Volume 2

ON THE WATER FRONT

Selections from the 2010 World Water Week in Stockholm

Edited by **Jan Lundqvist**

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Editor: Jan Lundqvist

ISBN: 978-91-975872-8-0

How to cite: Lundqvist, J. (ed.) 2011. On the Water Front: Selections from the 2010 World Water Week in Stockholm. Stockholm International Water Institute (SIWI), Stockholm.

Photo: SIWI

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 2010, the theme was "Responding to Global Changes: The Water Quality Challenge – Prevention, Wise Use and Abatement". 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.

This edition 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, September 5-11, 2010. The full programme for World Water Week and documents from the deliberations in 2010 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 (SPC) 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, Elin Weyler, publication manager and Elin Ingblom, design manager, to whom we would like offer our special thanks.

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Photo: SIWI

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THE INTRICATE CONNECTION OF CHOLERA, CLIMATE AND PUBLIC HEALTH

Key words: public health, cholera, climate, infectious disease, water supply and sanitation, microbiology, ecology, Stockholm Water Prize.

The words of Hippocrates set the stage: "Whoever wishes to pursue the science of medicine must first investigate the seasons of the year and what occurs in them."

Less than a third of the world population has access to safe drinking water. In countries such as Ethiopia, Cambodia and Zaire, the death rates for children under the age of five can be as high as 200 per 1000. In comparison, in countries like Sweden or the United States, where almost all have access to safe drinking water, the death rates of children from water-borne disease are significantly lower. One of the issues being discussed and documented during World Water Week 2011 is the relationship between safe drinking water and prevention of water borne diseases.

Cholera is a water-borne disease that can be traced back to historical times and has been described in early Sanskrit writings. The cartoon (Fig. 1) published in the New York Times in the late 1850s portrays 'Science' asleep as the spectre of 'Cholera' sweeps in from harbours and bays. The cartoon reflects the prevailing view that the disease arose in and spread from foreign lands. Unfortunately, the belief that cholera is introduced from elsewhere persists today, in spite of massive evidence that Vibrio cholerae, the causative agent of cholera, is a natural inhabitant of rivers, ponds, estuaries and coastal waters around the world.

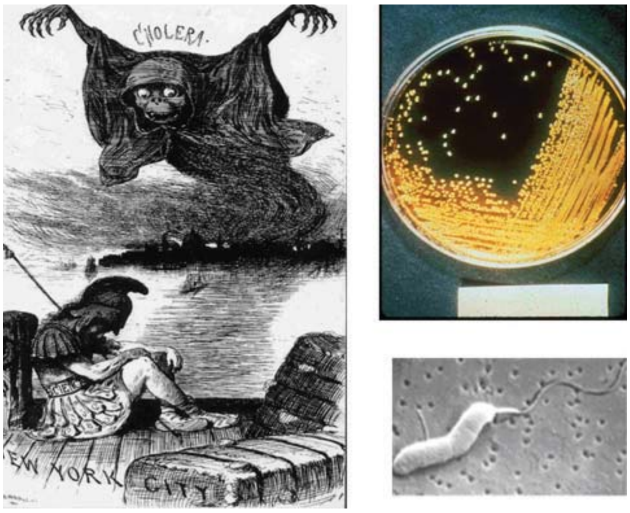

Figure 1. Vibrio cholerae as seen in the laboratory under the microscope (right) and cholera as depicted in a cartoon in a New York newspaper in the late 1800s (left)

V. cholerae, when grown in the laboratory, appears as bright yellow colonies on selective agar. Under the electron microscope, the bacterium is rod-shaped, with a single flagellum that confers motility (Fig. 1).

Historically, the defining of cholera epidemiology started with Sir John Snow, who published reports of his studies of the cholera epidemics of 1849 and 1854 in London. Snow traced the origin of cholera to water drawn from the Broad Street well. The map drawn by Snow showed the streets and houses where deaths from cholera had occurred, and provided the evidence for his conclusion that water pumped from the Broad Street well was the source of the disease. Yet, twenty years passed before Snow's correlation was accepted, namely that contaminated water was the source of the London cholera epidemics.

Cholera epidemics are more than unfortunate historical bookmarks. Data on the incidence of cholera worldwide compiled by the World Health Organization (WHO) show that the disease affects millions today. Writ large are the tragedies of Zimbabwe and Haiti. Cholera cases reported in Zimbabwe in 2007 numbered 65, and there were five deaths. One year later, a breakdown of the water purification and distribution systems resulted in a massive epidemic of more than 110,000 cases and around 4000 deaths. The epidemic in Zimbabwe continues today. The cholera outbreak in Haiti in 2010, in the aftermath of an earthquake, hurricane and flooding, was even more tragic and created untold misery for refugees.

Discoveries made 20 years ago at the University of Maryland showed that V. cholerae is naturally present in the environment and, under conditions adverse to growth, enters into a dormant state. For example, at temperatures of less than 15°C, V. cholerae cannot be cultured under routine laboratory conditions and can only be detected by molecular methods, such as staining with a fluorescent antibody or by genetic analysis. Under such conditions, the bacterium can remain viable for months and, even though not culturable, it is transmissible and can cause disease, as has been shown in both animal and human volunteer studies. With a fluorescent antibody or gene probes, the cholera bacterium can be detected in water samples when it cannot be detected by culturing. The accepted dogma had been that cholera could only be transferred person-to-person. That assumption was proved wrong when, although not culturable by classic methods, by using the tools of modern microbiology the bacterium, was found to be present in the aquatic environment and potentially pathogenic.

Furthermore, studies of V. cholerae in Chesapeake Bay and other estuaries around the world showed that this microorganism is a component of the natural flora of zooplankton, predominantly copepods, in estuaries, bays and coastal waters. A single copepod can carry 10,000 or more cholera bacteria on its surfaces and in its gut. Thus, when the number of zooplankton increases during spring and autumn 'blooms', an infectious dose (around one million cells per millilitre) can be ingested by those who drink untreated water, causing severe diarrhoea and vomiting (symptoms of cholera).

In 1991-1992, a massive epidemic of cholera occurred in Latin America, causing many deaths. This was years after the disease had apparently been absent from South American countries. Since the 'home' of cholera historically has been considered to be South Asia, the Latin American epidemic caught public health authorities by surprise, mainly because in the USA and Western Europe cholera has been controlled since the early twentieth century by providing safe drinking water. The Latin American cholera epidemic has since been linked to climate, notably the El Niño of 1991-1992.

The relationship between sea surface temperature and sea surface (tidal) height and cholera has been explored extensively, based on the previously demonstrated relationship between cholera and zooplankton. Phytoplankton blooms occur when there is more sunlight and water temperatures are warmer. Zooplankton feed on phytoplankton and, with more zooplankton, the Vibrio populations increase concomitantly. A mathematical model using physical-chemical parameters, which included salinity, nutrient concentrations, pH, water temperature, presence of plankton etc., was developed that permitted the correlation between climate and disease (cholera) to be determined. Poor sanitation and lack of safe water, of course, exacerbate the spread of the disease. The environmental parameters associated with cholera can be monitored using satellite sensors, namely sea surface temperature, sea surface height and chlorophyll, and provide the data for the model. The model has provided good estimates of the number of cholera cases in Bangladesh (Fig. 2).

A more sophisticated model has subsequently been developed, using the same environmental parameters, for cholera epidemics in Calcutta, India, as well as Matlab, Bangladesh. This powerful model established a significant relationship between cholera, levels of chlorophyll and rainfall.

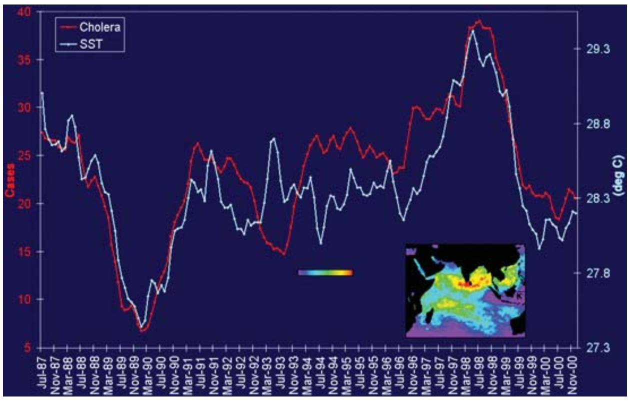

Figure 2. Sea surface temperature and incidence of cholera in the Bay of Bengal, July 1987-November 2000. Source: de Magny et al. (2008

In Calcutta, for example, a 1.0 mg ml-1 increase in chlorophyll (a surrogate measurement for the phytoplankton population) results in a 33 per cent increase in the number of cholera cases, and a 1 mm per day increase in rainfall results in a 6-7 per cent increase in the number of cholera cases. Similar results were obtained for Matlab, Bangladesh, and current studies include both Madras and Delhi in India. Studies carried out in several African countries have led to similar findings. Thus, the link between ecology and the molecular biology of the cholera bacterium elucidates the epidemiological patterns of the disease in these countries.

Based on these findings, and since zoo plankton carry cholera bacteria, the hypothesis was developed that a simple filter properly used by villagers in Bangladesh when collecting their drinking water from untreated sources, such as ponds and rivers, could reduce the incidence of cholera. Several materials were tested and sari cloth, folded 4-8 times, proved an effective filter. In fact, old sari cloth of the least expensive kind provides a 20 micron mesh filter and, in tests carried out in the laboratory, removed nearly 100 per cent of zooplankton and particulate matter from the pond and river water used by the villagers of Matlab for drinking.

A field study subsequently carried out in Matlab, covering 150,000 inhabitants in 50 villages over a three-year period, provided significant results. Bangladeshi village women were trained to fold sari cloth to make filters, use the filters to collect water, and to rinse and air dry the filters in sunlight after each use. These women proved excellent 'extension agents' for the study. They secured very good cooperation from the village women when they visited the villages every week to reinforce the practice of filtration and stress the reason for filtration. They explained that the removal of particulate matter, notably plankton, was beneficial for the health of their families since the cholera bacteria would also be removed. The incidence of cholera in families practicing simple filtration was reduced by approximately 50 per cent.

A follow-up study was conducted five years after the initial study ended to determine whether or not filtration was sustainable, i.e., continued, and whether or not there was a reduction in the incidence of cholera. Simple filtration proved both sustainable and effective. Interestingly, 'control' villagers, those who had not been instructed in the filtration method, had learned about the benefits of filtration and they too were filtering their water. Furthermore, a 'herd effect' was noted; those who did not filter, if surrounded by households that did filter, also showed a reduced incidence of cholera.

In 2000, the first genome of Vibrio cholerae was sequenced, and since then, the DNA of many additional strains have been sequenced. The cholera bacteria whose DNA has been sequenced include historical strains, such as V. cholerae, isolated in 1910, and geographically diverse isolates from Africa, India, the Sudan etc. What has been discovered is that the genomic sequence of these strains shows detectable variation. That is, there is a significant genetic exchange among V. cholerae, i.e., sets of genes found in V. cholerae transfer from strain-to-strain within V. cholerae populations. The evolution of V. cholerae was thus tracked by following gains and losses of sets of genes coding for pathogenic properties and serotype. Our studies have conclusively shown that genes coding for serotype are laterally transferred. The cholera bacterium, in effect, undergoes genetic 'drift and shift', and is a moving target in public health.

In summary, studies of cholera in Bangladesh, India, Africa and in Chesapeake Bay in the United States have provided a model for understanding the emergence of this disease from the natural environment globally.

It is appropriate to close with the words of John Muir, the founder of the Sierra Club: "When one tugs at a single thing in nature, he finds it hitched to the rest of the universe".

Further reading

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REGULATING FARM NON-POINT SOURCE POLLUTION: THE INEVITABILITY OF REGULATORY CAPTURE AND CONFLICT OF INTEREST?

Conventional rules for reducing non-compliance and corruption between firms and water quality regulators offer interesting, but limited, insights when the firms being regulated are farmers. Simply put, farmers and non-point source agricultural water pollution are fundamentally different from industrial firms and point sources of pollution, and thus need different types of regulations and different policy-making approaches to deal with the challenges of non-compliance. Several instances of regulatory capture and conflict of interest were observed during the implementation of nutrient management laws in three states in the United States which resulted in expected negative results, as well as some surprising positive outcomes.

Key words: agriculture, nutrient pollution, regulation, capture, water

Introduction

Water quality is one of the most significant environmental challenges of the 21st century. Nearly half the people in developing countries suffer health problems related to a lack of clean water and proper sanitation (UNDP, 2006). Water pollution stems from many pollutants and sources including, but not limited to, toxic chemicals from industrial activities, solid waste from urban areas with inadequate garbage collection and nutrient pollution from both point sources, such as sewage treatment plants, and from non-point sources, such as the diffuse runoff and leaching of fertilisers and animal manures from farm fields. This article will focus on the successes and shortcomings of policy approaches to reducing nutrient pollution from non-point source agriculture in the United States.

Water quality in the US is poor. Between 48 per cent and 61 per cent of assessed rivers, streams, lakes, reservoirs and estuaries are rated as threatened or impaired for their designated uses (USEPA, 2006). Agriculture is one of the largest sources of US nutrient pollution (excess nitrogen and phosphorus), causing harmful eutrophic or hypoxic conditions, known commonly as "dead zones" – areas where there is limited or insufficient oxygen to sustain life in marine or fresh waters. In one of the world's largest fisheries, Chesapeake Bay, agriculture is estimated to be responsible for 38 per cent, 45 per cent and 60 per cent of the nitrogen, phosphorus and sediment pollution respectively (Fig. 1), causing unhealthy eutrophic conditions (USEPA, 2009). In the Mississippi River Basin-Gulf of Mexico, agriculture is attributed as the source of 71 per cent and 80 per cent of the nitrogen and phosphorus pollution respectively (Fig. 2), causing one of the world's largest dead zones (Alexander et al., 2008).

At the federal and state levels of policy, the US has largely chosen to address farm nutrient pollution through voluntary approaches. These include providing technical and financial assistance to farmers to install best management practices (BMPs) that reduce the unintended losses of nutrients and soil from farms. Only a few of the largest confined animal feeding operations (CAFOs) are regulated through federal rules and a few states impose their own livestock rules, as well as the federal requirements. Very few states have opted to regulate water pollution stemming from crop fields. Despite the near USD5 billion provided, on average, every year from federal conservation programs (USDA, 2009), only about 13 per cent of all US farmers have received these payments (Claassen and Morehart, 2006). Thus, taxpayer resources have been insufficient to pay sufficient numbers of farmers to address the unintended environmental harms caused by farming. Thus, some states have begun to consider raising the environmental performance of farms by requiring some BMPs (Perez, 2009; ELPC and MRC, 2010).

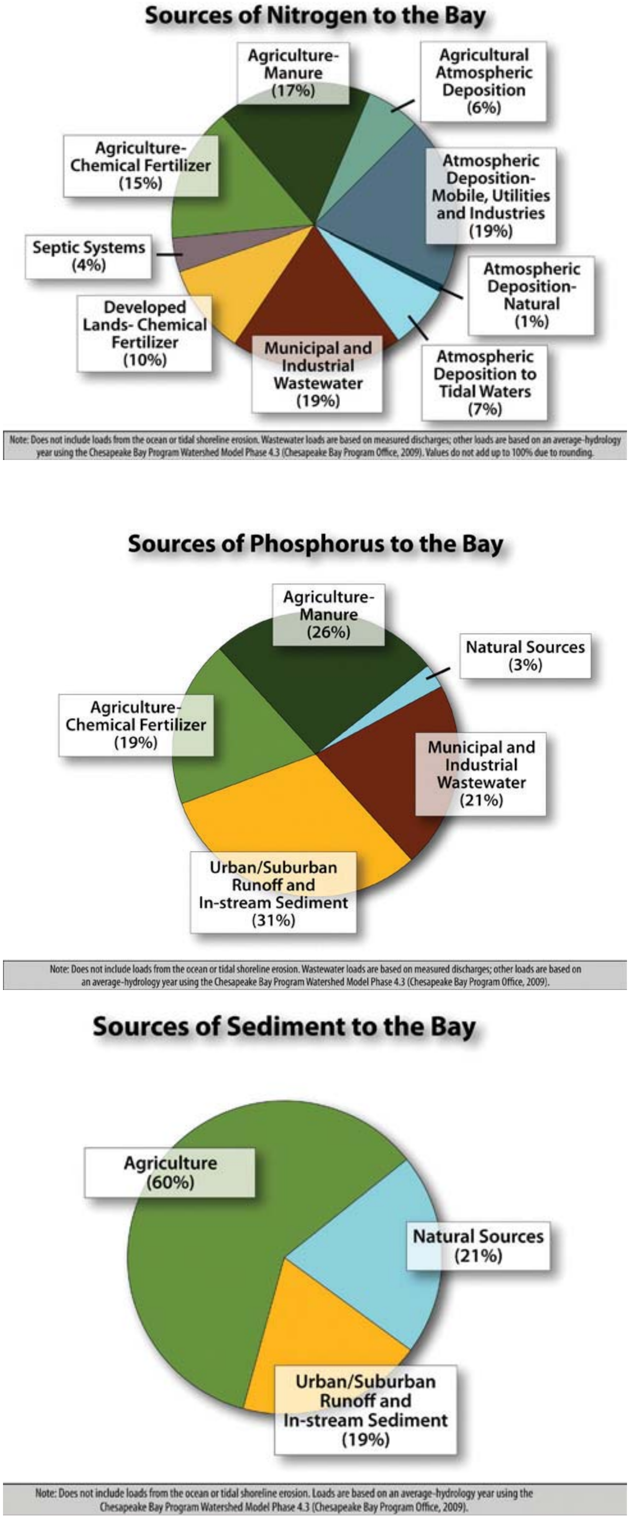
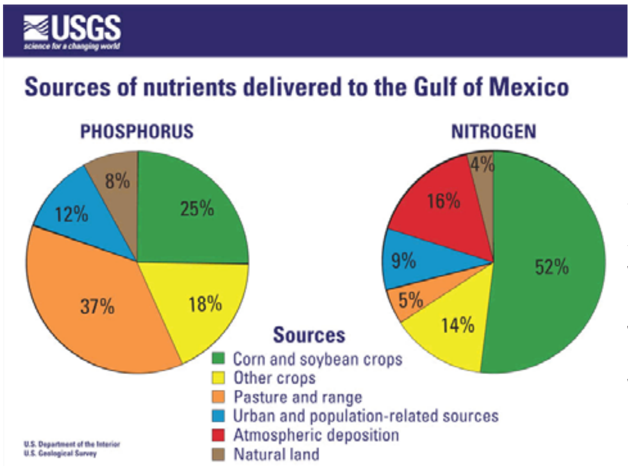


Figure 1. Agricultural land is a major source of nitrogen, phosphorus, and sediment pollution to the Chesapeake Bay.

Sources (from top to bottom): USEPA Chesapeake Bay Program (2009). Chesapeake Bay Health and Restoration Assessment: Factors Impacting Bay & Watershed Health. 08/28/09. Chesapeake Bay Program Phase 4.3 Watershed Model 2007 Simulation and the Airshed Model.



Source: Alexander et al. (2008)

Figure 2. Agriculture is the largest source of phosphorus and nitrogen nutrient pollution to the Gulf of Mexico causing hypoxia.

Source: Poultry Cooperative Research Centers (CRC).

Figure 3. Application of poultry manure as a fertilizer source to a crop field.

In 1997, a series of fish kills in Chesapeake Bay were associated with a toxic microorganism named *Pfiesteria piscicida*, which was linked to nutrient pollution from commercial fertiliser and animal manure runoff from crop fields. Specifically, policymakers raised concerns about the improper disposal of poultry manure on cropland and use of the manure as a commercial fertiliser substitute (Fig. 3). Three states on the Delmarva Peninsula – Delaware, Maryland, and Virginia – decided that voluntary approaches were no longer adequate and decided to require farmers to obtain and follow a nutrient management plan. Heretofore, each state's university extension service had been encouraging farmers, for decades, to voluntarily adopt such plans prescribing cost-effective nitrogen and phosphorus applications "to optimise crop yields while minimizing environmental losses".

Very little is known about how closely farmers are following their mandated nutrient management plans. In addition, little is known regarding whether the manner in which each state went about developing the regulations and enforcing the rules had an effect on how well farmers are complying with their plans. Thus, this author decided to study these three state laws as a case study for her dissertation published in 2010 (Perez, 2010). Interviews with 60 farmers and 60 policy stakeholders indicate that, overall, the laws did result in improved nutrient management behaviours in most of the farmers. Many farmers said that having a plan and being regulated helped them to reduce their fertiliser and manure application rates, lower the nitrogen and phosphorus content of the fertiliser mix they purchased, and stopped them from disposing manure on crop fields during the fallow winter season. However, other interviewed farmers reported poor adherence to their mandated nutrient management plans, protesting that "they would go out of business" if they "strictly followed their plans".

One surprising finding was the role that regulatory capture and conflict of interest played during the major policy stages (development, implementation and enforcement) in each state. Equally surprising was the finding that such relatively minor forms of corruption had some positive outcomes, as well as some conventional negative results. To be clear, this author did not find any instances of corruption in the form of bribes or other financial payoffs to government officials. Rather, there were examples of regulatory capture which is defined as occurring when private interests are favoured or otherwise served during the development and/or enforcement of regulations (Bardach and Kagan, 1982). As will be discussed, regulatory capture is one of the most common forms of corruption in the US. It is also a grey area in the normal workings of a democracy that involves interest groups pushing the government to achieve policies favourable to their private interests through lobbying, campaign contributions and 'revolving door' mechanisms. And even though regulatory capture involves the favouring of private interests, at the expense of the public interest – in this case, the environment – it is difficult to discern when things 'go too far'.

