deep tubewells continuously feel adversely affected because the power ration restricts the area they can irrigate. But farmers in hard-rock areas are less affected because the amount of water available in their well during a day is a more binding constraint on their pumping than the hours of daily power supply. Small farmers owning tubewells are happy with the improved power quality although they miss their water selling businesses. Landless share croppers and water buyers are adversely affected everywhere because water markets have shrunk and water prices have soared between 40% and 60%, driving many of them out of irrigated agriculture. The full import of the rationed power supply has yet not been felt by the farmers because 2005 and 2006 were both good monsoon years when wells were full and water levels were close to the ground. Come a drought year, farmers will find the JGS ration of power is too meagre to meet their irrigation needs.

Conclusion and policy implications

India is in the midst of power sector reforms and states have chosen different pathways to reform based on their political constituency. In this paper, we have documented the impact of electricity reforms on

Photo: Mats Lannerstad

Indicator	West Bengal	Uttarakhand	Gujarat
Key component of power sector reforms as it affected the groundwater sector	Metering of agricultural tubewells	Metering of agricultural tubewells	Separation of feeders supplying electricity to the agriculture and non-agricultural sectors
Degree of competency shown in implementing power sector reforms	Very high	Low	Very high
Use of modern information and technology in carrying out reforms	Very high	None	Moderate
Level of impact on groundwater users	Very high	Low to no impact	Very high
Degree of heterogeneity of impacts on different user groups	High. Electric tubewell owners gained, while their water buyers lost out in the process	No impact on any user group at all	Very high. The non agricultural rural sector benefitted the most, followed by electric pump owners, while water buyers lost out
Possible ways of reducing negative impacts or creating positive impacts on users	Lower entry barriers into groundwater markets by making it easy to get new electricity connections and provide a one-time capital cost subsidy to small and marginal farmers	Substitute manually read electronic meters with machine readable meters and ensure regular meter reading and billing	For agricultural users, shift to intelligent, demand-based power rationing; charge all consumers on a flat rate basis and continue energy auditing at the feeder level

Table 3. Summary of findings and impacts of electricity reforms on groundwater use

groundwater use in three Indian states. Table 3 summarises our main findings, while the rest of the section discusses some of the policy implications.

While most Indian states have resisted metering of agricultural tubewells, the states of West Bengal and Uttarakhand have embarked upon the metering of all tubewells. This paper compares and contrasts the initiatives of the two states in terms of the processes of metering and the impacts of this on groundwater use and users (including water buyers). It finds that both states have adopted vastly different attitudes to metering.

West Bengal, by adopting a hi-tech approach has successfully overcome some of the traditional problems of metering, such as meter tampering, collusion between the meter readers and the villagers and lack of manpower on the part of the electricity utilities. However, the state of Uttarakhand has done none of this and has deployed traditional ways of metering and billing. Given their lack of manpower and other logistical difficulties, it is fairly certain that metering efforts will fail in the state. This is quite unfortunate since metering (at existing rates) would have benefitted the tubewell owners without creating any negative effects on the water buyers, who, anyway, are few in number. In West Bengal, however, metering has benefitted a small section of wealthier pump owners at a cost to the majority of small and marginal farmers who have to buy water. The incentive structure inherent in the earlier flat tariff system, which encouraged pump owners to proactively sell water, has been lost. The main finding of this paper is somewhat of a paradox: it shows that where metering could have generated a win–win situation (as in Uttarakhand), the government has adopted a very ad hoc and ill planned approach to metering. However, in West Bengal, where the majority of the groundwater users (water buyers in this case) would be harmed, the government has taken a well-thought out approach.