Purpose of the article

The purpose of this article is to explore if, and how well, regulating farmers to reduce non-point source nutrient pollution via a nutrient management plan works. It also analyzes the regulatory capture and conflict of interest that can occur in the development and implementation of non-point source agricultural regulations. Furthermore, this article will analyze how well the literature on corruption and the lessons learned about reducing corruption in the regulation of point sources of water pollution can help explain and be applied to the observed regulatory capture and conflict of interest in non-point source regulation. This article will also touch on the many differences between farmers and industrial point sources of pollution and illustrate the special attention that must be paid to designing effective environmental policies during all stages of the agricultural policy-making process.

Policy relevance

Food production is vital to human existence. The increasing demand for food to supply the needs of a rapidly growing population will add even more pressure to expand and intensify agricultural production. Some estimate that to feed the nine billion people on the planet in 2050, agricultural production will have to increase by 70 per cent (FAO, 2009). Such an increase in demand for crops will raise crop prices, which in turn will increase pressure on farmers to raise their expectations for higher crop yields and will likely mean higher fertiliser and manure applications to support higher yields. This pressure will likely exacerbate the existing problem of the over-application of fertiliser nutrient sources and insufficient BMPs to trap and control nutrients before they pollute surface and ground waters.

Literature on corruption in the regulation of point sources of water pollution

In the spring of 2010, I was invited to join World Water Week's seminar entitled 'Cleaning up Corrupted Water – Enabling Mechanisms for Improved Water Integrity' to share the instances of capture and conflict of interest observed during my dissertation. I was to present my case study, as well as provide a second presentation to, among other things, review the lessons learned about reducing corruption in the water quality sector. As I prepared for my talks, I was surprised at the dearth of documented cases of corruption in the water pollution sector and the lack of sector-specific rules of thumb to reduce corruption between industrial firms and the agencies regulating them.

Among my literature review, Transparency International's 'Global Corruption Report 2008: Corruption in the Water Sector' provided a page-turning compendium of corruption cases, analysis and policy recommendations. The report was dominated by numerous cases of corruption related to water quantity, such as irrigation water projects, hydroelectric dam projects, and water delivery programmes to the urban poor. Most examples came from developing countries where large-scale water supply projects involve the transfer of large amounts of public or development funds which attract opportunities for 'grand corruption' to siphon off those funds. Transparency International defines 'grand corruption' as, "acts committed at a high level of government that distort policies or the central functioning of the state, enabling leaders to benefit at the expense of the public good" (TI, 2009).

There were many examples of 'petty corruption' too. Petty corruption being defined as the "everyday abuse of entrusted power by low- and mid-level public officials in their interactions with ordinary citizens, who are often trying to access basic goods or services in places like hospitals, schools, police departments and other agencies". Examples included such instances as when the urban poor customarily pay bribes to water utility inspectors to change their meter readings, to accelerate faucet connections, or to solve other water supply problems. The report offered only a handful of examples of petty corruption in developed countries such as the US and these cases involved collusion, i.e. firms that supply water pipes were caught working together to rig bids and fix prices to devise market-sharing schemes (TI, 2008).

To my surprise, the only cases of corruption from the 2008 report regarding water quality and water pollution regulations came from China. China's water pollution statistics are alarming. About 90 per cent of city aquifers are polluted, more than 75 per cent of river water flowing through urban areas is considered unsuitable for drinking or fishing and 30 per cent of river water is regarded as unfit for agricultural or industrial use (TI, 2008). Transparency International concludes that corruption is a significant factor, as only half the money earmarked for environmental protection was judged to have been spent on legitimate projects between 2001 and 2005. The 1,200 anti-corruption laws and environmental laws are poorly monitored and rarely enforced. In fact, only a quarter of the factories in 509 cities properly treat sewage before disposing of it.

Nevertheless, what was gathered from the literature review was sufficient to conclude that the lessons learned about why corruption occurs in the regulation of environmental goods and services, in general, and the measures that can be used to reduce that corruption was applicable to corruption issues in water pollution regulation and mostly applicable to agricultural non-point source water pollution.

Transparency International defines corruption as, "the abuse of entrusted power for private gain. Corruption can be classified as grand, petty and political, depending on the amounts of money lost and the sector where it occurs" (TI, 2009). Hence, corruption can be initiated by the regulated entities in order to influence the development of laws or regulations or to evade existing regulations. Corruption can also be initiated by the regulatory agency representatives and politicians in order to satisfy private or political motives (e.g. receive bribes or guarantee votes). Some forms of corruption are prone to make the headlines as they represent significant scandals: bribery, extortion, fraud and embezzlement. More subtle forms of corruption involve favouritism, nepotism, capture, collusion, conflict of interest and in-kind reciprocity (the 'revolving door'). This article will focus on the more subtle forms of regulatory capture, the revolving door and conflict of interest.

Regulatory capture occurs when a regulatory agency, created to act in the public interest instead becomes dominated by, and advances the commercial or special interests of, the industry or sector they are charged with regulating. In the regulation of water pollution, regulatory capture can manifests itself when agencies 'look the other way' regarding a firm's pollution. Cynics in the US might agree with Richard Posner who advanced the theory of regulatory capture in that, "Regulation is not about the public interest at all, but is a process, by which interest groups seek to promote their private interest ... Over time, regulatory agencies come to be dominated by the industries regulated" (Posner, 1974). The power of the private sector to shape public policy is starkly put by Nobel Laureate economist G.J. Stigler who wrote, "As a rule, regulation is acquired by the industry and is designed and operated primarily for its benefits" (Stigler, 1971).

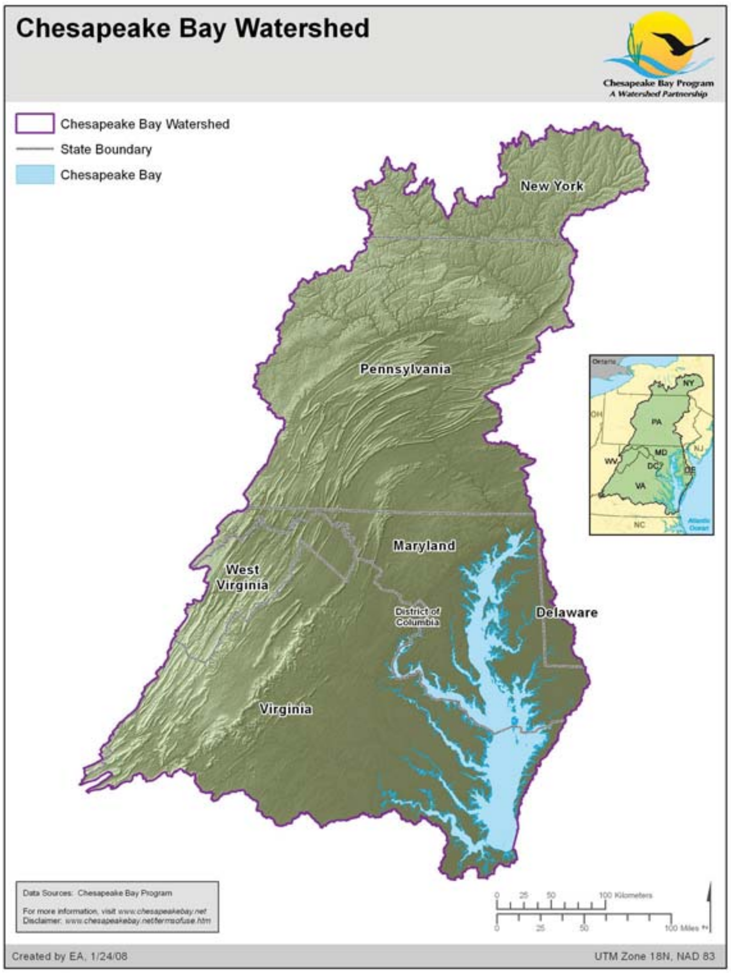
One method that enables regulatory capture to occur is the 'revolving door' phenomenon wherein, "…an individual moves back and forth between public office and private companies, exploiting his/her period of government service for the benefit of the companies they used to regulate" (TI, 2009).

Conflict of interest is defined as the "…situation where an individual or the entity for which they work, whether a government, business, media outlet or civil society organization, is confronted with choosing between the duties and demands of their position and their own private interests" (TI, 2009).

Case study of state regulations of farm non-point source water pollution

In 1997, a series of fish kills occurred on the eastern shore of Chesapeake Bay – off the coast of the Delmarva Peninsula, so named as it drains Delaware, Maryland and Virginia (Figs. 4 and 5). These fish kills resulted in considerable fear and media attention as they caused skin lesions not only on the fish (Fig. 6), but also on the fishermen and scientists trying to diagnose the problem. Furthermore, several individuals involved with the fish kills complained of headaches, dizziness and short-term memory loss. A toxic microorganism, *Pfiesteria piscicida*, was determined to be present and linked to the dead fish and the symptoms affecting people. However, much controversy surrounds this diagnosis, including the possibility that another toxic microorganism that is not harmful to humans may be to blame (Terlizzi, 2006) and that no other significant fish kill or *Pfiesteria* detection has been observed since.

The ensuing river closures to contain the fish kills and to protect human health had the unintended consequences of stopping business at recreational and commercial fishing operations and scaring away customers from Bay area restaurants and sea-



Source: U.S. Environmental Protection Agency Chesapeake Bay Program (2008).

Figure 4. Map of the Chesapeake Bay watershed.

Source: www.WorldAtlas.com

Figure 5. The Delmarva Peninsula, also known as the eastern shore of Chesapeake Bay, comprises the states of Delaware, Maryland and Virginia.

food distributors. The cause of the fish kills was determined to be nutrient pollution from agriculture that was the dominant land use on the Delmarva Peninsula and, in particular, excess manure from the area's chicken industry.

After much deliberation, all three states decided it was time to regulate farmers as the heretofore voluntary approach was deemed insufficient to reduce the farm sources of nitrogen and phosphorus ailing Chesapeake Bay. For decades, state and federal taxpayer funds provided technical and financial assistance to farmers to install BMPs that would 'avoid' excess application of nutrients on fields; 'control' the amount of nutrient and sediment runoff from fields into the watershed; and 'trap' nutrients and sediment before they leave the field. A nutrient management plan helps avoid generation of pollution by reducing excess nutrient application rates, but still seeks to optimise crop yield for the farmer. Other examples of BMPs that avoid excess nutrient application include crop rotation, cover crops, and livestock exclusion from streams. BMPs that control nutrients and sediment include residue and tillage management, contour farming, grassed waterways, and drainage water management. BMPs that trap nutrients and sediments include streamside vegetative or forest buffers, filter strips, and treatment wetlands.

All three states decided in their 1998 and 1999 state legislative sessions to enact laws requiring farmers to obtain and follow site-specific nutrient management plans that prescribe the rate, form, timing and method of application of commercial fertiliser and manure sources of nitrogen and phosphorus necessary to grow crops. Preparing a nutrient management plan involves several diagnostic tools such as soil fertility tests and manure nutrient tests which are conducted every year and used to update the annual or three-year plans. Under the decades-old voluntary programmes, state university extension specialists had prepared these plans for free for any farmer who asked for one. Now, all three states required all eligible farmers to obtain and follow the field-specific plans and to file annual reports summarizing what crops were grown each year and the total amount of nutrients applied to farm fields by type (i.e. commercial fertiliser and/or animal manure). To prepare a plan, farmers in all three states could obtain the free services of extension specialists and other public employees or they could hire a certified planner from the private sector, either a crop consultant or a fertiliser dealer that had undergone training and examination.

My dissertation asked two research questions. (1) Did the policy-making process have any influence on the rates of compliance by farmers in each state? (2) Did the laws improve farmer nutrient

Photo credit: Center for Applied Aquatic Ecology, North Carolina State University

Figure 6. *Pfiesteria*-related skin lesions on fish.

management behaviour? Estimates of compliance stem from an analysis of state regulatory data during the period 2000 to 2008 and interviews with 60 farmers on the Delmarva Peninsula conducted in 2005 and 2006. I also interviewed over 60 policy stakeholders (e.g. law makers, agency directors, scientists, crop consultants, university extension nutrient management specialists, etc.) from the three states during the period 2005 to 2009. The dissertation was defended and published in 2010.

Regarding the first research question, there were key differences in the policy development process in all three states that affected the rate of what I called 'administrative compliance' (i.e. on-time submission of the required plans or annual reports) and also likely affected the rate of 'adherence compliance' (i.e. how closely farmers were following the plans' nutrient recommendations).

Maryland is known for a confrontational political style and the legislature's approach to regulating farmers was contentious. Farmers and farm trade association stakeholders felt wrongfully attacked for causing the fish kills, reported feeling alienated from the policy-making process and believed they were less powerful than the environmental stakeholders. Subsequently, Maryland farmers refused to comply for the first several years by not obtaining or submitting their nutrient management plans. When the state began conducting on-farm inspections, the state inspected only, on average, 8 per cent of eligible farmers instead of the 10 per cent they had intended to inspect. Of the 35 per cent of farmers discovered to be non-compliant during these inspections, the most common reason for non-compliance was that the farmer had not updated his plan at least every three years, as required. This was an indication that farmers were not valuing the nutrient application information in their plan as the data must be updated to continue to be useful. However, by 2009, nearly all eligible farmers had come into compliance by obtaining a plan and filing the required annual reports.

In contrast, Delaware is known for a consensus-oriented political style. Delaware is also known for its active 'revolving door' with many government officials moving back and forth between public office and private industry. Delaware was not only highly inclusive of farmers and their farm trade association representatives in the policy-making process, but farmers dominated the process. Because of this political involvement and because of the economic incentives to comply early in the form of cost-share to hire private planners, Delaware saw twice as many farmers complying in the first two years of their five-year implementation phase as were necessary. However, in the last few years of available data (2008), when all farmers should have been in compliance, only 70 per cent of the eligible acres were associated with a nutrient management plan and only 30 per cent of the farmers required to file annual reports were doing so. In addition, Delaware has not come close to achieving the 10 per cent inspection rate it set out to accomplish every year, and instead only 2 per cent receive farm visits annually.

Virginia is known for having a negotiated political style. While Maryland and Delaware decided to regulate virtually all their farmers, Virginia decided to limit the regulations to only poultry growers since the nutrient pollution problem was linked to excess poultry manure. Additionally, Virginia already had much of its concentrated dairy and swine industry under a regulatory permit. Thus, all of Virginia's crop-only farms and its pasture-based beef and dairy farms remained unregulated. Because many poultry growers already had voluntary nutrient management plans and because many growers transferred their manure off their farm to neighbouring crop-only farms that used the manure as fertiliser, nearly all growers quickly came into compliance within the first year and maintained compliance every year since. Because the regulatory agencies in Virginia were already accustomed to conducting annual farm inspections at the regulated dairy and swine operations, the state set a 100 per cent annual inspection goal and has nearly achieved it every year. Though the state's compliance data are difficult to pull out for poultry farms only, it appears that over 90 per cent of poultry growers pass their near annual farm inspections every year as well.

Regarding the second research question, overall, farmers did improve their nutrient management practices because of the state laws. Although I felt that farmers were reluctant to admit to changing any of their fertiliser or manure use practices, and only 66 per cent provided me with a quantifiable answer, between 40 per cent and 80 per cent of those with answers said that they did change their nutrient management behaviour in response to the laws. The most common response when I asked them, "What changed?" was: "I have a greater awareness of nutrient management". More specific responses included: (1) lowering the nitrogen content in the commercial fertiliser, (2) not buying commercial phosphorus anymore, (3) reducing their poultry manure application rates from 5 to 3, 2 or 1 short tons/acre, and (4) taking soil diagnostic tests annually before deciding on nutrient applications.

In terms of assessing whether enough behaviour change has occurred to solve existing problems, Delaware is the only state that has conducted an evaluation of the impacts of their state law. Several soil scientists from the University of Delaware have concluded that the law has helped cut the state's nitrogen and phosphorus surpluses in half. In addition, the state's regulatory commission estimates that the excess poultry manure problem in Delaware has shrunk to nearly nil because of the law. Unfortunately, there are no state efforts underway in Maryland or Virginia to evaluate whether the laws have had an effect on water quality.

There remains, however, one fundamental challenge to all of these state regulations; many farmers reported to me that they do not believe that following their field-specific nutrient management plan is in their economic self interest. They think the fertiliser and manure recommendation rates in their plan are "too conservative" and that "they will not be satisfied with the crop they harvest if they were to strictly follow the plan".

Case study concerns about regulatory capture and conflict of interest

At every stage in the policy-making process – legislative, regulatory, implementation and enforcement – concerns were raised by the media, environmental stakeholders and policymakers about regulatory capture in almost every state. Based on my interviews with farmers and policy stakeholders and my review of eight years of state regulatory compliance data, I found most of these concerns to be well-founded. However as will be discussed later, it is not entirely clear whether these concerns are as detrimental as one would assume from the literature on corruption. In addition, from my interviews with farmers and their private crop consultants, I found additional concerns, in the form of conflicts of interest, which are likely having a detrimental effect on the effort to reduce excess nutrient application.

During the legislative stage, all three states received accusations of regulatory capture. As Maryland legislators were crafting the law, furious debates occurred over which agency would implement and enforce the regulations. All the environmental stakeholders expected the state's Department of Environment to become the regulator, as it already managed the regulation of point sources of pollution, such as sewage treatment plants, industrial facilities and a few of the largest CAFOs. In contrast, all the farm trade association stakeholders wanted the Department of Agriculture, whose mission was to support agriculture, to regulate farmers. When it was determined that the agricultural agency would be the better department to regulate farmers, given its expert knowledge of the regulated entities, the law was described as allowing the "fox to guard the hen house". In contrast, the agriculture agency was unhappy with its new role as regulator because it felt the role was in direct opposition to their long-time effort to be a friend and partner to the farmer.

In contrast to the Maryland experience where many contentious debates took place in front of and were covered by the news media, much of Delaware's experience was collaborative and occurred outside of the media glare. The Governor of Delaware reached out to farm leaders and asked them to work together with the agriculture and the environment agencies to develop the law. These private and public sector stakeholders formed a task force to study the problem and discuss what to do. The task force came to agreement and brought policy recommendations to the Chairman of the state legislature's House Agriculture Committee. This Committee Chairman, in turn worked in consultation with the major state farm trade association leaders to craft Delaware's law. Several years later, it should be noted the Chairman became the Administrator of the leading farm trade association in Delaware. The resulting legislation called for creation of a new, quasi-governmental 'Commission' to develop, implement and enforce the regulations. Nine of the 15 members of the new Nutrient Management Commission would be farmers, in effect relegating the professional staff at both agricultural and environmental agencies to the sidelines. Delaware received its share of accusations that this farmer-dominated, quasi-governmental institution was in effect letting "the fox guard the hen house".

Although no public accusations of regulatory capture occurred in Virginia, there are several indications that it occurred. The state legislature decided to limit the regulations to just one sub-set of farmers (poultry growers) and ignored all crop-only famers and pasture-based livestock farmers. Furthermore, the Virginia law only requires the management of poultry manure on the producing farms (not on the crop-only farms where approximately 70 per cent of the state's poultry manure is transferred to). Hence, Virginia enacted a poultry manure law that, in effect, allows the majority of the poultry manure to go unregulated.

Delaware also appears to suffer from regulatory capture during its enforcement stage. Though the Commission publishes annual compliance reports, it continues to not report the number of farmers who have and have not obtained the required nutrient management plan. Instead, Delaware reports only the number of acres that are managed under a plan. Based on the estimate of the number of acres that the Commission Administrator believes should be in compliance, only 70 per cent of the farm acres are in compliance and thus 30 per cent of the acres, representing an unknown percentage of the state's farmers, are not in compliance. Furthermore, only about 30 per cent of the farmer annual implementation reports required to be submitted every year are being filed with the Commission, and thus 70 per cent are not being filed and are out of compliance. In both instances, the Commission has chosen to not pursue enforcement action against these two groups of non-compliant farmers.

There are some concerns about the effects of regulatory capture during the enforcement stage in all three states. My interviews with representatives of each state's regulatory agency led me to conclude that despite being afforded a conventional regulatory 'stick', the states all preferred to enforce the law with a very 'soft touch'. For example, all the state representatives I interviewed used the term "bringing farmers into compliance". That is, during on-farm inspections, if problems were discovered, these regulatory representatives "work with the farmer" to fix the problem and bring them into compliance. In many cases, if the problem is fixed, the non-compliance issue is not counted and not reported as non-compliance.

Finally, there are some serious conflict of interest concerns that raise the real spectre of adherence non-compliance and defeat the underlying spirit of the law to reduce excessive nutrient application to cropland. Recognizing that the state could not do the job alone, all three states decided to allow private sector crop consultants and fertiliser dealers to become certified to help prepare the required nutrient management plans for farmers. Hence all three governments certified private sector stakeholders to act on behalf of the state to carry out the laws.

Based on my interviews with 60 farmers in all three states and with five private crop consultant who had become certified nutrient management planners, I discovered that about 15 per cent of the interviewed farmers in all three states were using three of the crop consultant who reported to me that they evaded the nutrient management application standards of the state laws. One crop consultants even reported having special deals with specific fertiliser dealers to sell fertiliser to his clients and that he was "in business with the farmer to maximise not optimise yields." Several farmers and one crop consultant told me that they keep 'double books' – one set of plans that a government inspector would review and which would meet the state's certification standards for appropriate nutrient application recommendations and one set of plans with higher nutrient application rates that the farmer actually uses to grow his crops. Other farmers who hired two separate crop consultants were told by the consultants to set their crop yield goals higher than the yield results they customarily achieved in the past in order to justify higher nutrient application rates. Still other farmers say that they continue to apply poultry manure rates that are higher than the rates they know they should be using. These examples underscore the conflict of interest that can arise from involvement of the private sector to implement a nutrient management plan law.

However, some farmers with plans prepared by public sector planners, such as a state university extension nutrient management specialists, reported to me that they do not follow their plans either. Saying that they thought their state plan fertiliser recommendations are "too conservative," they go to fertiliser dealers for their 'true' rates. This illustrates the challenge of regulating farmer nutrient management behaviour with a plan when there is disagreement about the content of the plan.

Rules for reducing corruption in regulating point sources

My brief scan of the literature on measures to reduce non-compliance and corruption did not yield many tips specifically for the water quality sector. Most examples of water corruption had to do with water quantity issues, i.e. abstraction projects and drinking water provisioning services rather than corruption in the effort to improve water quality. However, I believe that most of the lessons learned about reducing corruption in general, should apply to regulatory agencies dealing with farm sources of nutrient pollution. What follows is a collection of measures to reduce capture that I found most compelling and that I organised into general rules for reducing corruption (1) during the policy development stage, (2) between firms and regulatory agencies in general, (3) during the data submission stage by firms, and (4) at regulatory agencies. These tips seem reasonable and straightforward enough but, as Frederick Boehm reminds us, "There is no easy way in fighting corruption" (Boehm, 2009).

One important mechanism for reducing corruption opportunities is to help the regulatory agency maintain autonomy from the influence of politicians. One method is to separate the rule-making agency from the implementing agency. Another is to require annual reporting from the regulatory agency to legislators. Ugaz (2001) clarifies that "independence should not be confused with lack of accountability". To increase the regulator's accountability and limit the discretionary power available for abuse, Smith (1997) identifies the following measures to increase "rigorous transparency" – including, "open decision making and publication of decisions and the reasons for those decisions, an appeals process, scrutiny of the agency's budget, usually by the legislature, prohibit conflicts of interest, subject the regulator's conduct and efficiency to scrutiny by external auditors or other public watchdogs, permit the regulators removal from office in cases of proven misconduct or incapacity". One overarching rule of thumb that is a useful guide to reduce corruption in either the development of water quality policies or the implementation and enforcement of those regulations is Lambsdorff's (2007) 'principles of the invisible foot'. Taking the famous 'invisible hand' metaphor of what guides the markets, Lambsdorff underscores the importance of reducing the close interaction between firms and regulators in order to hamper the get-together of potential corrupt partners. One way to achieve the principle is to rotate regulators into and out of position of contact with the firms they are regulating to reduce the formation of close ties.

One group of measures for reducing corruption is to focus on developing and implementing effective data reporting systems to ensure that the regulations are being properly implemented and enforced. First, one frequent challenge facing regulatory agencies is that the regulated firms do not submit the required data. Establishing clear and standardised reporting rules for firms helps lower the problem of poor data reporting. Regulatory agencies should also train their staff in "forensic accounting" to detect fraudulent data and detect non-compliance problems. Finally, agencies should try developing benchmarking 'report cards' systems to foster data submission. These report cards, which grade firm's not only for their reporting compliance, but also for achieving the required environmental goals, such as effluent standards, fosters competition between firms to report data on time and to demonstrate achievement of the goals. Making the competition and report cards public brings media attention to the problem and applies more pressure on firms to comply with both the administrative requirements and the actual environmental requirements of regulations.

Several measures are directed at reducing corruption among members of the regulatory agency itself. Above all else, the agency should develop a strategy to foster an anti-corruption workplace culture. Such a strategy includes:

- Clear rules about corruption and serious sanctions against corruption.
- Effective training to ensure staff know the rules.
- A protective whistle-blowing system.
- A clear 'conflict of interest' disclosure policy to automatically reduce the risks of corruption so that regulators recuse themselves when necessary.
- Adequate remuneration to reduce the temptation to accept bribes from firms.
- An anti-revolving door policy.

Perhaps the most logical, but challenging, mechanism for reducing corruption is the same mechanism for reducing non-compliance with environmental regulation – altering the incentive system. Plummer (2008) points out that, "corruption flourishes whenever the short-term benefits outweigh the expected losses". Indeed, a company owner in China, according to Transparency International (2008), admitted in an interview that "he would ignore guidelines to install cleaner technologies since they would cost as much as 15 years' worth of fines". From the compliance literature, Charlton (1985) provides four elements of deterrence critical to a state agency trying to prevent non-compliance: (1) credible likelihood of detection of the violation, (2) swift and sure enforcement response, (3) appropriately severe sanction, and (4) all three of these actions is perceived as real. For agencies to influence firms to comply with water quality regulations and reduce their motivation towards corrupt behaviour regulators must have the technical ability and resources necessary to detect non-compliance or corruption and they must have the political will to respond appropriately with economically meaningful penalties.

In reality, developing effective water quality policies and fostering strong water quality agencies goes a long way to reducing opportunities for corruption. Simply put, confusing policies and weak institutions raise risks for corruption. Well-designed regulatory standards that are straightforward for the firm to understand and implement and straightforward for the regulatory agency to observe and enforce are essential for reducing opportunities for corruption.

And finally, Transparency International underscores the importance of "understand(ing) the local water context, otherwise reforms will fail". Recognizing that one size never fits all, diagnosing the local conditions and then designing effective solutions with local input and buy-in is critical to reducing non-compliance and corruption.

Analysis

Applicability of the corruption literature to farm non-point regulations

I have grouped my analysis of the applicability and usefulness of the non-compliance and corruption literature for understanding and reducing the regulatory capture and conflict of interest issues I observed in my case study of agricultural non-point source regulations into three categories, (1) useful, (2) not useful, and (3) undecided.

Useful

I found the insight that weak rules and weak institutions open up opportunities for non-compliance and conflict of interest resonated with the experiences in Maryland, Delaware and Virginia. Given the difficulty of detecting and measuring the diffuse nutrient pollution running off and leaching from farm fields, perhaps the weakest regulatory option all three states chose was a nutrient management plan, as it is inherently difficult to determine compliance with the plan. None of the states chose what might be considered stronger regulations that required BMPs that can be easily seen, measured and verified, such as edge-of-field setbacks, streamside buffers, treatment wetlands, grassed waterways, or filter strips.

A regulation based on a plan requires more staff resources to deliver than most governments have. They do not have the staff to:

- prepare plans for hundreds or thousands of farmers' fields or train private consultants to prepare the plans.
- verify all farmers have obtained a plan.
- evaluate the quality of the plan to make sure it represents nutrient applications that meet the state's scientific standards of "optimizing crop yields while minimizing environmental losses".
- and then detect actual adherence to those recommendations in the plan.

None of the three states had the administrative capacity to implement the law themselves and had to allow the private sector to help prepare the necessary plans. This of course, opened the doors for non-compliance due to conflict of interest by some crop consultants, who see their job to "maximise crop yield" rather than optimise crop yield to minimise environmental losses.

The importance of conducting locally-relevant assessments of the non-compliance and corruption challenge is also very important to these three case study states. All states have largely ignored the murmurings that many farmers do not want to follow their certified nutrient management plans prepared by state extension service specialists because they think it will "put them out of business". Instead, states must confront this 'elephant in the room' and directly address the perception shared by some farmers, private crop consultants, and fertiliser dealers that the amount of nutrients scientists believe is sufficient to grow crops is not enough. State regulatory agencies, agricultural scientists and agricultural economists must work together to dissect the real or perceived reasons why farmers think the plans will make them lose money.

If the perception is not true, the policy stakeholders must develop educational programmes to convince the regulated farmers that their fears are not justified. However, if there is cause for some economic concern, the stakeholders must quantify the cost and decide whether the cost of compliance is justified to bring about environmental benefits. If the policy stakeholders believe that society must share in the cost of these regulations, new cost-share programmes should be developed. If the stakeholders believe that the cost is appropriate for the agricultural sector to bear as a "normal cost of doing business" to address the environmental harms of farming, then the stakeholders should develop a non-compliance penalty system to make the cost of non-compliance greater than the cost of compliance.

Finally, I found the principle of altering the incentive system compelling and applicable. After years of "bringing farmers into compliance", it may be time for the states to try implementing this economic theory of deterrence by increasing their inspection rates and levying large and meaningful fines for non-compliance. In addition, states should pursue and penalise the crop consultants, fertiliser dealers, and farmers who are working together to evade the laws.

Not useful

I found that three recommendations for reducing corruption between conventional firms and regulatory agencies engaging in regulatory capture were not useful to the challenges of regulatory capture observed in my case study. First, the 'principle of the invisible foot' actually runs counter to most of the literature describing the variables that are successful in persuading farmers to adopt BMPs. Instead of rotating regulators so as to avoid opportunities for capture, the farm conservation literature underscores the importance of developing trust and a bond between conservationists and farmers. Such a bond takes a very long time to develop and must be earned, cultivated and maintained through continual interaction.

Second, although publishing annual reports and fostering other forms of reporting transparency are important mechanisms for achieving accountability, without political will they can be 'paper tigers'. Delaware publishes an annual report that reveals the Commission is aware that serious non-compliance is occurring with their law and yet they have taken no enforcement action.

Third, the recommended methods to improve data submission by regulated firms were interesting, but did not seem very helpful when dealing with farmers or for the implementation of plan-based regulations. Farmers regard their fertilization plans as highly confidential and proprietary. Given the numerous examples of how farmers can simply not follow their plans or go to lengths to have two sets of plans developed for them, a focus on plan submission in all three states created significant stress which slowed down or halted any real changes in nutrient management behaviour that could have better protected the environment.

Undecided

Finally, I am undecided about the detailed recommendations for achieving an anti-capture culture at regulatory agencies. Although the list is comprehensive, reasonable and admirable, without political will from inside or outside of the state regulatory agencies, there will be no impetus to embark on establishing such an agenda.

Advantages and disadvantages of regulatory capture

Although I may be committing a sacrilege by suggesting there is anything advantageous to regulatory capture and lest I be associated with the controversial 'grease the wheels' theories about the advantages of corruption, as described in Hanna et al. (2008), there do appear to be a few, time-constrained advantages to regulatory capture in the development and implementation of agricultural non-point source nutrient regulations.

First, regulatory capture helped achieve 'buy-in' from farmers and the regulated community in Delaware to come quickly into compliance in the initial phases of the regulation. In contrast, a lack of regulatory capture in Maryland meant farmers felt like they were 'outsiders' in the policy-making process, which alienated them, created great resistance and resulted in poor compliance rates in the early stages. In Delaware, for the first two years of the phased-in compliance stages, the state had double the expected number of farmers come into compliance. In contrast, Maryland farmers refused to comply for many years, filing instead 'justification of delay' forms long after they had any justifiable reasons for delaying compliance.

To Delaware farmers, regulatory capture meant that their interests were being well-represented by their peers on the Commission and, thus, they felt they had "a fair say" when the regulations were being developed. This feeling of inclusion in the policy-making process went a very long way as most Delaware farmers – in contrast to Maryland and Virginia farmers – said they thought "the regulations were justified", and "that they would be happy with the crops they would harvest if they strictly followed their plans". These positive opinions and the fact that the farmer-led Commission decided to allow all farmers to receive cost-share to hire private planners to prepare the required plans helped Delaware to achieve earlier than expected administrative compliance.

In contrast, in Maryland, farmers felt like they were on the "outside looking in" on the policy-making process. The balance of power favoured environmental interests, due in part to the strong environmental culture in Maryland and, in particular, to the strong affiliation with Chesapeake Bay. However, Maryland's political style is naturally strident and often political fights occur in the media limelight. All of this makes for less opportunity for capture, of course, but also little opportunity for collaborative policy-making and does not foster a feeling of 'buy-in' from farmers. Maryland farmers reported that "the regulations were not justified" and "their plan is too conservative". Less capture in Maryland meant more resistance to being regulated and seriously delayed administrative compliance in the early stages.

However, the advantages of regulatory capture – achieving a calm early implementation phase with better than necessary compliance rates – did not last in Delaware. Towards the end of the five-year implementation stage, the more conventional and negative effects of regulatory capture began to materialise with increasing and sustained rates of non-compliance.

Conclusions

Regulatory approaches to agricultural sources of water pollution are reasonable policy options since (1) voluntary approaches do not compel sufficient participation and (2) cost-share programmes have insufficient funds to pay farmers to implement all the structural practices and behaviour changes necessary to reduce pollution and clean up polluted water bodies. In addition, regulatory approaches observed in three nutrient management laws in Delaware, Maryland, and Virginia did produce improvement in several important farmer nutrient management behaviours.

However, non-point nutrient pollution, by its very definition, is diffuse and difficult to observe, let alone measure. Thus, by relying only on a mandatory nutrient management plan to address the problem and largely ignoring the many other important BMPs that control and trap nutrient and sediment pollution before reaching waterways, all three states limited the potential for significant environmental outcomes. Furthermore, none of the states sought to define any nutrient pollution reduction goals or water quality improvement goals associated with their regulations. That is, other than requiring farmers to obtain a farm-specific plan, states did not attempt to quantify how much fertiliser or manure application would be avoided if farmers were to follow their nutrient management plans. Nor did the states say what that pollution reduction would mean for local water bodies.

Thus, relying solely on a nutrient management plan as the regulatory mechanism creates tremendous administrative, educational, financial and inspection challenges for governments. In addition, given the difficulty of detecting adherence to the plans, many opportunities for non-compliance, either by direct evasion or by corruption via conflict of interest, have occurred.

This article has demonstrated that, although less regulatory capture occurred in Maryland, there was greater difficulty in implementing the law in the early stages of the regulation, although compliance improved in the later stages. In contrast, more regulatory capture occurred in Delaware, which resulted in far easier and faster implementation of the law because there was less resistance. But poor implementation and little or no enforcement occurred in the later stages of Delaware's regulation. Capture in Virginia meant developing and implementing a law that barely addresses 70 per cent of the poultry manure, the identified source of the water quality problem.

What is the bottom line? Capture easily happens in environmental regulation when the regulated sector is more powerful than environmental interest group stakeholders. Conflict of interest can occur when states rely on the private sector to implement laws. When the source of water pollution is not 'visible', but is diffuse and dispersed across the landscape, as is agricultural non-point source pollution, regulatory efforts are inevitably vulnerable to regulatory capture. And when farmers are the focus of the regulations rather than industrial firms, and they call attention to their special place in society with the 'agrarian myth' and argue that they deserve special consideration, regulatory agencies inevitably take a 'soft' regulatory approach.

To better regulate non-point source agricultural pollution, states must examine the difference in opinion between farmers and scientists about the economic viability of following state-certified nutrient management plans. Closing this gap will go a long way towards getting farmers to follow more economically and environmentally sound nutrient application rates. Requiring other important BMPs that are easier to observe and measure and which control and trap nutrient and sediment pollution may go further towards improving water quality, with greater certainty.

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A VULNERABILITY-BASED MUNICIPAL STRATEGIC SELF-ASSESSMENT TOOL ENABLING SUSTAINABLE WATER SERVICE DELIVERY BY LOCAL GOVERNMENT

A key challenge for South Africa is the delivery of universal and sustainable water services. Despite notable progress, many local government Water Services Authorities are battling with sustainable service delivery. This paper provides feedback on refinements to a five-year national programme by the Department of Water Affairs which harnesses a municipal self- assessment to direct attention to key areas of vulnerability within the business health of a municipality. The local government self-assessment outputs inform inter alia South Africa's high priority Local Government Turnaround Strategy and the associated efforts of all tiers of government towards efficient, effective and sustainable water services delivery.

Key words: sustainable water services, municipal self-assessment, vulnerability

Introduction and purpose

Local government in South Africa has contributed towards the achievement of a number of significant social and economic development advances since the introduction of the democratic municipal dispensation in South Africa during December 2000. The majority of South Africans now have significantly increased access to a wide range of basic and improved services, including water services. Nevertheless South Africa, like many developing countries, faces significant challenges in the sustainable provision of adequate and safe water services. In South Africa, the responsibility for water services delivery resides with designated local government authorities (i.e. local or district municipalities) who are termed Water Services Authorities (WSAs).

Notwithstanding the valuable role that local government WSAs have played in the provision of improved water services delivery, including considerable progress in addressing water services backlogs, key elements of the local government system have been showing signs of distress in the last few years (CoGTA, 2010). Against the backdrop of an ongoing need to continue accelerating service delivery to meet the 2014 service delivery targets, many municipalities continue to have inter alia inadequate drinking water and effluent treatment, poor associated water quality management practices, a lack of proper infrastructure operations and maintenance, and a lack of the necessary asset management practices, altogether resulting in many dysfunctional schemes and even the eventual collapse of some schemes. This is within an environment of growing development-driven water demand, as housing development and service upgrading accelerate, and is in conflict with increasingly stressed water resources.

There have been a number of government initiatives and programmes to advance service delivery and provide institutional support to WSAs. While all of the programmes have assisted in specific ways, it is still clear that a number of stubborn service delivery and governance problems remain.

A key and stubborn problem in local government service delivery is that of capacity at local government level (personnel, finances, systems and expertise) and the consequent effect it has on the ability of local government to perform, thereby preventing the delivery of sustainable water services. In addition (and contributing to the current situation) there are acknowledged capacity limitations at both provincial and national government levels. This situation has led to a progressive series of substantial and resolute intergovernmental efforts to turn the tide, to effect a successful turn-around strategy, for local government.

This paper provides feedback on a past successful initiative by the national Department of Water Affairs (DWA) to assess, assist and guide local government's capacity to provide sustainable municipal water quality management (via the use of a municipality-specific, risk-based, strategic self-assessment). It also shows how this initiative is now being enhanced to provide a broader assessment of the 'business health' of water services delivery by local government WSAs and thereby to guide and assist them.

Context

Current business health of local government water services delivery

In October 2009 DWA undertook an assessment of the state of water services provision in municipalities across South Africa; the emphasis being on operational and technical performance, rather than on provision of services or financial performance. The assessment was based on drinking water and wastewater regulatory assessments, a first-order assessment of wastewater treatment works, regulatory actions by DWA, municipalities placed under administration and key technical skills for drinking water quality and wastewater management, as specified in national regulations.

The DWA national assessment revealed that many municipalities were in deep trouble. With reference to Fig. 1, the assessment found that water services provision in 23 municipalities – 9 per cent of the total – was in a crisis state, with an acute risk of disease outbreak. A further 99 municipalities, or 38 per cent, were at high risk, with the potential to deteriorate into a state of crisis. Importantly, it was noted that chronic delivery weaknesses were tipping into outright service emergencies in a growing number of municipalities (DWA, 2010a).

The list of municipalities at risk or high risk includes the full spectrum of municipal categories, from two of the largest metropolitan areas to some smaller cities, with the most widespread problems found in municipalities comprising small towns.

The DWA survey findings were confirmed by other assessments as to the state of local government water services delivery in South Africa. These key water services sector weaknesses and challenges can be attributed to a lack of adequate funding and poor revenue collection leading to financial instability; a lack of technical, management and business skills (less than 15 per cent of municipalities have a qualified civil engineer employed); inadequate water and sewage master planning (only 55 of 166 WSAs have adequately completed their water services master planning); and political interference and corruption often compounded by political instability. The situation is further exacerbated by unclear municipal powers and functions, non-ring fenced water services functions, and inadequate provision of bulk distribution infrastructure.