In view of this, our recommendations are as follows:

- The GoU should learn from the GoWB example and introduce tamper-proof and remotely sensed meters to overcome the problems associated with meter reading and billing. This will of course necessitate additional funds.
- In West Bengal, to safeguard the interest of the water buying farmers, the government should ease the process of electrification of tubewells and provide a one-time capital subsidy for constructing tubewells, especially for the small and marginal farmers. This will lead to an increase in the number of electric tubewells and enhance competition in the water markets through which water prices may come down in the future.
- Village level governments (panchayats) can play an important role in West Bengal by regulating the price at which water is sold to the buyers.

The Jyotirgram Scheme in Gujarat has pioneered real-time co-management of electricity and groundwater irrigation. It has unshackled domestic and non-farm rural electricity supplies from the clutches of an invidious political economy of farm power supply. Its highly beneficial and liberating impacts on rural women, school children, village institutions and the quality of rural life are all too evident. Its impact on spurring the non-farm rural economy is incipient, but all the indicators suggest that this will be significant and deepen over time. But above all else, the Jyotirgram Scheme has created a switch-on/off groundwater economy that is amenable to vigorous regulation at different levels. It can be used to reduce groundwater withdrawal in resource-stressed areas and to stimulate it in water-abundant or water-logged areas; it can be used to stimulate conjunctive use of ground and surface water; and it can be used to reward "feeder communities" that invest in groundwater recharge and penalise villages that overdraw groundwater.

Elsewhere in India and the rest of the world, groundwater management has experimented with diverse sets of resource governance regimes – using water laws, tradable groundwater rights, economic incentives and disincentives – to achieve improved groundwater demand management for productivity, equity and sustainability. These regimes have proved ineffective, costly and time-consuming. In comparison, Gujarat under JGS has shown that the effective rationing of the power supply can indeed act as a powerful tool for groundwater demand management. And in so far as metering over 600,000 electric tubewells scattered over a large area of countryside may entail very substantial transaction costs which JGS saves, it may well be the "best" and not a second-best solution to the farm power imbroglio that all western and southern Indian states are confronted with.

However, as it is managed now, JGS has a big downside: its brunt is borne largely by marginal farmers, and the landless because of the shrinking of water markets and of irrigated agriculture itself. There is no way of eliminating this completely except by increasing the hours of power supply and introducing a subsidy, both of which will defeat the purpose of the entire initiative. JGS can significantly reduce the misery of the agrarian poor by replacing the present rationing schedule by intelligent, demand-adjusted power rationing. The equity impact on the poor can be further enhanced by providing the daily power supply in two or more instalments to respond to the behaviour of wells in hard-rock areas. The equity impact can also be enhanced a great deal by charging a common flat tariff to all tubewells regardless of whether they are metered or not. This would turn a large number of metered tariff paying tubewell owners from reticent sellers to aggressive water marketers to their poor neighbours.

Acknowledgements

The authors gratefully acknowledge the financial support for this study from the Challenge Program for Water and Food (CPWF) project on "Strategic Analyses of India's National River Linking Project" and "Groundwater Governance in Asia" and the "Indus-Ganges Basin Focal Project". This is a synthesis paper based on Mukherji et al. (2009) in Energy Policy; Shah and Verma (2008), published in the Economic and Political Weekly; and an unpublished paper by Umar et al. (2008). ■