Lessons learnt from past progress with municipal drinking water and wastewater management

The provision of safe drinking-water and effective sanitation are considered the most important determinants of public health. In recent years, South Africa has taken special efforts and made significant progress in the area of municipal water quality management. These efforts include the exceptionally successful national deployment of a web-based municipal water quality management tool; the national deployment by DWA of an annual local government risk-based self-assessment to provide a strategic

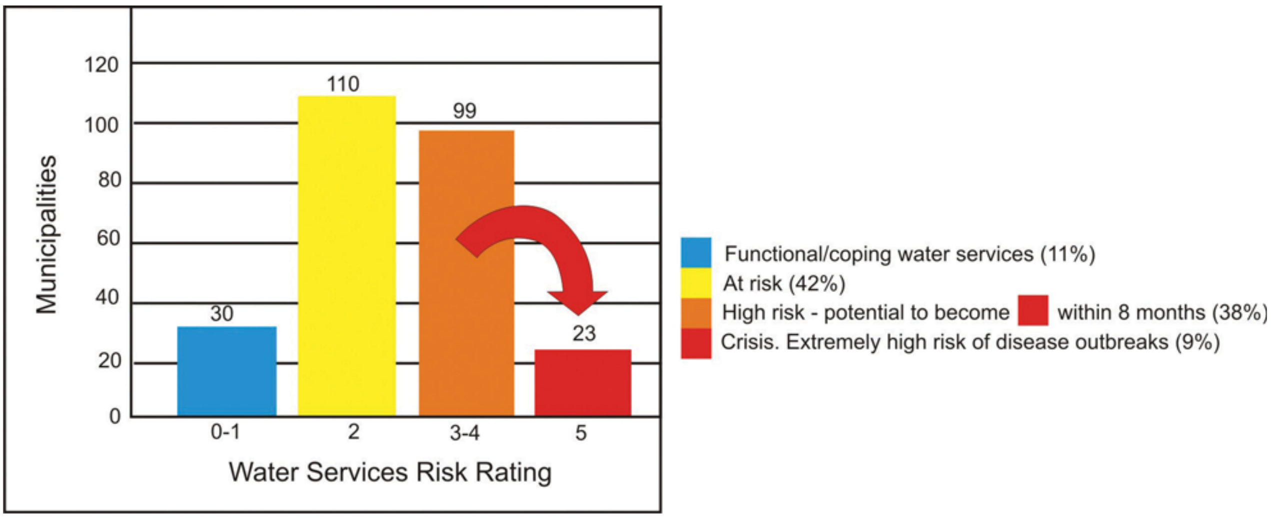


Figure 1. Risk rating of water services provision by local government municipalities

assessment of each municipality's capacity to implement sustainable water quality management; and the subsequent deployment, starting September 2008, of the 'Blue Drop/Green Drop' incentive-based regulation programme by the Department. Summarised pertinent additional detail of each of the aforementioned initiatives is provided below.

National deployment of municipal water quality management tool (eWQMS)

Whilst there has been considerable success in addressing water services backlogs throughout the new democratic South Africa, surveys by DWA during the mid-1990s showed that drinking-water quality in non-metropolitan areas remained unacceptably poor. Very few of the responsible WSAs (or designated municipalities) had satisfactory drinking-water quality monitoring programmes in place and even fewer utilised the data as intended. In particular, it was evident that a need existed for a drinking-water quality data capture and information dissemination tool, which could both assist WSAs to meet their responsibilities, and meet the Department's needs to monitor and regulate the operation of WSAs. Consequently, DWA, together with the Institute of Municipal Engineering of Southern Africa (IMESA) and Emanti Management (Pty) Ltd, rolled out a web-based water quality management system (eWQMS) to all 166 WSAs (Stevens et al., 2008).

To raise the likelihood of success with the roll-out of eWQMS to all WSAs in South Africa, an appropriate mode of engagement was developed (Mackintosh et al., 2007), and is described further in Box 1. Ultimately, a key yardstick as to the success of the eWQMS roll-out was the extent to which water quality data flowed from WSAs onto eWQMS. Fig. 2 below shows the progress achieved and the participation rate as regards monthly data submission by WSAs. For this exceptional progress DWA, IMESA and Emanti Management were awarded the International Water Association's (IWA's) Global Project Innovation Award for Operations and Management in 2008/2009.

National deployment of municipal strategic self-assessment by local government of local government's capacity to implement sustainable water quality management

Following the deployment of the eWQMS, DWA realised that municipal challenges relating to sustainable, effective and efficient water quality management were significant with each municipality having its own peculiar mix of circumstances and shortcomings. The national provision and support in the use of the eWQMS tool alone will not resolve the situation, and it would be important to identify the issues before deploying any further efforts to remedy the situation.

Accordingly, a risk-based decision support tool, using performance indicators relating to the progressive attainment of the provision of safe drinking water and effective effluent treatment by municipalities, was developed and rolled out nationally (Wensley et al., 2008).

The municipal strategic self-assessment (MuSSA) survey is undertaken annually, and in its original format measures each WSA's risk profile as regards sustainable water quality management via assessing six key sustainability aspects: (1) water legislation, policies and regulations; (2) water resources and water system infrastructure; (3) water quality monitoring, laboratories and logistics; (4) human resources; (5) management; and (6) finances.

The outputs of the municipal self-assessments are presented to individual municipalities in easy-to-use colour coded 'spider diagrams' (Fig. 5) indicating clearly the risk/vulnerability status of each 'leg of sustainable water quality management (WQM)'.

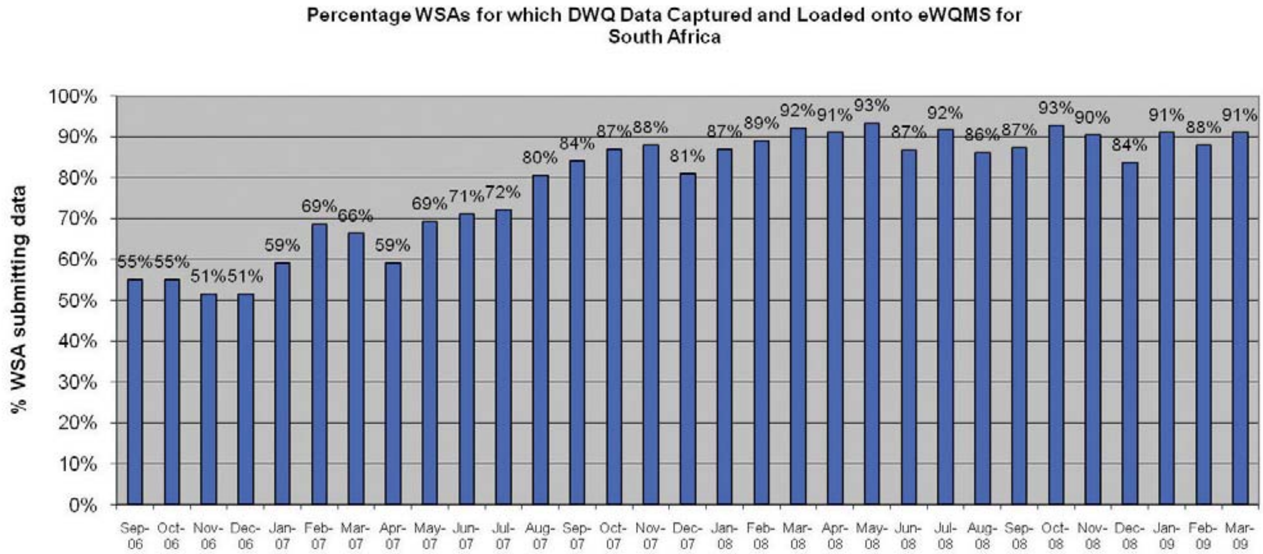
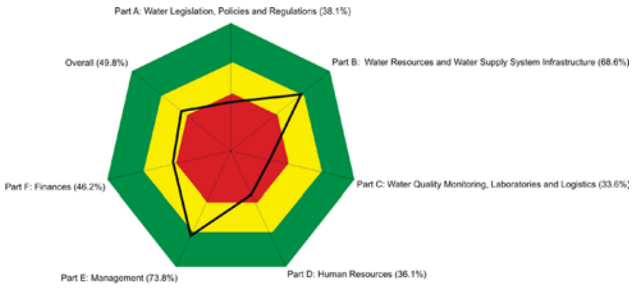


Figure 2. WSAs in South Africa loading drinking-water quality data onto the eWQMS.



Category Score	Characterisation	Comment
>70% - 100%	Acceptable	No/minor intervention required
>45% - 70%	Marginal	Interventions required
0% - 45%	Poor	External support & intervention required

Figure 5. Example of a 'spider diagram' municipal self-assessment output, highlighting the municipal water quality management risk profile.

These simple 'spider diagram' summaries have been found to be particularly effective in assisting technical and management staff to convey to non-technical, elected municipal councillors those areas of the municipality's operation requiring their prioritised attention and assistance. The overall score for the municipality is used as an indicator of the level of intervention that is required by regional and national government. Use of MuSSA has been found to have played an important role in assisting South Africa's initiatives regarding improved municipal water quality management.

Incentive based regulatory approach: drinking water quality

Incentive-based drinking water regulatory assessments, the so-called Blue Drop assessments, started in late 2008/early 2009 with 66 per cent of municipalities participating, whilst the second round of assessments occurred in 2009/2010 with 94 per cent of municipalities participating (DWA, 2009a). Data and information from the Blue Drop assessments are captured on the DWA internet based Drinking Water Quality Regulation System (or Blue Drop System).

The Blue Drop Certification criteria include: (1) water safety planning, (2) process control, maintenance and management skill, (3) drinking water quality monitoring programme, (4) drinking water sample analysis (credibility), (5) submission of drinking water quality results, (6) drinking water quality compliance, (7) drinking water quality failure response management, (8) publication of drinking water quality management performance and (9) drinking water asset management (DWA, 2010b).

A number of improvements were noted in the second round of Blue Drop assessments, including both clearer/improved assessment criteria and improvements to the assessment process. In particular, the number of systems assessed in 2010 almost doubled from the first to the second round (440 to 787 assessments) and the number of water supply systems receiving Blue Drop Certification increased from the first to the second round (23 to 38

BOX 1

Adopting a business capability development approach to ensuring stepwise improvement in municipal water quality management in South Africa

At the time of the national initiative to roll-out the eWQMS to all Water Services Authorities (WSAs) in South Africa, considerable general shortcomings in municipal water quality management existed (Mackintosh et al., 2004) including:

- Inadequate monitoring (i.e. water treatment plant and within networks)
- Lack of well structured maintenance (crisis management basis)
- Lack of management awareness and buy-in
- Lack of capacity to perform water quality management functions
- Lack of budget for water quality management at all levels
- Lack of structured programmes to deal with water quality issues

In order to successfully bring about the necessary change management and in particular as regards the deployment of an electronic tool (the eWQMS), an appropriate mode of engagement with WSAs was required (Mackintosh et al., 2007). The engagement model that was utilised can be represented as an arch made of five blocks (see Fig. 3). Each part of the arch is an aspect that can help or hinder the achievement of sustainable municipal water quality management, as follows:

- National leadership (clear and effective leadership, guidance and support from DWA)
- Municipal appropriate solutions (ensuring via IMESA that an effective 'bottom-up' approach was used)
- Support existing good practice (positively engage good practice and develop towards full legislative compliance)
- IT supports business (tools introduced by DWA for municipal use must provide positive value to municipal users)
- Prioritisation of water quality management within municipalities (what is needed and where is it needed)

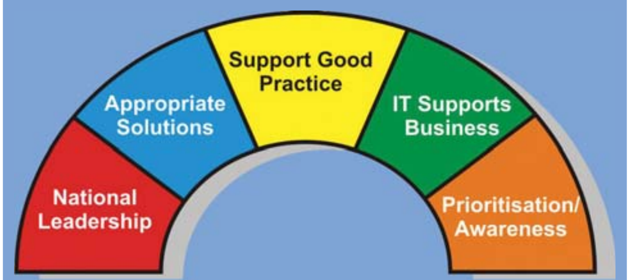


Figure 3. Effective municipal engagement arch.

systems). Whilst some 13 per cent of WSAs scored greater than 90 per cent (rated as Excellent), a combined total of 45 per cent of WSAs were reflected as needing to place more attention on water quality management.

Incentive based regulatory approach: wastewater quality

The first round of incentive based regulatory assessments of waste water, the so-called Green Drop assessments, occurred simultaneously with the first round of Blue Drop assessments with 66 per cent of municipalities participating (DWA, 2009b).

The Green Drop certification criteria for the first round of assessments included the following categories: (1) process control, maintenance and management skill, (2) wastewater quality monitoring programme, (3) wastewater sample analysis (credibility), (4) submission of wastewater quality results, (5) wastewater quality compliance, (6) wastewater quality failure response management and (7) wastewater treatment works capacity. In addition, a First Order Assessment of Municipal Wastewater Treatment Plants was also conducted. Key observations from these included that only six out of 166 WSAs managed to obtain Green Drop status, with 55 per cent of participating systems scoring between 0 and 49 per cent for the assessment. Furthermore, the assessments covered less than half of the 1000 odd wastewater treatment systems of South Africa. As many systems have not yet been assessed, it is acknowledged that the above results probably reflect a best-case scenario of the current status of wastewater treatment systems in South Africa.

The previous sections have demonstrated that despite a number of admirable national municipal drinking water and wastewater initiatives, considerable local government water services provision challenges still exist. The following section describes in more detail the past progress and future tactical plans for further harnessing the aforementioned MuSSA to achieve this.

Harnessing the power of municipal strategic self-assessments

International use of local government self-assessment and management tools

Local government self-assessment and management tools are reported to have been used to good effect in various parts of the world. For example, in Canada, self-assessment tools are used to help municipalities identify their level of fiscal and administrative sustainability and inform the development of sustainability plans towards becoming self-sustaining local government administrations. Municipalities that are no longer viable due to their inability to balance revenues with required expenditures, or fill vacancies on their municipal councils, may opt for dissolution (Saskatchewan Ministry of Municipal Affairs, 2010).

In the United States of America (USA). the Safe Drinking Water Act requires that public water supply systems in the USA dem-

>> BOX 1

Furthermore, given the then substantial variance in capacity and practice across the 166 WSAs, it was also crucial that the approach take cognisance thereof and both (i) assist progressive improvement and (ii) allow for these different entry and end levels of participation. The model used to assist WSAs migrating towards optimum water quality performance made use of a five step business capability model (Fig. 4) and is presented as follows:

- Step 1: Unconscious incompetence – the municipality is unaware of what it does not know – it does not know the requirements for effective water quality management and the municipality is ignorant and it isnot aware of its ignorance. The municipality now knows the basics of water quality management, but is unsure of how to practically implement a water quality management programme or respond to issues of concern.
- Step 2: Conscious incompetence – the municipality is aware of what it does not know (i.e. the municipalityis ignorant and it is aware of its ignorance). The municipality now knows the basics of water quality management, but is unsure of how to practically implement a water quality management programme or respond to issues of concern.
- Step 3: Conscious competence – the municipality is aware of how to do things properly (i.e. the municipality has the ability to do something, but it has to concentrate on doing it properly). The municipality implements a basic water quality management programme and starts to practice identifying and resolving issues of concern.
- Step 4: Unconscious competence – the municipality is unaware of how it does the things it knows how to do (i.e. the municipality does things without even thinking about them). At this stage the municipality (and especially the staff comprising the water quality team) automatically responds to and resolves issues of concern. The municipality is also striving to continuously improve and would like to benchmark its performance against other municipalities.
- Step 5: Mastery – this would apply to a municipality that has taken a step further than unconscious competence and has optimised the total water management cycle within its area of jurisdiction. Municipalities at this stage are very proactive, identify issues, and formulate strategies to close any gaps and timeously resolve issues.

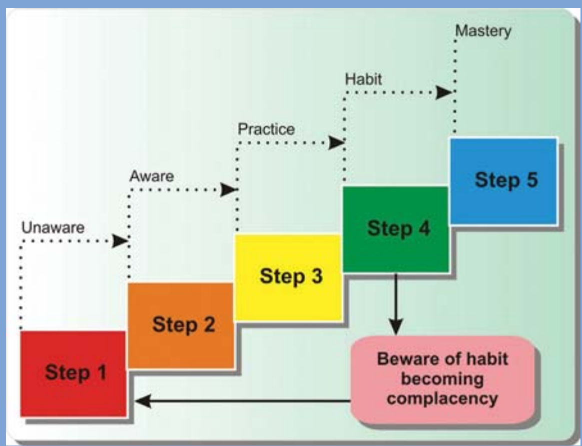


Figure 4. Five-step business capability model for achieving optimum water quality performance (adapted from Ingham, 2007).

onstrate technical, managerial and financial capability to meet regulations, provide adequate water service and operate as financially viable entities. This responsibility is referred to as 'capacity development.' The National Rural Water Association (NRWA) developed the Rural and small water system self-assessment for capacity development to support the annual assessment of the critical, basic components of a water system. Further examples as to the use of self-assessment tools include for the purposes of identifying security threats that could compromise a water system's ability to provide adequate potable water. The NRWA, together with the Association of State Drinking Water Administrators, developed the Security vulnerability self-assessment guide (2002). This guide is designed to help small water systems (serving populations of 3300 or less) determine possible vulnerable components and identify security measures to help prevent loss of service through terrorist acts or vandalism. Municipal self-assessment tools are furthermore used to inform planning. For example, the State Planning Act of New Jersey requires the submission of municipal self-assessment reports as a means for municipalities to assess the consistency of their planning documents with the state plan. A self-assessment report provides a comprehensive overview of a municipality in terms of demographics and infrastructure as well as a review of its existing planning studies in relation to the state plan (Borough of Wanaque, 2008).

In the Philippines, the Department of the Interior and Local Government developed the local governance performance management system (LGPMS), which is a self-assessment and management tool for local government units (LGUs) to help them identify development gaps for appropriate executive and legislative actions (LGPMS, 2011). The LGPMS was first implemented in 2005. The LGPMS is a self-assessment, management and development tool that enables provincial, city and municipal governments to determine their capabilities and limitations in the delivery of essential public services.

The LGPMS serves three primary purposes:

- Supporting the development of local government through the improved use of financial and human resources
- Benchmarking local government performance against established standards
- Informing national policy-makers on the state of development in local governments.

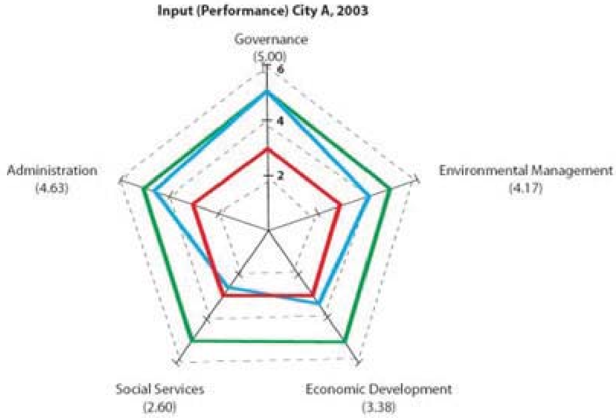


Figure 6. Outputs from the LGPMS of the Philippines.

After the collection of indicators, the LGUs upload the data into the web-based LGPMS database. The results of the LGPMS indicators are converted by the software into performance levels ranging from 1 to 5. A typical output is shown below (Fig. 6). It is said that the LGPMS improves local government management and operations, suggests ways to provide high quality public services, improves planning, budgeting and the rational allocation of resources, stimulates innovations and strengthens the norms of transparency, accountability, equity and participation.

South Africa's use of municipal strategic self-assessments

As mentioned earlier, South Africa has used MuSSAs since 2005 to assist in understanding, supporting and guiding the status of municipal water quality management and related water services quality within WSAs. In support of the emerging Blue and Green Drop regulatory initiatives, the MuSSA has identified where threats to sustainable services provision remain, and prompted the development of local, regional and national strategies regarding measures that are required to close these 'sustainability gaps'. Over the last two years, very close to 100 per cent participation was achieved – an almost unique achievement in terms of South African municipal participation in national government data and information collection.

The positive impact of the MuSSAs at a local government level is that WSAs can assess their own performance, identify areas requiring corrective action, benchmark themselves against peers, and monitor their trends. An example of the benefits arising to a WSA is described in the case study presented in Box 2.

Box 2: Case study – Kamiesberg Municipality

Kamiesberg Municipality is located in the Namakwa District in the Northern Cape Province of South Africa. The municipality spans roughly 11, 742 km2 bordering the Atlantic coast. The municipality consists of five main towns (Hondekilpbaai, Kamieskroon, Garies, Koiingnaas and Kharkams) and 11 rural settlements. Although the area is world famous as a tourist destination for its wild flowers and 4x4 routes, there is approximately 60 per cent unemployment, resulting in many social problems and poor payment for services. Challenges are compounded by low rainfall/limited water resources, long distances to communities and poor road infrastructure. In 2006, the municipality was experiencing continuous microbiological failures within certain towns. As identified by the municipal strategic self assessment (MuSSA) and as confirmed by spot water quality sampling, the health risk was increasingly becoming critical and the Department of Water Affairs (DWA) required an investigation to assess the situation and provide recommendations on how to improve the situation. The process required technical site evaluations to be conducted of the affected areas within the municipal jurisdictional area.

Following an introductory meeting, the first task was to review the MuSSA with the municipal top management team. This was to ensure common understanding of the critical limitations and challenges within the municipality and assist in determining the sustainability of providing safe, affordable water to all. Key findings included:

- Lack of understanding and implementation of national water legislation, policies and regulations
- Non-functional water treatment equipment
- Poor maintenance at reservoirs
- No formal drinking-water quality management programme
- Drinking-water quality was not monitored at all communities on a monthly basis
- Many staff vacancies (i.e. not all required posts are filled)
- Need for skills improvement and operational training was highlighted at both management and technical staff levels
- Lack of reporting on water services performance
- Lack of adequate funding for water treatment and maintenance (resulting from poor/no payment by communities)

The second task was to carry out a complete technical assessment as to the status of all of the various small community drinking water supply systems. This assisted in determining the limitations and challenges being experienced in each community, and allowed for development of appropriate recommendations for immediate action. In addition, short to medium term goals to allow sustainable provision of drinkingwater by the municipality could also be determined.

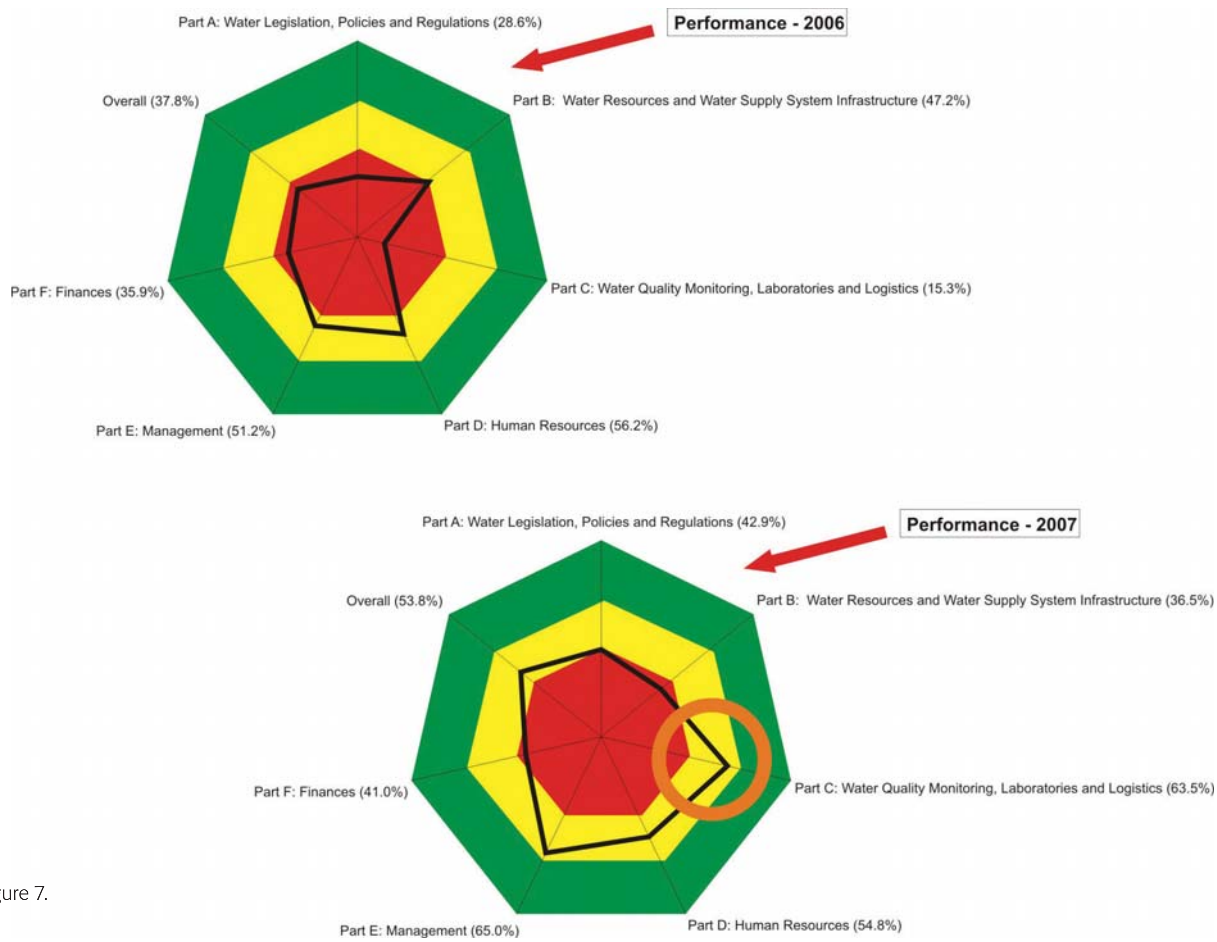


Figure 7.

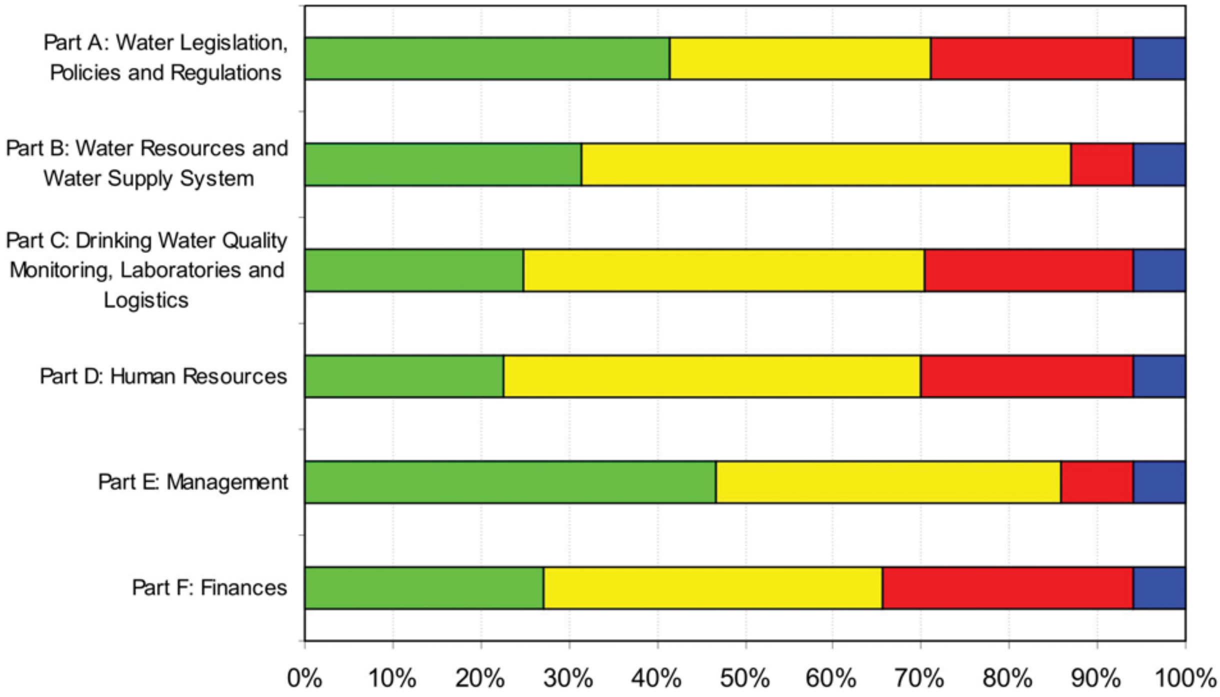


Figure 8. A typical rolled-up summary view of the six key performance areas per regional province.

Outputs are also rolled up into regional views which assist risk/vulnerability benchmarking between municipalities across each of South Africa's nine provincial regions. This assists in regional supportive interventions by provincial and national departments, both in terms of identifying most vulnerable municipalities and in addressing regional themes (see Fig. 8).

Finally, outputs are rolled up into national views as per priority issues of the time, and used for national planning and business intelligence purposes (see Fig. 9).

In this manner MuSSA outputs have been used as inputs into the high priority 'Local Government Turnaround Strategy' in terms of (i) confirming high risk municipalities, and (ii) providing specific details on those areas of high risk within weak municipalities.

The updated need and retaining the value of MuSSA: developing an holistic business health vulnerability check

Although some modifications and enhancements have been made to MuSSA since its initial deployment in 2005, the MuSSA survey has largely remained unchanged for this five-year period. Given sector progress over this period, and in particular given both (i) the improved municipal and water services regulatory information gathering processes, and (ii) the number of additional national water sector developments and associated revised needs which have developed (for example, increased focus on asset management, water demand management, integrated water management and water safety planning) an updated and revised approach was considered. A conventional SWOT analysis (strengths, weaknesses, opportunities, threats) (see Table 1) resulted in a revised MuSSA launched in 2010/2011.

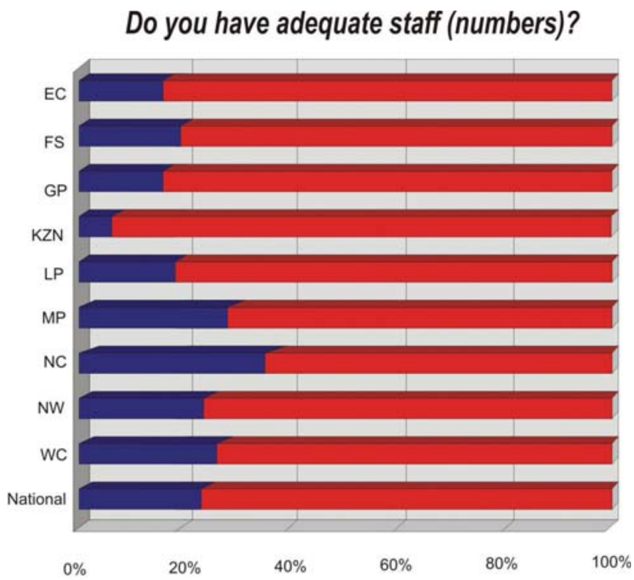


Figure 9. A typical rolled-up summary of the provincial perspectives for a specific query regarding technical staffing capacity.

Table 1. Local government SWOT analysis of municipal self-assessment survey methodology

STRENGTHS	WEAKNESSES
• Identify and communicates key issues hindering service delivery • Effectively communicates technical issues in non-technical terms to councillors • Allows benchmarking of municipalities against their own prior preference and other similar municipalities • Once populated it is easy to update – Immediately captures and reflects either positive or negative change – No unnecessary repetitive answering of questions • Provided a lot of 'live' strategic information as to the reason for municipalities struggling, especially since no other information was available at the time • High level of ongoing municipal participation	Did not reflect the complete business health, but rather focused on key issues of the time, i.e. WQM • Focussed on a mixture of 'inputs, outputs and outcomes' • As the regional data capture strengthened, the tool became misaligned and the data set became superfluous • The level of detail required made the completion of the survey time-consuming and laborious • The municipal reaction to the Department's regulatory approach has diverted municipal attention from running an effective business to focussing on regulatory requirements
OPPORTUNITIES	**THREATS**
• Move away from a focus on business health to a focus on vulnerability and alignment with local government turn-around strategy (LGTAS) • Offer strategic direction to LGTAS and development of specific turn-around strategies • Provide a standardised perspective of that need • Offers proactive prediction of an impending crisis, i.e. a worsening and where correction is required	• Worsening municipal situation has resulted in municipal officials being very overloaded and experiencing difficulty in completing • Roles and responsibilities between sector departments, which is hampering service delivery • DWA, although the leader of the water sector, is not responsible for delivery of municipal services and therefore assessments may not be acted upon • Many small municipalities do not have skills to complete and then expert team support is needed

The new revised MuSSA seeks to focus more broadly on the overall 'business status' of the municipality and in particular the 'business health' thereof, so that areas of vulnerability to the sustainability of municipal water services provision can be readily identified. This quick and high level 'vulnerability health check' seeks to facilitate and support the development of local, regional and national strategies and timely actions relating to the measures that should be put in place to close these municipal performance 'sustainability gaps'. The updated MuSSA therefore compliments the regulatory-based Blue Drop/Water Safety Plan oriented approach, by assisting municipalities, water services sector partners and DWA to identify critical municipal areas requiring support.

The objectives of the revised approach include providing an educational tool and common language of communication between technical and non-technical municipal officials and office bearers while supporting and informing national regulatory needs, national sector planning needs, and monitoring and benchmarking of sector performance.

The revised MuSSA is a simpler, more easily answered survey with 'essence' questions (five questions per topic) with a substantial (70 per cent) reduction in the number of questions. It is more quickly updated and easier to complete. There is no repetition of data, and it is more municipal management friendly, providing strategic flags (vs. deep technical detail, which is now captured elsewhere). The revised MuSSA considers 'business health' and provides improved strategic insight. Sixteen vulnerability indicators for the health and sustainability of the municipal water services business were developed in consultation with key stakeholders, namely: (1) water services development planning, (2) management skill level, (3) staff skill levels, (4) technical staff capacity, (5) water resource management, (6) water conservation and demand management, (7) drinking water safety and Blue Drop status, (8) wastewater/environmental safety and Green Drop status, (9) infrastructure asset management (10) operation and maintenance of assets, (11) financial management, (12) revenue collection, (13) information management, (14) organizational performance, (15) water service quality and (16) customer care.

Preliminary outputs to updated MuSSA survey

The survey is substantially easier to complete, taking less than an hour to obtain a strategic oversight of key vulnerability issues within the municipality. Based on the response, a vulnerability level per category is calculated and the results are displayed via a 'spider diagram' (see Figs. 10 and 11).

The figures below show the results from a leading South African metropolitan municipality and confirms the current status of water services. In contrast, the figure below shows the results from a municipality that has suffered political turbulence and staff losses over the last number of years. The negative impact of this is clearly evident in the results.

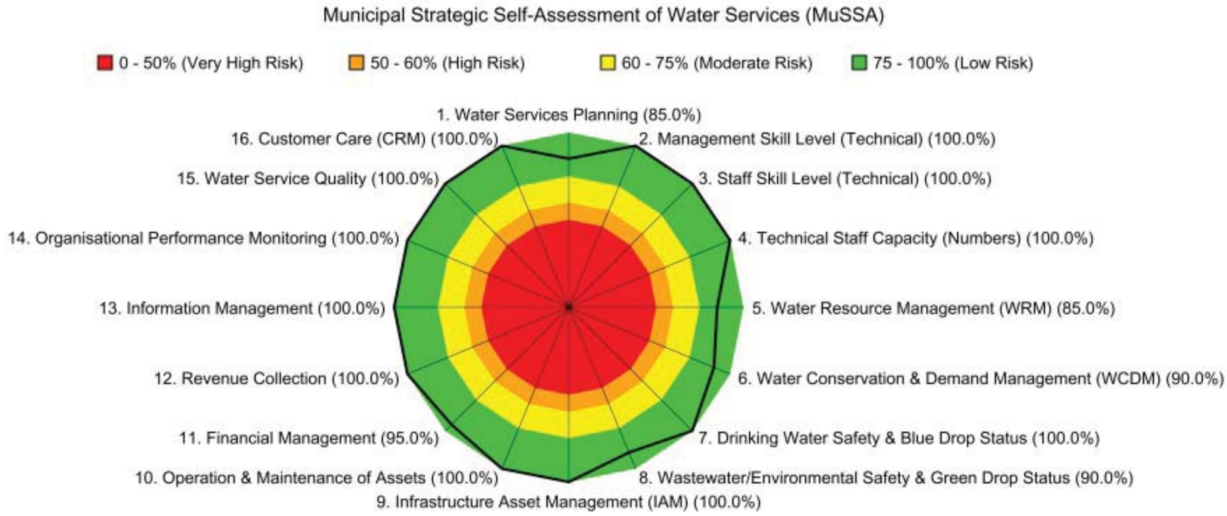


Figure 10. Typical updated MuSSA output indicating vulnerability (metropolitan municipality).

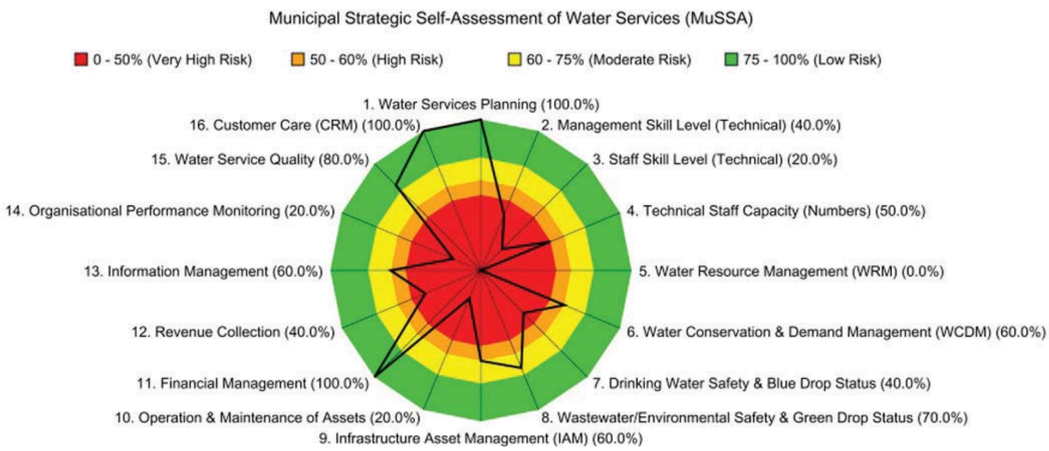


Figure 11. Typical updated MuSSA output indicating vulnerability (local municipality).

Conclusions and Way Forward

The 2011 MuSSA started in January 2011 and, by mid-March 2011, had been completed by 142 of South Africa's 166 (i.e. ~86 per cent) municipal WSAs. Municipal interaction has been through the municipal technical manager and/or water services manager. Initial feedback has been positive, with statements like "MuSSA immediately helps me to focus on where my key issues of concern are", "MuSSA correctly confirmed my municipality's greatest areas of technical vulnerability" and "vulnerabilities are immediately evident and can be addressed in a prioritised manner". These statements and other feedback have confirmed the effectiveness and value of the revised MuSSA as a municipal self-assessment, management and development tool to help WSAs identify their business development gaps and vulnerabilities arising therefrom.

As well as municipalities obtaining immediate online feedback on their MuSSA status, all data will be collated and analyzed for all nine provinces in South Africa following the national completion of the MuSSA survey (envisioned for the end of March 2011). Automated eWQMS-based analysis will be used to generate national and provincial MuSSA status reports. In so doing, the MuSSA will contribute towards benchmarking local government performance against local, regional and national established standards. It will also help inform regional and national policy-makers about the state of business health of local government water services delivery. Importantly, the MuSSA will contribute significantly towards South Africa's local government turn-around strategy, and should form the basis of any anticipated intervention and turn-around actions at municipal level, whether from a 'quick win' or from a long-term sustainability perspective.

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DEVELOPMENT OF THE HEALTHY RIVER ECOSYSTEM ASSESSMENT SYSTEM (THREATS) FOR INTEGRATED CHANGE ASSESSMENTS OF WATER QUALITY IN CANADIAN WATERSHEDS

Effective water management requires systematic tracking of change and diagnosis of areas at risk. Integrated water resource management (IWRM) is strongly linked to global health targets such as the Millennium Development Goals, but cannot be implemented in the absence of this information. We present a novel approach for understanding cumulative effects assessment; an implementable form of IWRM. The Healthy River Ecosystem AssessmenT System (THREATS) is a software tool that was developed at a national scale to perform river health diagnosis in a common system context irrespective of the watershed. THREATS supports a three-tiered structure: (1) Tier one (data screening and selection), (2) Tier two (defining the reference condition) and (3) Tier three (defining exceedances from reference condition). The application of this tool is illustrated using two Canadian case studies. It is also being expanded to the global context in partnership with the United Nations Environment Programme Global Environment Monitoring System.

Key words: cumulative effects assessment, THREATS, watershed, reference condition, hot spots, decision tree

Introduction

The impacts of anthropogenic development on global aquatic resources are extensive and a threat to the health of both aquatic ecosystems and humans. Water shortages, changes in natural flow regimes (from both natural and anthropogenic causes) and contamination of source waters (including ground, sub-surface and surface waters) are some of the main drivers impacting the state of our waters. In many cases, the realised impact of development is observed after the fact, when the damage has been done, e.g. microbial and chemical contamination, outbreaks of waterborne disease and loss of fisheries resources for human consumption. As a consequence, our actions are reactive as opposed to pre-emptive.

In Canada, the consequences of poor water management were realised by such events as the Walkerton, Ontario (2000) tragedy where microbial contamination of the water supply resulted in seven deaths and more than 2000 violently ill. In North Battleford, Saskatchewan, (2001), over 7100 local residents and hundreds of travellers were violently ill as a consequence of drinking water contaminated with sewage (Jameson et al., 2008). Such local effects are observed the world over and are becoming increasingly common. In addition, events acting at even greater scales, such as climate change, are impacting water abundance, especially in many parts of the developing world.

IWRM and CEA

IWRM has evolved to holistically understand the impact of human activities on aquatic ecosystems for their preservation and protection (Biswas, 2004). Although the concept has been around for a long time, its implementation has not been overly successful. The Global Water Partnership (2000) defines IWRM as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems".

IWRM is fundamentally based on approaches that link land use and human activities to changes in aquatic ecosystem health including water quantity and quality. Whole watershed-ecosystem experiments within the northern woods of New Hampshire USA in the late 1960s were instrumental in setting the stage for landscape watershed science (Likens, 2004; Likens et al., 1970). Likens et al. demonstrated that catchment landscapes were tightly coupled to stream water chemistry by manipulating the terrestrial landscape within the watersheds and comparing stream chemistry pre and post disturbance. They demonstrated that the sum total of ecosystem processes was influenced by current and historical events and the chemistry of stream water draining a watershed could be used to diagnosis the 'health' of the watershed-ecosystem similar to the diagnostic approach a physician uses in measuring the chemistry of blood in a human patient (Likens, 2004). Since then, however, watershed science has been slow to move forward and our abilities to assess the effects of individual versus cumulative stressors on the landscape have fallen short (Duinker and Greig, 2006; Dubé, 2003; Schindler, 1998).

Cumulative effects assessment (CEA) is the process of systematically assessing impacts resulting from incremental, accumulating and interacting stressors (Dubé et al., 2006). In our opinion, it is an implementable form of IWRM. A CEA method for rivers should measure responses in indicators and determine if responses are outside of an expected 'normal' condition (effects-based assessment). CEA should also include an assessment of change in stressors accumulating on the landscape over space and time (stressor-based analysis). Finally, and in its most complete form, relationships between responses and stressors can be used to build CEA predictive models so the impacts of development can be evaluated from the past, to the present and predicted into the future. Impacts accumulating along the river continuum as measured over history to the present day should be considered as well as over multiple scales (i.e. reach, catchment and regional landscape) (Schindler, 1998). Consistent indicators should be evaluated over space and time and be responsive to man-made stressors and representative of the biophysical condition of the river (Munkittrick et al., 2000).