References

- Briscoe, J. (2005) *India's water economy: Bracing for a turbulent future. India Water Review.* Washington, DC, USA: World Bank.
- CGWB (2006) *Dynamic groundwater resources of India* (as on March 2004). Faridabad, India: Central Groundwater Board, Ministry of Water Resources, Government of India.
- GoI (Government of India) (2003) *All India report on minor irrigation census, 2001-02.* New Delhi, India: Ministry of Agriculture, Government of India.
- Gulati, A., Shah, T., Shreedhar, G. (2009) *Agriculture performance in Gujarat since 2000: Can it be a divadandi (lighthouse) for other states?* New Dehli, India. Monograph. International Water Management Institute (IWMI) and International Food Policy Research Institute (IFPRI).
- ICICI (2000) *Financial restructuring of Uttar Pradesh State Electricity Board.* Revised final report, submitted by ICICI Bank: Website publication http://www.uerc.in/ordersPetitions/Petitions/2010-11/ARR%20&%20Tariff%20Petitions%20filed%20by%20UPCL%20for%202010-11/Volume-II.pdf.
- Mukherjee, S. (2008) Decomposition Analysis of Electricity Consumption: A State-wise Assessment. *Economic and Political Weekly* 43(3): 57–64.
- Mukherji, A. (2006) Political Ecology of Groundwater: The Contrasting Case of Water Abundant West Bengal and Water Scarce Gujarat, India. *Hydrogeology Journal* 14(3): 392–406.
- Mukherji, A. (2007) The Energy-irrigation Nexus and its Implications for Groundwater Markets in Eastern Indo-Gangetic Basin: Evidence from West Bengal, India. *Energy Policy* 35(12): 6413–6430.
- Mukherji, A. (2008) Spatio-temporal Analysis of Markets for Groundwater Irrigation Services in India, 1976-77 to 1997–98. *Hydrogeology Journal* 16(6): 1077-1087.
- Mukherji, A., Das, B., Majumdar, N., Nayak, N.C., Sethi, R.R., Sharma, B.R. and Banerjee, P.S. (2009) Metering of Agricultural Power Supply in West Bengal: Who Gains and Who Loses? *Energy Policy* 37(12): 5530–5539.
- Narendranath, G., Shankari, U. and Reddy, K.R. (2005) To Free or Not to Free Power: Understanding the Context of Free Power to Agriculture. *Economic and Political Weekly* 40(53): 5561–5570.
- National Sample Survey Office (NSSO) (1999) *54th round: Cultivation practices in India, January 1998-June 1998.* New Delhi, India: Department of Statistics and Programme Implementation, Government of India, August 1999.
- Planning Commission (2002) *Annual Report (2001-02) on the working of state electricity boards and electricity departments.* New Dehli, India. Planning Commission (Power and Energy Division), Government of India, May 2002.
- Shah, T. (1993) *Water Markets and Irrigation Development: Political Economy and Practical Policy.* Bombay, India: Oxford University Press.
- Shah, T. and Verma, S. (2008) Co-management of Electricity and Groundwater: An Assessment of Gujarat's *Jyotirgram* Scheme. *Economic and Political Weekly* 43(7): 59–66.
- Tongia, R. (2004) *What IT can and cannot do for the power sector and distribution in India: Link to reforms, incentives and management.* Working Paper No. 19. California, USA: Program on Energy and Sustainable Development, Stanford University.
- Umar, A., Singh, A.K., Srivastava, S. and Mukherji, A. (2008) *Metering of agricultural tubewells under the accelerated power reform development program in Uttarakhand: An assessment.* Draft report submitted to IWMI, 28 pp.
- West Bengal State Electricity Board (WBSEB) (2006) *West Bengal State Electricity Board Yearbook.* Kolkata, India: WBSEB.
- WIDD (Water Investigation and Development Department) (2004) *Groundwater resources of West Bengal: An estimation by GEC-1997 methodology.* Kolkata, India: Water Investigation and Development Department, Government of West Bengal.

Photo: Digital Archive Japan, SIWI

Biographies

Catarina de Albuquerque

Ms. Catarina de Albuquerque, a Portuguese lawyer, was appointed as the Independent Expert on the issue of human rights obligations related to access to safe drinking water and sanitation in September 2008. She is currently working as a senior legal adviser in the area of human rights at the Office for Documentation and Comparative Law (an independent institution under the Portuguese Prosecutor General's Office). She has represented her country on numerous occasions in international negotiations and conferences at the UN, Council of Europe and European Union (especially concerning economic, social and cultural rights and the rights of the child). She is also an Invited Professor at the Universities of Coimbra, Braga, ISCTE (Higher Institute of Business and Labour Sciences) and Autonomous University of Lisbon (Portugal). Between 2004 and 2008, she was the Chairperson-Rapporteur of the Working Group on an Optional Protocol to the International Covenant on Economic, Social and Cultural Rights.