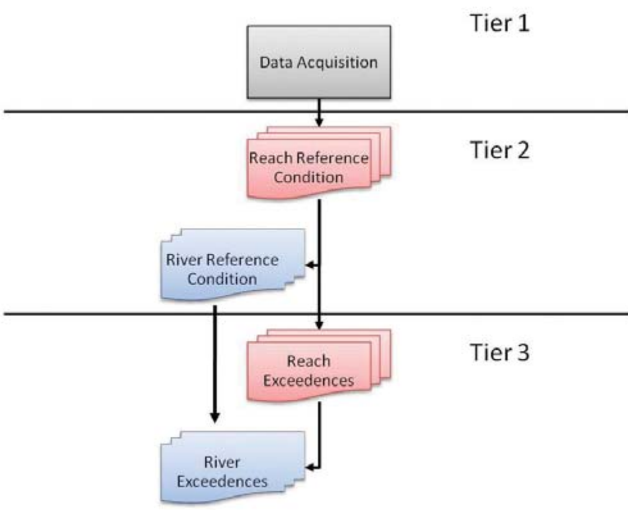

Figure 1. Main elements of THREATS effects-based decision trees. Three tiers of decision trees exist with Tier 1 identifying available data, Tier 2 identifying reference conditions in time (at the reach level) and in space (at the river level), and Tier 3 identifying deviations or exceedances from the reference condition, in time (at the reach level) and in space (at the river level).

Objective

The objective of this paper is to describe the effects-based component of a CEA methodology for rivers. The CEA methodology is being constructed within a decision-support software tool called THREATS (The Healthy Rivers Ecosystem AssessmenT System). We use a systems approach and a series of decision trees to measure change in response variables in a watershed over space and time, where change is defined as a deviation of a response variable (water quality, quantity, biological health) outside of normal (natural variability). The approach tracks data for different indicators, identifies a reference or a series of reference conditions, compares each indicator to the reference condition, and subsequently, identifies where (hot spots) and when (hot moments) exceedances from the reference condition occur. These locations in space and/or time can then be linked back to stressors specific to a spatial and/or temporal domain.

Approach

The THREATS effects-based decision trees determine the reference conditions specific to data availability, and subsequently, to quantify exceedances or deviations from the reference condition. These decision trees support a three-tiered structure (Fig. 1); Tier one (data screening and selection); Tier two (defining the reference condition); and Tier three (defining exceedances from reference condition).

The first Tier (Decision Tree 1) of the framework is used to identify datasets of interest based on a series of criteria that are specific to the geospatial information and the types of integrated aquatics information available. In this capacity, a geographic information system (GIS) is used to display the geospatial information and THREATS allows the end user to load, access and mine available data. For each watershed, the spatial extents for the watershed boundaries are defined, and within each watershed, reaches, or sub-basins along the mainstem are further identified.

The second series of decision trees (Tier 2) focus on water quantity (Fig. 2), and subsequently, on water quality (Fig. 3). Each flowchart is structured to accommodate the properties of different types of time series monitoring data, with special focus on long term trends, seasonal patterns and outliers. Hydrologic/climate variability plays an important role in controlling the rates and quantities of material movement from the terrestrial landscape into source surface waters and is thus considered an important factor when defining the reference condition.

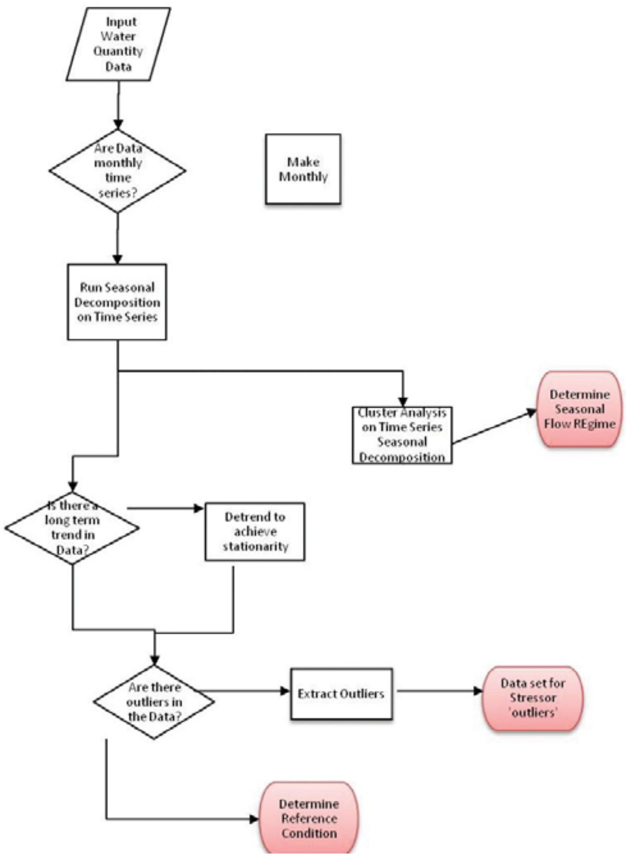

Figure 2. Effects-based decision tree for defining water quantity reference condition, seasonal flow regimes and sub-setting extremes in data for the stressor data set.

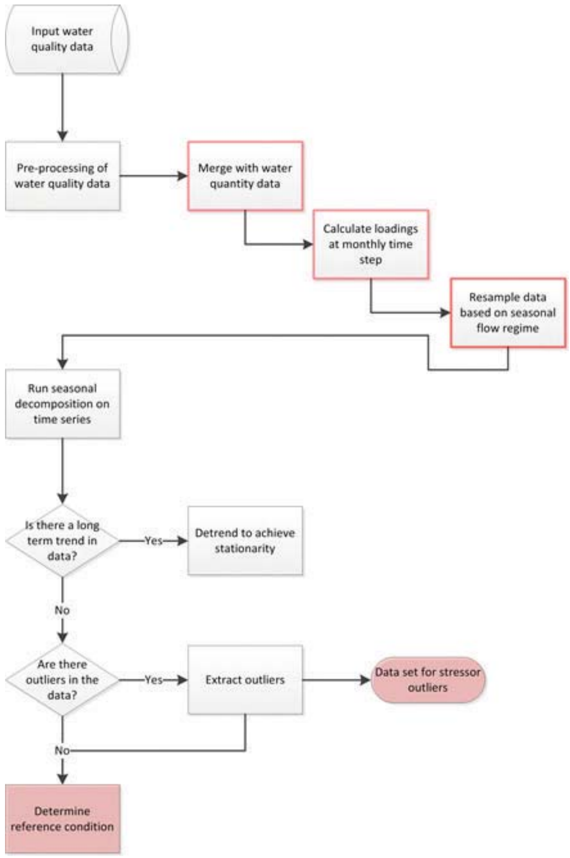

Figure 3. Effects-based decision tree for defining water quality reference condition (loadings), and sub-setting extremes in data for stressor data set.

Red boxes denote new data sets and outputs generated from the decision tree, diamonds require yes or no responses, and boxes involve procedures applied to data.

Boxes outlined in red denote manipulation and re-sampling of data for defining reference condition. Red boxes denote new data sets and outputs generated from the decision tree, diamonds require yes or no responses, and boxes involve procedures applied to data.

The water quantity Decision Tree first identifies the seasonal flow regime to group monitoring data into hydrological and ecologically relevant seasonal cycles. For rivers, material inputs from the terrestrial landscape and ecosystem function and structure (in-stream processing; Poff et al., 1997) are variable depending on timing within the hydrograph (e.g. spring freshet, summer rainfall events and winter base flows). Reference conditions are subsequently determined for water quality and quantity based on the seasonal flow regime.

Reference condition

The choice in quantifying reference condition can be quite arbitrary, and numerous approaches have been used. The debate in terminology including baseline, reference, background condition and natural variability can also be endless and the criticism is often presented that with global warming there are no reference conditions. Despite this banter, collection of data that are not compared to a benchmark provides no useful assessment of change. Thus, despite the extended discussion around the context of reference condition, the need to compare an existing state to a previous state in time or an alternate state in space is greater in our opinion than the banter of its limitations. Further, in an adaptive management framework, any limitations in defining the reference state can be addressed as analysis proceeds.

Stoddard et al. (2006) define four primary approaches to quantifying reference condition: historical condition, least disturbed condition, minimally disturbed condition and best attainable condition. In the technical document REFCOND Guidance, the reference condition is described as a state in the present or in the past corresponding to very low pressure, without the effects of major industrialization, urbanization and intensification of agriculture, and with only very minor modification of physico-chemistry, hydromorphology and biology (Wallin et al., 2003). For our purposes, the reference condition is based on the statistical properties of the available monitoring data, and thus may not parallel the same representation across all systems of study. In addition, the reference condition is defined by the range of the indicator, and thus describes a distribution rather than a single absolute value.

Reach versus river

Assessments for the reference condition at the reach level reflect cumulative effects identified in time at a specific location in a river,

whereas assessments of the river reflect cumulative effects with reference conditions identified across space. The river level integrates the reach level effects and thus identifies a cumulative response, first determined across the time interval of the monitoring data within each reach, but then across space (from upstream to downstream, integrated over time). The focus of the effects-based assessment thus allows the integration for all impacts or stressors without first needing to identify the causal factors.

Exceedances or deviations from the reference condition

The final process within the framework (Tier 3) is to identify exceedances or deviations in magnitudes of change relative to the reference condition. From Tier 2, we first determined what is 'normal' for the parameter loading of interest, presented as percentile ranges (5 per cent and 95 per cent) for a given normal. Tier 3 identifies exceedances for each reach in time (years and seasons) and across the river continuum (space) that fall outside of the normal range. At the reach level, exceedances can assist to quantify temporal sensitivities, or 'hot moments' such as seasonal effects of increased material transport during freshet or sensitivities to biota during low flow conditions. Alternatively, annual exceedances may reflect pulses of increased inputs (annual hot moments) to the rivers due to shifts in climatic regimes or changes in anthropogenic activities over longer time periods. At the river level, exceedance values are determined cumulatively from upstream to downstream, and these 'hotspots' identify discrete reaches along the river continuum where our rivers are most sensitive to human activities. We can then combine the location and timing for impacted areas of the river, and focus our efforts on exploring causal factors affecting these trends (stressor impacts), and subsequently, monitor, mitigate and manage the causes.

Canadian river case studies

Case study 1. The Athabasca River basin

The Athabasca River basin is located in the province of Alberta, Canada and covers 157,000 km2, accounting for approximately 22 per cent of the landmass of Alberta (Gummer et al., 2000). It originates at the Columbia Ice Fields in Jasper National Park (Fig. 4) and flows northeast 1300 km across Alberta until it terminates in Lake Athabasca. The Athabasca River is a 6th order stream which flows through four major physiographic provinces: Rocky Mountains, Great Plains, Athabasca Plain and Bear-Slave-Churchill Uplands (Culp et al., 2005). There has been an increasing level of industrial (forestry/pulp and paper, coal mining, oil, natural gas and oil sands mining), urban and other land-use related development (agriculture, tourism, wildlife trapping and hunting) within the Athabasca River basin (Culp et al., 2005; Wrona et al., 2000).

The Athabasca River basin was our first river system to develop an approach for CEA because of its landscape characteristics, changes in land use along its continuum, and the opportunity to integrate a large amount of existing information in a cumulative effects context. It is also home to the world renowned Athabasca oil sands deposits (Dubé et al., 2006). For this river we (1) quantified spatial and temporal changes in water quantity and quality over the entire Athabasca River mainstem across pre-development (1966-1976) and current day (1996-2006) time periods and (2) evaluated the significance of any changes relative to existing benchmarks calculated from the earlier time period (our reference condition for this system). For greater detail on this case study, please refer to the paper published by Squires et al. (2010).

Water quality, water quantity, climate and water allocation data were collected from several federal, provincial and non-government sources and integrated into a single database. Based on the examination of available data at several water quantity and quality stations (over four million data points) along the Athabasca River and the locations of several urban, agricultural and industrial inputs, the basin was divided into six reaches (Fig. 4). For each reach, the weighted average of several water quantity and water quality parameters were graphed over two time periods, pre-development (1966-1976) and current (1996-2006), to assess the differences in trends between periods. Water quality parameters used in this study were chosen based on the availability of data across the entire basin for both time periods. This was a challenge due to both the frequency of collection and the changes in analytical methods of analysis over time. Consequently, there were many parameters which did not either have consistent data

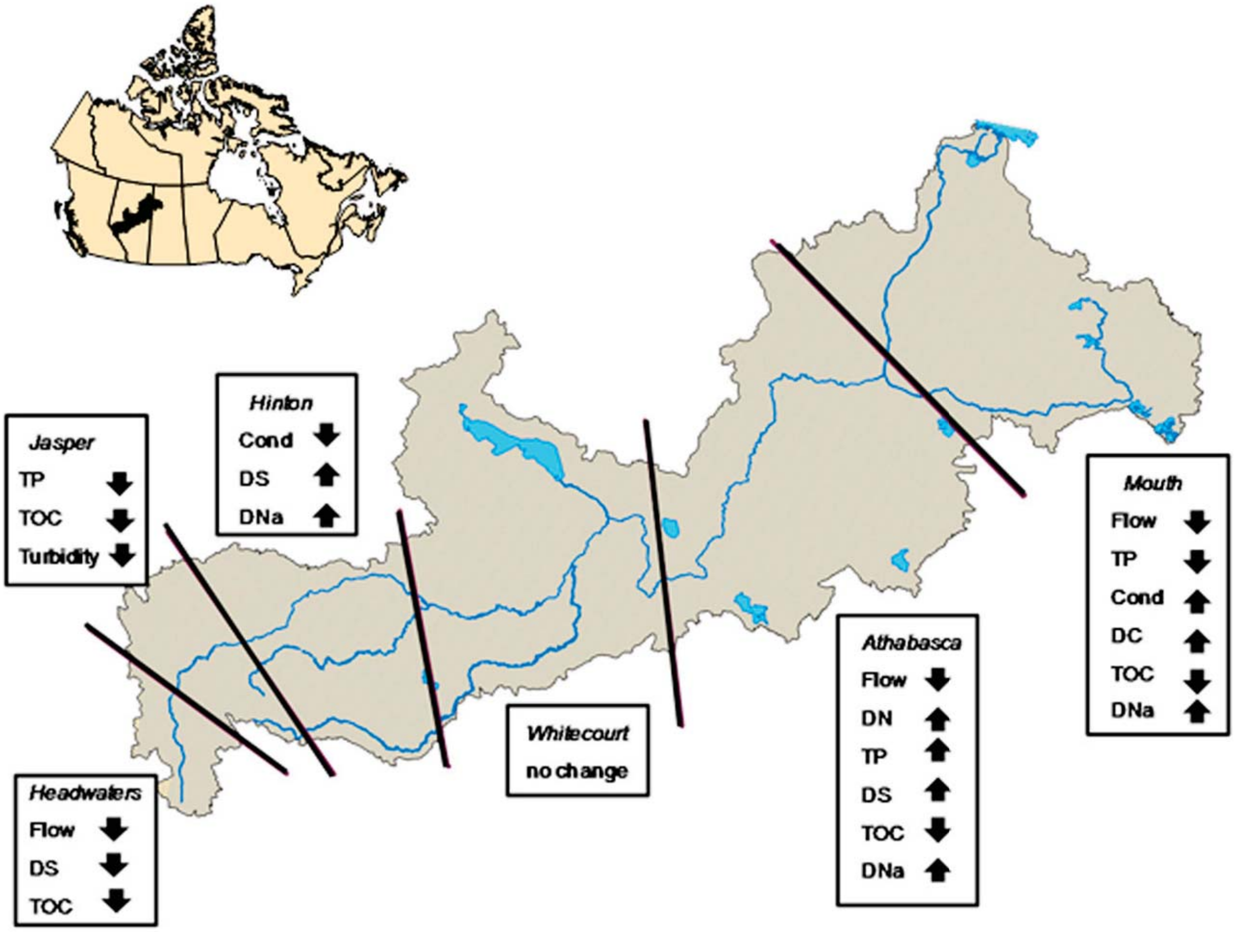

Figure 4. Summary of change assessment in average flow (m3/s) and water quality in the Athabasca River basin in the current day (1996-2006) relative to historical conditions (1966-1976). Increases and decreases are shown as significant ($p<0.05$) changes in current day compared to historical conditions.

in both time periods, or were analyzed from stations only in specific portions of the basin. Parameters which showed significant trends across space and/or time were then assessed against the 10th and 90th percentiles from the first time period which were considered to represent the reference condition.

A 14-30 per cent decrease in discharge was observed during the low flow period in the current time period in the lower three river reaches with the greatest decrease occurring at the mouth of the river. Significant changes from the reference condition (pre-development time period) were observed for several parameters including dissolved nitrogen, total phosphorus, conductivity, dissolved sulphate, dissolved chloride, total organic carbon, dissolved sodium and turbidity (Fig. 4).

Further comparisons can be done using the 10th and 90th percentiles calculated from the pre-development time period. Using these percentiles as benchmarks of the reference condition, we can show exceedances (hot spots) outside of this reference range in the current time period. This is illustrated using both dissolved nitrogen and weighted average flow (Fig. 5). Concentrations of dissolved nitrogen in the second time period fell outside of the reference condition, and in most cases exceeded it, especially in the lower part of the river. Weighted average flow showed greater variability in the reference condition as you move further downstream. Nevertheless, values in the current time period fell below this range; especially in the lower two reaches.

Results from this case study show that significant changes have occurred in both water quantity and quality between the pre-development and current day Athabasca River basin. Changes in phosphorus, chloride, sulphate and sodium are likely related to the discharge of point sources (municipal sewage and pulp and paper) with some changes associated with improved effluent treatment and altered manufacturing processes, respectively.

Flow = average weighted flow, DN = dissolved nitrogen, TP = total phosphorus, Cond = conductivity, DS = dissolved sulphate, DC = dissolved chloride, TOC = total organic carbon and DNa = dissolved sodium. Adapted from Squires et al. (2010).

Reasons for reduced carbon along the system are unknown (Squires et al., 2010). Lowered flows in the lower reaches are significant and are likely due to extraction of water for oil sands processing. Using results from this study, we can begin to quantify the dominant natural and man-made stressors affecting the Athabasca River basin as well as place the magnitude of any local changes into an appropriate context relative to trends in temporal and spatial variability.

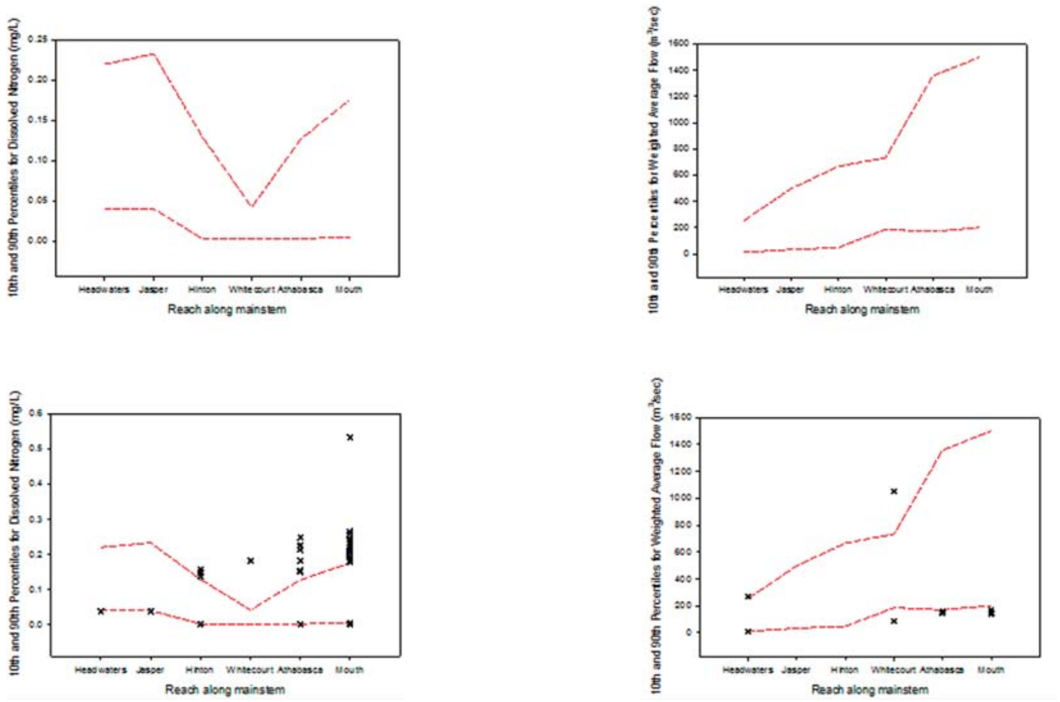

Figure 5. The calculated 10th and 90th percentiles for reference condition (pre-development time period, 1966-1976) for dissolved nitrogen (mg/L) (A) and weighted average flow (m3/sec) (C) across all reaches in the Athabasca River. Exceedances in the current time period (1996-2006) outside this reference condition are shown by the blue crosses for dissolved nitrogen (B) and weighted average flow (D).

Case study 2. The Qu'Appelle River basin

The Qu'Appelle River runs west to east across southern Saskatchewan in Canada. The river is 430 km long from its headwaters at the South Saskatchewan River, from Lake Diefenbaker (to the west) and flows eastward to the Assiniboine River in the province of Manitoba. The diversion from Lake Diefenbaker to the Qu'Appelle River via the Qu'Appelle River dam began in 1967 and as a consequence flows were significantly increased and regulated. For the case study presented, we were limited to availability of quality data that represented post diversion conditions and thus no assessment pre and post were made. All analyses were done with flow data impacted by the diversion. Although the Qu'Appelle River watershed is relatively small, it supports greater than 22 per cent of the Saskatchewan population. Over the past 30 years, sewage treatment practices have significantly changed within the watershed and, as a consequence, water quality within the river is believed to have significantly improved. Agricultural activities have, however, substantially increased, and there are concerns that agricultural practices are a significant source of contamination to the river. Using the effects-based framework, we assessed hot moments and hot spots within the watershed to ascertain if reaches along the river were impacted. This case study was built upon the Athabasca River study allowing for development of the decision trees and more direct statistical quantification of change.

Within the watershed, we identified five reaches or sub-basins that drain directly to the mainstem (Fig. 6). Water quantity (HYDAT data, Environment Canada) and quality (Ministry of the Environment, Saskatchewan and Environment Canada) data were obtained and a subset selected based on two criteria: (1) spatially located on the mainstem of the Qu'Appelle River; and (2) monitored a minimum of 10 years with a sampling interval of no less than monthly. Because our interest was in exploring the influence of urban and agricultural development within the watershed, our analysis was conducted on nitrate loadings to the river.

Our first key finding was the seasonal decomposition of the water quantity time-series data and subsequent groupings into a seasonal flow regime. Four seasonal groups were identified: Season 1 (January, February and March), ecological condition is low flow under ice; Season 2 (April, May and June), spring freshet; Season 3 (July, August and September), transition between high and low flows, warm temperatures leading to high biological productivity within the river; and Season 4 (October, November and December), low flow, cold temperatures leading to ice conditions (Fig. 7). Secondly, the 'relative' reference condition changes across seasons and the river continuum. Thirdly, greatest loadings to the river occurred during spring freshet followed by summer high productivity. Material transport is greatest during the spring when source waters are dominated by snow melt and increased surface and sub surface runoff associated with spring and summer rains. Fourthly, main source inputs were not consistently associated with the same reach across all seasons suggesting that loadings for nitrate may be driven by different source waters at different times of the year. Lastly, hot spots within the watershed were more centralised to reach 2 (Wascana), followed by reaches 3 and 4 (Central Loon and Central Pheasant, respectively).

Our effects-based approach showed specific reaches are sensitive to greater exceedances from reference conditions and that the range in

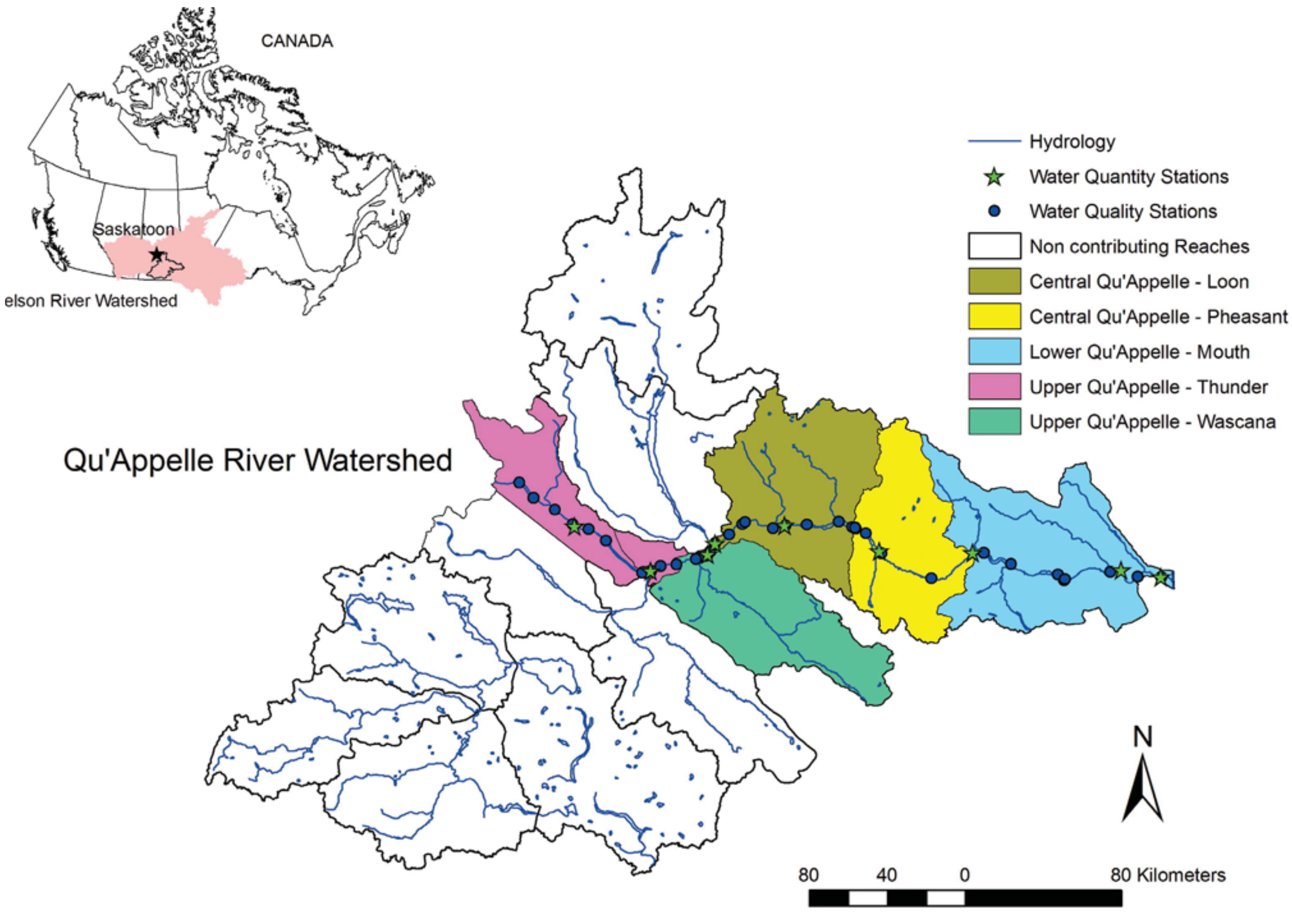

Figure 6. The Qu'Appelle River watershed is a sub watershed of the Nelson River watershed (light pink in Canada map on far left) that drains waters across the Canadian prairies from the glaciers in the Rocky Mountains in the west to Hudson Bay in the east. River reaches were identified based on drainage networks containing the mainstem and coded based on position along the length of the river. Water quantity (HYDAT data) and quality monitoring (Ministry of the Environment, Saskatchewan and Environment Canada) stations are shown.

values was influenced by temporal patterns, season as well as specific years. This variability in hot moments and hot spots is speculated to be influenced by cumulative inputs that are impacted by the hydrologic regime, with agricultural practices and urban development source inputs having unique patterns of delivery to the river. Further studies can be conducted with management efforts focused on specific stressors associated with these hot spot locations and hot moments.

Discussion

We described our systems approach to change assessment in the effects-based portion of our CEA framework. The output of the decision trees measures where and when exceedances occur outside of 'normal' for water quantity and quality. This approach can apply to any indicator, chemical, physical-chemical or biological (e.g. primary producers, invertebrates and fish stocks) from single metrics to complex indices. The approach is cumulative and integrates trends in time (at each reach along the river) with trends in space (along the river). Changes outside of a statistically defined 'normal' are identified as hot moments and/or hot spots and can subsequently be linked back to stressors on the landscape. At the reach level, seasonal or annual effects (hot moments) can identify impacts linked to source waters that are variable in time, and causal stressor effects can be evaluated within that context. At the river level, spatial effects (hot spots) can identify contamination or impacts linked to source waters that are variable in space, and stressor impacts can be evaluated within this spatial context.

Many have argued that the ecological and hydrological differences within a watershed and across watersheds are so great that defining a systems-based diagnostic approach to river health assessment is not possible. We suggest that the significance of the differences is dependent upon scale. Very detailed hydrological models, for example, are often applied at very fine scales of resolution. For the purposes of CEA, watershed scales that incorporate site specificity are the most appropriate unit of analysis (Dubé, 2003). Furthermore, our approach is not prescriptive with respect to the application of common coefficients or assumptions across watersheds that may or may not hold true. Our approach is consistent in terms of process with the actual data for the specific watershed determining the reference condition and deviations from that. Thus, we argue that the watershed scale for our effects-based assessment incorporates the required site or station specific resolution within a broader watershed scale.

Along this same line of thinking is the use of benchmarks (reference condition). Values which exceed normal are identified both

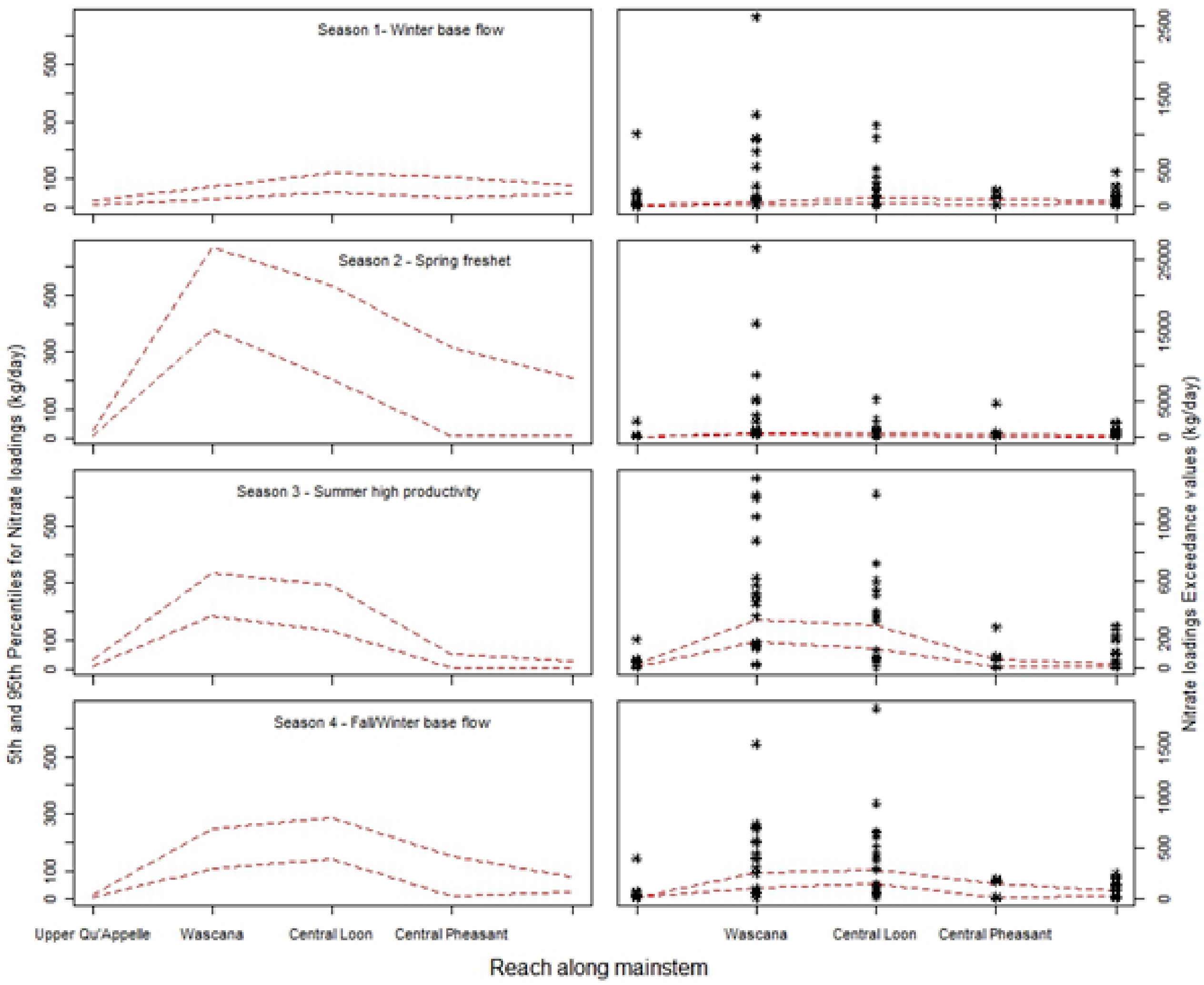

Figure 7. Figures denoting reference condition with 95 per cent confidence intervals (CI) for median nitrate loadings (kg/day) from Upper Qu'Appelle, (reach 1; upstream) to Lower Qu'Appelle (reach 5; downstream) along the Qu'Appelle River and magnitude of deviations outside of normal. Figures on left show seasonal dependence on reference condition; with greatest loadings in Season 2, followed by Seasons 3 and 4. Figures on right show (1) number of deviations outside of normal and (2) magnitude of deviations outside of normal. Deviations in nitrate loadings are greatest in Wascana and Central Loon reaches.

in time and space within a reach and across reaches along a river. Without the definition of a reference condition, an exceedance cannot be tracked or measured. There are many forms of benchmarks that are used around the world to assess water quality. For example, the World Health Organization has established global drinking water quality guidelines. In Canada the Canadian Council for Ministers of the Environment has also established national drinking water guidelines as well as guidelines for the protection of freshwater aquatic life. Many would argue that the need to define a benchmark from a reference condition analysis at a reach is negated by the existence of existing guidelines. However, we disagree with this for two primary reasons: (1) guidelines do not exist for many water quality parameters (and water quantity metrics, for that matter) of great significance to human and ecosystem health; and (2) many guidelines established at a national or global level, especially those for the protection of freshwater aquatic life for example, are insensitive to site-specific considerations. Natural ecological differences, completely independent of any man-made influence, exist in the environment due to ecozone, latitude, soils and surficial geology. In many cases guidelines are exceeded purely due to natural ecological differences, which, of course, then renders them of little value to measure real changes due to man's activities. Hence we argue that establishing a benchmark from normal using real data at a reach and river level is more realistic and we would argue protective.

Access to data is one of the greatest factors limiting our ability to understand and manage water. Monitoring stations have been discontinued due to financial constraints and those monitoring programs that do exist on a global scale, such as GEMS/Water, struggle to remain sustainable. In Canada, as in many parts of the world, management of water is fragmented by artificial jurisdictional boundaries. The boundaries are not artificial in a political sense (in Canada, the provinces hold jurisdiction over water management), but from the perspective of an aquatic ecosystem. Most of the world's watersheds are transboundary and fragmentation due to political jurisdiction complicates assessment at the scales needed to truly understand and manage water (the watershed scale). Our THREATS approach requires a reasonable dataset with its scientific rigour increasing with the amount of monitoring data available. In the Athabasca River case study, six different databases from six different sources were acquired and integrated, and after examination of over 4 million data points (Squires et al., 2010) the only water quality parameters that could be assessed temporally were parameters such as sulphate, chloride, carbon and phosphorus. Complex organics (pesticides and herbicides) were only available for more recent time periods. Thus we can use the present day to set expectations for the future for these contaminants, but the understanding of how far the system has shifted from the past is not available. Considering the Athabasca River is economically one of the most significant watersheds in Canada with the oil sands developments, fragmentation of monitoring to track the health and sustainability of that system is an unnecessary limitation. Development of the THREATS approach not only allows us to communicate what we know and understand about a system in a manner that serves science and decision making, but also shows what we do not know due to a lack of data. As we begin to do our assessments for watersheds around the world, we hope that this result begins to make a case of its own for encouraging collection of monitoring data and sustaining and building existing monitoring networks.

The THREATs CEA framework is designed to be an implementable form of IWRM. The THREATS approach identifies 'hot moments' and 'hotspots' for assessing and managing watersheds towards sustainability. The two case studies presented herein identify how this effects-based approach is used to quantify normal variability and exceedances from normal, (using two time periods in the Athabasca River system, and a continuous temporal profile in the Qu'Appelle River system). Most importantly, the scientific change assessments are reported in a risk-based context. Our success has been founded in understanding that, irrespective of the watershed examined, core commonalities in water quality assessment exist and must be built into a decision-making framework for consistent application over time within a watershed and across different watersheds. It is only in this manner that a scientifically rigorous process can be consistently developed over the temporal and spatial scales required for CEA to support IWRM.

Acknowledgements

We acknowledge our exceptional THREATS research team of technical staff and students. This work was funded through the Canada Research Chairs Program and the Canadian Foundation for Innovation (Dubé) as well as through the Canadian Water Network and the Province of Saskatchewan.

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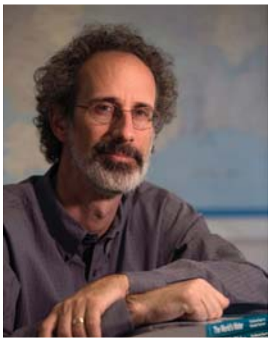

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THE CONCEPT OF PEAK WATER*

The new concept of 'peak water' is described here in the context of global and local water challenges. Three different definitions are provided: 'peak renewable,' 'peak non-renewable,' and 'peak ecological' water, with specific examples of each and their role in characterizing water problems and solutions. Regions around the world are increasingly experiencing peak water constraints, as evidenced by a growing competition for water, increasing ecological degradation associated with human extraction of water from surface and ground water systems and political controversies around water. Understanding the links between human demands for water and peak water constraints can help water managers and planners move towards more sustainable water management and use by moving away from peak limits, by cutting non-renewable water use to more sustainable levels and by restoring aquatic ecosystems as a way to reduce ecological damage from exceeding 'peak ecological water'.

Key words: peak water, peak ecological water, peak renewable water, peak non-renewable water, fresh water resources, climate change

Purpose of the article

In the past few years, resource challenges around water, energy and food have led to new debates over definitions and concepts about sustainable resource management and use. Energy experts have long debated the timing of the point of maximum production of petroleum, or 'peak oil' (Bardi, 2009; Kerr, 2007; Duncan, 2003; Bentley, 2002). More recently, there has been a growing discussion of whether we are also approaching a comparable point for water resources, where natural limits will constrain growing populations and hinder economic expansion (Gleick and Palaniappan, 2010). In this article, we present and review the concept of 'peak water,' evaluate the similarities and differences between water and oil, and offer some thoughts about the applicability of this concept to hydrologic and water-management challenges. Brief recommendations are made for avoiding these peak constraints.

Humanity faces serious water challenges. These include the failure to meet basic human needs for safe water and sanitation, growing water contamination, the consequences of extreme events such as floods and droughts, disruptions in aquatic ecosystems, increasing concerns about water shortages and scarcity and the new risks to water resources and systems from climatic changes. Considering the total volume of water on Earth, however, the concept of 'running out' of water on a global scale is of little practical utility. There are huge volumes of water – many thousands of times the volumes that humans appropriate for all purposes. The world's fresh water stocks (< 3 per cent of all water) are estimated at around 35 million km^3. Much of this fresh water is locked up in the icecaps of Antarctica and Greenland, permanent snow cover in mountains or high latitudes, or deep ground

* This is a condensed and modified version of an article that appeared in the Proceedings of the National Academy of Sciences, Gleick, P.H. and M. Palaniappan. 2010. Peak Water: Conceptual and Practical Limits to Freshwater Withdrawal and Use. Proceedings of the National Academy of Sciences (PNAS), Vol. 107, No. 25, pp. 11155–11162 Washington, D.C. June 22, 2010.

water. Only small fractions are available to humans as 'green' or 'blue' water in river flows, accessible surface lakes and ground water, soil moisture, or rainfall (Shiklomanov, 2000; CSD, 1997; Falkenmark et al., 1989). Table 1 shows the distribution of the main components of the world's water. In the early 2000s, total global withdrawals of water were approximately 3700 km^3 per year (excluding water used directly as rainfall or soil moisture), a tiny fraction of the estimated stocks of fresh water.

A more accurate way to evaluate human uses of water, however, would look at specific, often localised, stocks and flows of water and the impact of human appropriations of rainfall, surface and ground water stocks and soil moisture. An early effort to evaluate these uses estimated that substantially more water in the form of rain and soil moisture –perhaps 11,300 km^3/y – is appropriated for human-dominated land uses, such as cultivated land, landscaping and to provide forage for grazing animals. Overall, that assessment concluded that humans already use, in one form or another, more than 50 per cent of all renewable and 'accessible' fresh water flows, including a fairly large fraction of water that is used in-stream for the dilution of human and industrial wastes (Postel et al., 1996). It is important to note, however, that these uses are of the 'renewable' flows of water (described in more detail below). In theory, the use of renewable flows can continue indefinitely without any effect on future availability. In practice, however, while many flows of water are renewable, some uses of water will degrade the quality or reduce quantities to a point that constrains the kinds of use possible. In this context, the three concepts of 'peak water' presented here may be especially useful.