Arthur G Baggett, Jr

Arthur G Baggett, Jr., currently serves as a member of the California Water Resources Control Board. He was first appointed in 1999 by former Governor Gray Davis and continues to serve as Governor Arnold Schwarzenegger's appointee. The Board is responsible for protecting, preserving, and restoring the beneficial uses of the water of California and providing for their equitable use. He also teaches environmental and water law for the San Joaquin College of Law.

Mr. Baggett is past president of the Association of State and Interstate Water Pollution Control Administrators, a member of Dividing the Waters (a project of judges in the western United States that focus on adjudication of water rights), and has served on numerous United States Environmental Protection Agency advisory committees. As a scientist and teacher, he has guided for the Yosemite Mountaineering School, been on the faculty of Yosemite Institute and the University of California's Sierra Institute, and served as adjunct faculty for Fresno State University's Department of Chemistry.

In his spare time, Art enjoys part time status as a musician in his son's bluegrass and country band, Pine Crow, and skis and hikes the backcountry of the Sierra Nevada Mountains with family and friends.

David J.H. Blake

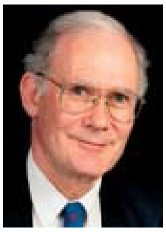
David Blake has worked for over a dozen years in Northeast Thailand and Lao PDR in a number of positions within the field of rural development, sustainable agriculture, water resources management and smallholder aquaculture extension. Between 2004-07 he worked as an IUCN technical advisor to the Mekong Wetlands Biodiversity Conservation and Sustainable Use Programme in the lower Nam Songkhram River Basin wetlands, the Thailand component's "demonstration site". In 2008 he commenced a PhD researching aspects of the political ecology of NE Thailand's irrigation development at the School of International Development, University of East Anglia, United Kingdom.

Robert Bos

Since April 2009, Robert Bos is the Coordinator of Water, Sanitation, Hygiene and Health at the World Health Organization in Geneva. A public health biologist by training, he has held different positions in the World Health Organization for over 25 years. He started his career 1981 as a Costa Rica-based WHO Associate Professional Officer, where he assisted the Government in the establishment of an immunology unit. Since 1983 he held various positions at WHO headquarters, first in the Division of Vector Biology and Control, later in the Environmental Health Division, which evolved into the current Department of Public Health and Environment.

In his present position of Coordinator he is working towards the development of strategies for the different WSH programme components, with a view towards the development of a comprehensive WHO water, sanitation and health strategy for the period 2012-2020, with an enhanced and diversified resource base. His areas of expertise include environmental management for vector control (in the context of water resources development), health impact assessment, safe use of wastewater in agriculture and the economics of water interventions for improved health.

David Bradley



David Bradley is an epidemiologist, physician and zoologist. He lived and worked in East Africa for a decade, also in many parts of Asia and Africa. After work on the public health importance of schistosomiasis he studied domestic water supply and health in East Africa, Mycobacterium ulcerans, malaria, and concepts in tropical public health. He devised the now generally adopted functional classification of water-related diseases. From 1974 he was Professor of Tropical Hygiene at the London School of Hygiene & Tropical Medicine, directing the Ross Institute, a highly interdisciplinary department that particularly developed thinking on water, sanitation and malaria control. Since 'retirement', based in the Oxford Zoology Department, he works with Ugandan colleagues on settling nomadic pastoralists, and the resulting environmental, water and health changes and has returned to his fascination with the role of water bodies in disease and landscape epidemiology.

Gunilla Carlsson

Gunilla Carlsson was a Member of the European Parliament for the Moderate Party between 1995 and 2002. She was elected to the Swedish Parliament in 2002 and has been First Vice Chair of the Swedish Moderate Party since 2003. Between 2004 and 2006 she was Vice Chair of the European People's Party (EPP). During the same period she was Deputy Chair of the Swedish Parliament's Committee for Foreign Affairs and she has also been a member of the Committee on EU Affairs. She has been Minister for International Development Cooperation since September 2006.

Chua Thia-Eng

Former Regional Programme Dictor of Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) and currently Chair of PEMSEA's Governing Council. He is also serving concurrently as a member of Research Council and Visiting Fellow of the Ocean Policy Research Foundation of Japan (2008-), Chair Professor at the Coastal and Ocean Management Institute of Xiamen University (China) (2008-).

He had served in various capacities with UN and international organisations including FAO, IMO, GEF/ UNDP and ICLARM. He also served as associate editor of the Journal of Coast and Ocean until 2009. He published more than 220 scientific papers, articles, reports and books.

Ines Dombrowsky

Ines Dombrowsky is a senior scientist at the Helmholtz Centre for Environmental Research – UFZ in Leipzig, Germany. She holds a PhD in Economics and an MSc in Environmental Engineering. Her research focuses water governance issues, with particular emphasis on transboundary water management and the institutionalisation of Integrated Water Resources Management (IWRM). Prior to joining the UFZ, she worked on transboundary water issues in the Nile and Jordan River Basins with World Bank (1997–2001) and German Technical Cooperation (GTZ, 1995–1997) assignments respectively.

Jan Eliasson

Ambassador Jan Eliasson was 2007–2008 Special Envoy of the UN Secretary-General for Darfur. Prior to this, Jan Eliasson was President of the 60th session of the UN General Assembly. He was Sweden's Ambassador to the US from September 2000 until July 2005. On 27 March 2006 Mr. Eliasson was appointed Foreign Minister of Sweden and served in this capacity until the elections in the fall of 2006.

Ambassador Eliasson served from 1994 to 2000 as State Secretary for Foreign Affairs, a key position in formulating and implementing Swedish foreign policy. He was Sweden's Ambassador to the UN in New York 1988-92, and he also served as the Secretary-General's Personal Representative for Iran/Iraq.

Mr. Eliasson was the first UN Under-Secretary-General for Humanitarian Affairs and was involved in different operations in Africa and the Balkans. He took initiatives on landmines, conflict prevention and humanitarian action.

1980–1986, Mr. Eliasson was part of the UN mediation missions in the war between Iran and Iraq, headed by former Prime Minister Olof Palme. In 1993–94 Mr. Eliasson served as mediator in the Nagorno Karabakh conflict for the Organization for Security and Co-operation in Europe (OSCE). He is Visiting Professor at Uppsala University in Sweden, lecturing on mediation, conflict resolution and UN reform.

Ambassador Eliasson has had diplomatic postings in New York (twice) Paris, Bonn, Washington (twice) and Harare, where he opened the first Swedish Embassy in 1980.

Jan Eliasson is Chairman of WaterAid/Sweden and the Anna Lindh Memorial Fund and serves as Adviser to the International Committee of the Red Cross (ICRC)

Junguo Liu

Dr. Junguo Liu is a professor of hydrology and water resources at Beijing Forestry University (China) and a research scholar at the International Institutes for Applied Systems Analysis (IIASA, Austria). His main research interests include hydrology and water resources, water-food relations, ecosystem services and management, and the impacts of climate change on water, food and ecosystems. Prof. Liu is author of 20 peer-reviewed papers. He published two correspondences in Nature and one letter in Science, and one original article in PNAS. He also serves as an editor of the international journal Hydrology and Earth System Sciences (HESS). He is a recipient of a string of prizes including a prestigious Outstanding Young Scientists Awards of European Geosciences Union.

David S. McCauley

David McCauley is Principal Climate Change Specialist in ADB's Climate Change Program Coordination Unit, attached to its Regional and Sustainable Development Department. He serves as lead technical specialist on climate change issues within ADB, involved with all aspects of programme development, oversight and outreach. Dr. McCauley is an international environmental specialist with more than 25 years of experience working across Asia and the Pacific, Africa, Latin America and Eastern Europe. His work has centered on strengthening environmental policies and institutions, water management, forest conservation, air quality management and arresting natural resources degradation. Prior to his current position he served as ADB's Senior Environmental Economist, its Principal Environment Specialist and as focal point for its partnership with the Global Environment Facility. He joined ADB in 2004, and has previously worked for the Ford Foundation, Harvard Institute for International Development, the East-West Center in Hawaii, the US Agency for International Development and as an advisor to many international development agencies. He holds a PhD in resource economics from the University of Hawaii/East-West Center, with undergraduate training in environmental sciences.

Aditi Mukherji

Dr. Aditi Mukherji is a Researcher (Social Scientist) at the International Water Management Institute (IWMI), Colombo. Aditi received her PhD degree from the University of Cambridge, United Kingdom, in 2007. She has edited two books and written more than 30 academic papers on social and economic aspects of groundwater irrigation in South Asia. In 2006, she co-edited a special issue of the Hydrogeology Journal dedicated to social and economic aspects of groundwater governance. In 2008, she was awarded the coveted Global Development Network Award for best paper under the category of Natural Resources Management. In 2009, she was nominated for CGIAR's Young Promising Scientist of the Year award. She specialises in institutions and policies of water resources management and has wide experience in the field of groundwater management, energy-irrigation nexus and management of public irrigation systems. In addition, she is interested in applying principles of political ecology to understand processes of policy making in the fields of agriculture, rural development and natural resources.

Mohan Munasinghe

Prof. Mohan Munasinghe shared the 2007 Nobel Prize for Peace (as Vice Chair-AR4). Currently, he is Chairman, Munasinghe Inst. of Development (MIND), Colombo; Director-General, Sustainable Consumption Institute (SCI) and Institute Professor at the University of Manchester, UK; and Honorary Senior Advisor to the Sri Lanka Govt. He has earned post-graduate degrees in engineering, physics and development economics from Cambridge University (UK), Massachusetts Institute of Technology (USA), and McGill University and Concordia University (Canada). Prof. Munasinghe has also received several honorary doctorates (honoris causa).

He has worked as Senior Energy Advisor to the President of Sri Lanka, Advisor to the United States Presidents Council on Environmental Quality, and Senior Advisor/Manager, World Bank. He has been Visiting Professor at leading universities worldwide, and won many international prizes and medals for his research. Prof. Munasinghe has authored 92 books and over three hundred technical papers on many topics. He is Fellow of several internationally recognised Academies of Science, and serves on the editorial boards of a dozen academic journals.

Stuart Orr

With WWF since 2006, Stuart engages the private sector on water-related issues from water footprint measures to public policy engagement and has published numerous papers on water accounting, agricultural policy and water-related risk. Stuart is part of the World Economic Forums' global agenda council on water security and is co-drafting the 'Responsible Business Engagement with Water Policy' guide in support of the UN CEO Water Mandate. Stuart has researched agricultural systems in West Africa and worked for many years in Asia and the US. He holds an MSc from the School of International Development at the University of East Anglia and is based at WWF-International in Switzerland as a Manager in the Freshwater Team.

Bindeshwar Pathak

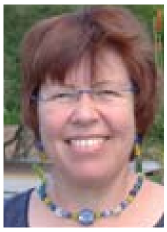
Dr. Bindeshwar Pathak, founder, Sulabh Sanitation and Social Reform Movement, is a great humanist and social reformer of contemporary world. He has developed technologies for hygienic disposal of human waste and shown how open defecation and manual scavenging could be stopped. He has changed the lives of 'human scavengers' in India, earlier treated as 'untouchables' and improved the living conditions of millions. He loves the downtrodden, has restored their human rights and dignity and brought them in the mainstream of society. His work has had great impact on environmental sanitation, public health, saving of water and production of bio-fertiliser.

Tushaar Shah

Tushaar Shah, an economist and public policy specialist, is a former director of the Institute of Rural Management at Anand in India. Over the past 30 years, Shah's main research interests have been in water institutions and policies in South Asia, a subject on which he has published extensively. His notable contributions have been in comparative analyses of groundwater governance in South Asia, China and Mexico. More recently, his interests have lay in comparative analyses of water institutions and policies across Asia and between South Asia and Sub-Saharan Africa. Shah was honored with the Outstanding Scientist award of the Consultative Group of International Agricultural Research (CGIAR) in 2002. His most recent publication is Taming the Anarchy: Groundwater Governance in South Asia published by the Resources for the Future Press, Washington.

Shah is a Senior Fellow of the Colombo-based International Water Management Institute, and works out of Anand in western India.

Barbara van Koppen



Barbara van Koppen is Principal Researcher Poverty, Gender, and Water with the International Water Management Institute. Her research, policy dialogue and capacity building focuses on pro-poor and gender equitable development of water for multiple uses and plural institutional and legal frameworks in rural Africa and South Asia. She has authored and edited four books and over 80 international publications. Before joining the International Water Management Institute, she was lecturer Gender and Irrigation at Wageningen University and Research Center, Netherlands. She also worked in Burkina Faso as Technical Assistant of Netherlands Development Cooperation.

Shilp Verma

Shilp Verma completed his graduation with honors in Economics from the University of Delhi (1998) and a post-graduate programme in Rural Management at the Institute of Rural Management, Anand (2001). Between 2001 and 2005, Shilp worked with the International Water Management Institute (IWMI) as part of the IWMI-Tata Water Policy Program in Gujarat, India. In 2005, Shilp was awarded an IWMI fellowship for M.Sc in Water Resources Management at UNESCO-IHE Institute for Water Education, Delft, the Netherlands (2005–2007). Since 2007, Shilp has been with the Department of Management and Institutions at UNESCO-IHE pursing his doctoral research in Water Resources Management. Shilp has published several papers in national and international journals and has co-authored two books.

Alain Vidal

Alain Vidal's expertise in water conservation in agriculture developed in him a lifetime's interest in the global water, food and poverty crises. In 2004, it led him to discover the work CGIAR Challenge Program on Water and Food. The following year he began part-time as a member of the programme's management team, before being appointed as the CPWF Director in May, 2009. Alain began his professional activity in Morocco in 1986, which ignited a 10-year research career with the French Environmental Research Institute, Cemagref. He worked with FAO on innovations in scientific research uptake and technology exchange, before returning to Cemagref from 2003 to 2009 as its Director of European and International Affairs. He has authored or co-authored more than forty refereed papers, and edited 5 books. Alain received his PhD in water science from the University of Montpellier in 1989.

On the Water Front

World Water Week in Stockholm

Building Capacity – Promoting Partnership – Reviewing Implementation

The World Water Week in Stockholm is the leading annual global meeting place for capacity-building, partnership-building and follow-up on the implementation of international processes and programmes in water and development. It includes topical plenary sessions and panel debates, scientific workshops, independently organised seminars and side events, exhibitions and festive prize ceremonies honouring excellence in the water field. Stockholm is the meeting place for experts from businesses, governments, the water management and science sectors, inter-governmental organisations, non-governmental organisations, research and training institutions and United Nations agencies. The World Water Week is organised by the Stockholm International Water Institute.

www.worldwaterweek.org • www.siwi.org

SIWI

Stockholm International Water Institute, SIWI
Drottninggatan 33, SE-111 51 Stockholm, Sweden
Phone +46 8 522 139 60 • Fax +46 8 522 139 61 • siwi@siwi.org • www.siwi.org