Peak resource production

The theory of peak resource production originated in the 1950s with the work of geologist M. King Hubbert and colleagues who suggested that the rate of oil production would likely be characterised by several phases that follow a bell-shaped curve (Hubbert, 1956). The first phase is the discovery and rapid increase in growth in the rate of exploitation of oil as demand rises, production becomes more efficient, and costs fall. Second, as stocks of oil are consumed and become increasingly depleted, costs rise and production levels off and ultimately peaks. Finally, increasing scarcity and costs lead to a decline in the rate of production and the growing effort to develop and substitute alternatives. The phrase 'peak oil' refers to the point at which approximately half of the existing stock of petroleum has been depleted and the rate of production peaks. In his classic paper, Hubbert (1956) correctly predicted that oil production in the United States would peak between 1965 and 1970. Indeed, in 1970, oil production in the US reached a maximum and has since declined (Fig. 1).

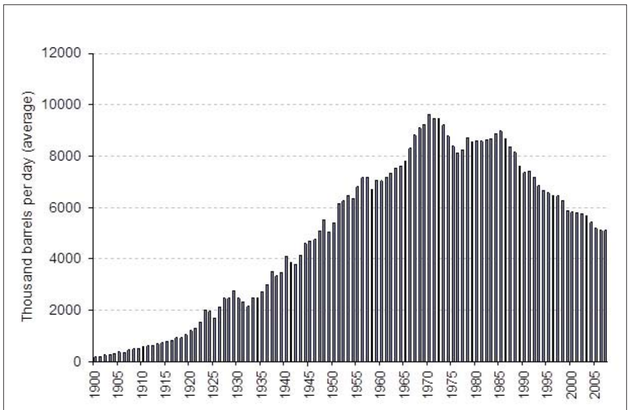

Figure 1. Total annual U.S. production of crude oil, 1900–2007. US production peaked in 1970. Source: USEIA (2008, 2009)

The concept of a roughly bell-shaped oil production curve has been proven for a well, an oil field, a region, and is thought to hold true worldwide, although there is still a significant debate about when the world as a whole will reach the point of peak oil. Forecasts range from the coming decade to substantially after 2025. One of many recent estimates suggests that oil production may peak as early as 2012 at 100 million barrels of oil per day (Gold and Davis, 2007). The actual peak of production will only be identified in hindsight, and its timing depends on the demand and cost of oil, the economics of technologies for extracting oil, the rate of discovery of new reserves compared to the rate of extraction, the cost of alternative energy sources and political factors. But a peak in the production and consumption of non-renewable resources is inevitable.

Analysis: comparison of peak production in oil and water

Does production or use of water follow a similar bell-shaped curve? In the growing concern about global and local water shortages and scarcity, is the concept of 'peak water' valid and useful to hydrologists, water planners, managers and users? In the following sections, we consider the differences and similarities between oil and water. The focus is on the characteristics of renewable and non-renewable resources, consumptive versus non-consumptive uses, transportability and substitutability (Table 2 summarises these characteristics for oil and water), and then we define three forms of 'peak water'.

Key characteristics of renewable and non-renewable resources

There are important differences between renewable and non-renewable resources. As traditionally defined, renewable resources are flow- or rate-limited while non-renewable resources are stock limited (Ehrlich et al., 1977). Stock-limited resources, especially fossil fuels, can be depleted without being replenished on a time-scale of practical interest. Stocks of oil, for example, accumulated over millions of years and are effectively independent of any natural rates of replenishment because such rates are so slow. Conversely, renewable resources, such as solar energy, are virtually inexhaustible over time, because their use does not diminish the production of the next unit. Such resources are instead limited by the flow rate, i.e. the amount available per unit time.

Water demonstrates characteristics of both renewable and non-renewable resources. Renewable water systems experience rapid flows from one stock and form to another, and the human use of water, with a few exceptions, has no effect on natural recharge rates. But there are also stocks of local water resources that are effectively non-renewable cept

Table 1. Major stocks of water on Earth.

	Distribution area (10^3 km^2)	Volume (10^3 km^3)	Total water (per cent)	Fresh water (per cent)
Total water	510,000	1,386,000	100	
Total fresh water	149,000	35,000	2.53	100
World oceans	361,300	1,340,000	96.5	
Saline ground water		13,000	1	
Fresh ground water		10,500	0.76	30
Antarctic glaciers	13,980	21,600	1.56	61.7
Greenland glaciers	1,800	2,340	0.17	6.7
Arctic islands	226	84	0.006	0.24
Mountain glaciers	224	40.6	0.003	0.12
Ground ice/permafrost	21,000	300	0.022	0.86
Saline lakes	822	85.4	0.006	
Fresh water lakes	1,240	91	0.007	0.26
Wetlands	2680	11.5	0.0008	0.03
Rivers (as flows on average)		2.12	0.0002	0.006
In biological matter		1.12	0.0001	0.0003
In the atmosphere (on average)	12.9	0.0001	0.04	

Table 2. Summary comparison of oil and water.

Characteristic	Oil	Water
Quantity of resource	Finite	Literally finite, but practically unlimited at a cost
Renewable or non-renewable	Non-renewable resource	Renewable overall, but with locally non-renewable stocks
Flow	Only as withdrawals from fixed stocks	Water cycle renews natural flows
Transportability	Long-distance transport is economically viable	Long-distance transport is not economically viable
Consumptive versus non-consumptive use	Almost all use of petroleum is consumptive, converting high-quality fuel into lower quality heat	Some uses of water are consumptive, but many are not. Overall, water is not 'consumed' from the hydrologic cycle
Substitutability	The energy provided by the combustion of oil can be provided by a wide range of alternatives	Water has no substitute for a wide range of functions and purposes
Future prospects source	Limited availability; substitution inevitable by a backstop renewable source	Locally limited, but globally unlimited after backstop (e.g. desalination of oceans) is economically and environmentally developed

ble because they are consumed at rates far faster than natural rates of renewal. Most non-renewable resources are ground water aquifers – sometimes called 'fossil' aquifers because of their slow recharge rates. Tiwari et al. (2009) recently calculated that a substantial fraction of water used in India comes from non-renewable ground water withdrawals and leads to ground water depletion. Syed et al. (2009) found similar transfers of non-renewable ground water for a wide variety of ground water basins using new data from the GRACE satellite. Some surface water systems in the form of lakes or glaciers can also be used in a non-renewable way where consumption rates exceed natural renewal, a problem that may be worsened by climate change, as noted below.

Consumptive vs. non-consumptive uses

Another key factor in evaluating the utility of the concept of a resource peak is whether the resource use is 'consumptive' or 'non-consumptive.' Practically every use of petroleum is consumptive; once the energy is extracted and used it is degraded in quality. According to the law of the conservation of energy, energy is never literally 'consumed' – simply converted to another form. But the use of oil converts concentrated, high-quality energy into low-quality, unusable waste heat. Almost every year, the amount of oil consumed closely matches the amount of oil produced. Thus a production curve for oil depends on pumping rates from fixed stocks.

Not all uses of water are consumptive and even water that has been 'consumed' is not lost to the hydrologic cycle or to future use – it is recycled by natural systems. Consumptive use of water typically refers to uses that make water unavailable for immediate or short-term reuse within the same watershed. Consumptive uses include water that is evaporated, transpired, incorporated into products or crops, heavily contaminated or consumed by humans or animals. There are also many non-consumptive uses of water, including water used for cooling in industrial and energy production and water used for washing, flushing or other residential uses if that water can be collected, treated and reused. This water recycles into the overall hydrological cycle and has no effect on subsequent water availability in a region.

Substitutability

The concept of peak resource use also depends on the availability and form of 'substitute' resources. The purpose of using oil is not to 'use' oil, but to provide social or economic benefits, such as transportation, heating, cooling, industrial production and more. With very few exceptions, there are other means or resources (e.g. solar, natural gas and alternative liquid fuels) that can produce these same benefits. As oil production declines and prices increase, substitutes for oil become increasingly attractive. In this sense, any resource that can be depleted, such as fossil fuels, serves only as a transition to long-term renewable options. Like energy, water is used for a wide variety of purposes and, like energy, the efficiency of water use can be greatly improved by changes in technologies and processes. Unlike oil, however, fresh water is the only substance capable of meeting certain needs and has no substitutes for most uses.

As a result, when peak water limits are reached, there are only a few possible options for satisfying new needs; (1) reducing demand, (2) substituting one use of water for another that has higher economic or social value, (3) physically moving the demand for water to a region where additional water is available, or (4) investing in a higher priced source of supply, including bulk imports or transfers of water. For water, the cost of a new supply, including the cost of transporting water, is often a key limiting factor.

A relevant concept to both peak water and peak oil, therefore, is the introduction of a 'backstop' technology when the price of the resource rises. This was described early by Nordhaus (1973) who defined a backstop to be an alternative capable of meeting the demand with a virtually infinite (or renewable) resource base. According to classical economics, as oil production peaks and then declines, the price of oil will rise until the point when a substitute, or backstop, for oil becomes economically competitive. At this point prices stabilise at the new backstop price.

Similarly, for water, as cheaper sources of water are depleted or allocated, more expensive sources must be tapped, either from new supplies or the reallocation of water among existing users. Ultimately, the 'backstop' price for water will also be reached. Unlike oil, however, which must be backstopped by a different, renewable energy source, the ultimate non-renewable water backstop is to identify and tap a renewable source, such as desalination of ocean water. The amount of water in the oceans that humans can use is limited only by how much we are willing to pay to remove salts and transport it to the point of use, and by the environmental constraints of using it. The growing use of costly desalination in regions where water is scarce is a clear example of peak water limits falling back on an expensive renewable alternative (NRC, 2008; Cooley et al., 2006).

Transportability

Because the Earth will never 'run out' of fresh water, concerns about water scarcity result from the tremendously uneven geographic distribution of water (due to both natural and human factors), the economic and physical constraints on tapping some of the largest volumes of fresh water (such as deep ground water or ice in high-latitude environments), human contamination of some readily available stocks and the high costs of moving water from one place to another.

This last point – the 'transportability' of water – is particularly relevant to the concept of peak water. Oil is transported around the world because it has a high economic value compared to the cost of transportation. For example, one of today's supertankers carries as much as 3.6 million barrels of oil. At prices approaching $100 per barrel in 2011, that oil would be worth $360 million dollars and the cost of transportation is minor. As a result, regional limits on oil availability can be overcome by moving oil from any point of production to any point of use and there is a large international trade in oil. In contrast, that same supertanker filled with fresh water would have an economic value of only around $500,000 assuming a price equivalent to what industry and urban users might pay for high-quality reliable municipal supplies. This is far too little to support the high costs of long-distance shipping. As a result, we see almost zero international trade in water, with the exception of very short term and short distance emergency transfers such as those associated with the recent Japanese earthquake, tsunami and nuclear disaster where emergency water was brought in by tanker.

As a result, the concept of 'peak water' is primarily a local issue. Where water is scarce, water constraints and the real implications of a 'peak' in availability are already apparent. Because the costs of transporting bulk water from one place to another are so high, once a region's water use exceeds its renewable supply, it will begin tapping into non-renewable resources, such as slow-recharge aquifers. As noted above, once extraction of water exceeds natural rates of replenishment, the only long-term options are to reduce demand to sustainable levels, move the demand to an area where water is available, or to shift to increasingly expensive sources, such as desalination or imports of goods produced in regions with adequate water supplies, the transfer of so-called 'virtual water' (Allan, 1999).

Science and policy relevance: three peak water concepts

Given the physical and economic characteristics of resources presented above, how relevant or useful is the concept of a peak in the production of water? Gleick and Palaniappan (2010) present three definitions of 'peak water' in the context of water resources management – 'peak renewable', 'peak non-renewable' and 'peak ecological' water. These peak water concepts should help drive important paradigm shifts in how water is used and managed.

Peak renewable water

A significant fraction of the total human use of water comes from renewable water resources taken from rainfall, rivers, streams and ground water basins. Such systems experience stochastic and variable hydrology, but the use of the water does not affect the ultimate renewability of the resource, much like solar energy use. Because a particular water source may be renewable, however, does not mean that it is unlimited. Indeed, the first 'peak' water constraint is the limit on total renewable flows of water that can be withdrawn from a system.

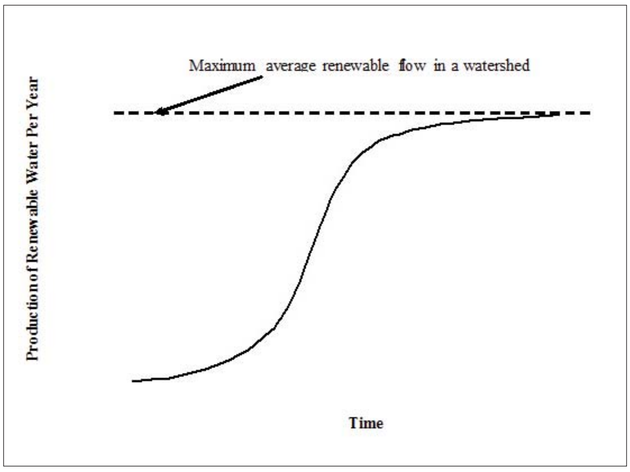

Figure 2. The theoretical logistics curve shows increasing annual production of renewable water from a watershed. Annual renewable water production increases exponentially, and then levels off as it reaches the total annual renewable water supply in the watershed.

When the production of renewable water from a watershed reaches 100 per cent of renewable supply, it forms a classic logistics curve (Fig. 2). Each watershed only has a certain amount of renewable water supply that is replenished every year. If the annual production of renewable water from a watershed increases exponentially, it eventually approaches the natural limits of the total annual renewable supply of water (shown as a dashed line). This limit may go up or down with natural hydrologic variability, but it is an ultimate limit in terms of appropriation of a renewable water supply. The appropriate practical limit may be substantially less than this, as discussed below under peak 'ecological' water. Increasing annual renewable water use to the theoretical renewable limit has been shown to result in ecological, environmental and human damage.

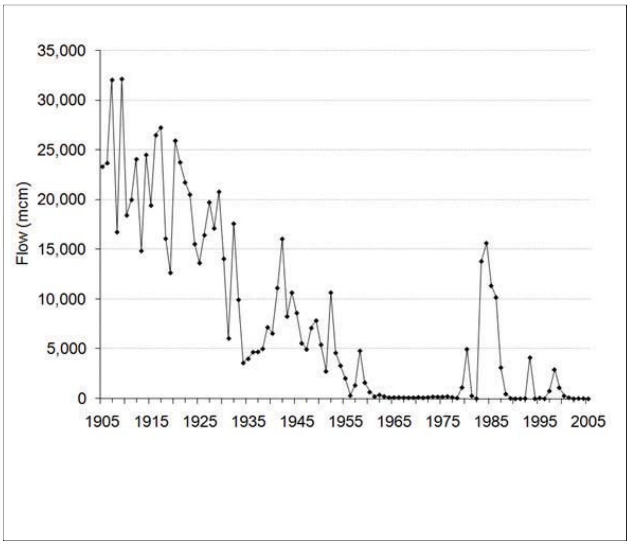

Figure 3. Annual flows (in million m3) of the Colorado River into the delta from 1905 to 2005 at the Southern International Border station. Note that in most years after 1960, flows to the delta fell to zero as total withdrawals equalled total (or peak) renewable supply. The exceptions are extremely high-flow years when runoff exceeded demands and the ability to store additional water (IBWC, 2010).

For a number of major river basins, peak renewable water limits have already been reached as human demand consumes close to the entire annual supply. The Colorado River in the US, for example, is shared by seven U.S. states and Mexico, and in an average year no water reaches the delta (Fig. 3). For this watershed, the limit of peak renewable water is an average of around 18 billion m3 annually – the total average annual flow. Other rivers are increasingly reaching their peak renewable limits as well, including the Huang He (Yellow River) in China, the Nile in northern Africa and the Jordan in the Middle East, where formerly perennial river flows now often fall to zero.

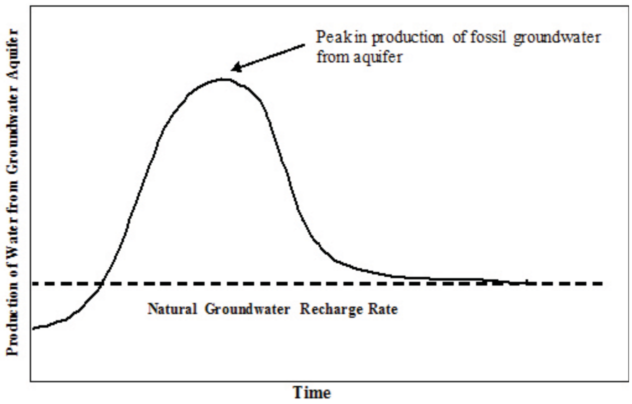

Figure 4. This theoretical curve shows the progression of unsustainable water extraction from a ground water aquifer, hypothesizing a peak-type production curve for water after the production rates surpass the natural ground water recharge rate and production costs rise. Long-term sustainable withdrawals cannot exceed natural recharge rates.

Peak non-renewable water

In some watersheds, a substantial amount of the current water use is satisfied by non-renewable sources, such as ground water aquifers with very slow recharge rates or over-pumped ground water systems that lose their ability to be recharged due to compaction or other physical changes in the basin. When the use of water from a ground water aquifer far exceeds the natural recharge rate, this stock of ground water will be quickly depleted; or when ground water aquifers become contaminated with pollutants that make the water unusable, a renewable aquifer can become non-renewable.

Peak non-renewable water is most analogous to the concept of peak oil. Continued production of water above natural recharge rates will become increasingly difficult and expensive as ground water levels drop, leading to a peak of production, followed by diminishing withdrawals and use. This kind of unsustainable ground water use can be seen in the Ogallala Aquifer in the Great Plains of the U.S., the North China Plains, around Bangkok, Thailand, in parts of California's Central Valley and numerous basins in India (Chatterjee and Purohit, 2009). Tiwari et al. (2009) estimate that the non-renewable use of water in India averaged 54 ± 9 km3 per year between 2002 and 2008 or around 8 per cent of India's total water withdrawals. Overdraft of ground water from California's Central Valley has been estimated at between 1.2 and 2.5 km^3 per year (CDWR, 2003).

Even when the rate of withdrawal from a ground water aquifer passes the natural recharge rate for the aquifer (shown as a dashed line, Fig. 4), the production of water from the aquifer can continue to increase until a significant portion of the ground water has been removed. After this point, deeper boreholes and increased pumping will be required to obtain additional water, potentially reducing the rate of production of water and substantially increasing the cost. When production of water from the aquifer becomes too expensive, the production of water drops quickly to the renewable recharge rate where economically and physically sustainable pumping is possible.

Peak ecological water

For many watersheds, a more immediate and serious concern than 'running out' of water is exceeding a point of use that causes serious or irreversible ecological damage. Water provides many services; it sustains human life and commercial and industrial activity, but it is also fundamental for the sustenance for animals, plants, habitats and environmentally dependent livelihoods (Daily et al., 1997, 2000; Gleick, 1998).

Each new water project that takes water for human use and consumption decreases the availability of that same resource to support ecosystems. The water taken by humans was once sustaining habitats and terrestrial, avian and aquatic plants and animals.

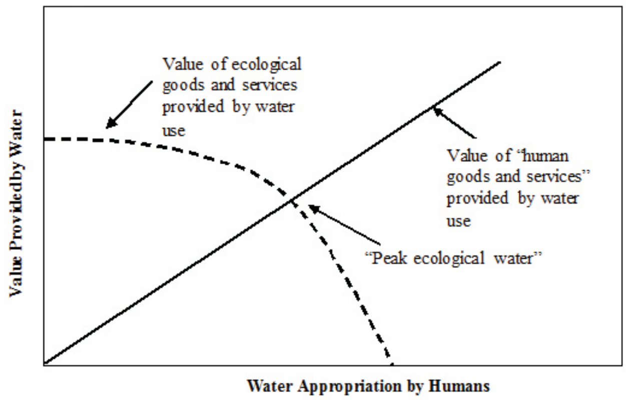

Figure 5. This graph charts the value of water provided by increasing supply from various sources in a watershed against the loss in value of ecological services provided by that water. As water withdrawals for human needs increase (solid line), the ecological services provided by same water are in decline (dashed line). At a certain point, the value of water provided through new supply projects is equal to the value of the ecological services. Beyond this point ecological disruptions exceed the benefits of increased water extraction. We call this point 'peak ecological water'

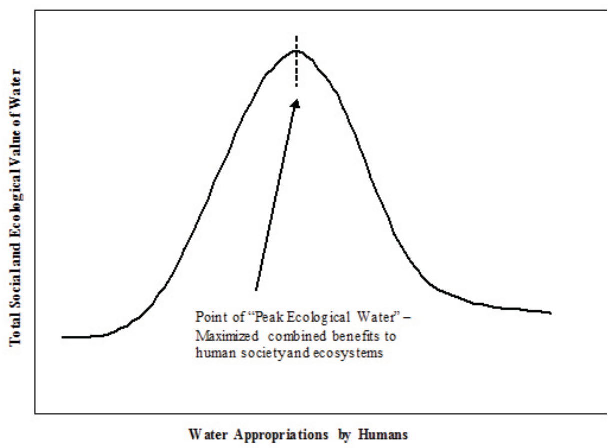

Figure 6. This g raph charts the overall value of water – a combination of social, economic and ecological values – as water appropriation by humans increases. The value increases to a peak, where benefits to society and ecosystems is maximised, but then declines as increased appropriations lead to excessive ecosystem and social costs. Non-monetary costs and benefits are hard to quantify, but must be included to avoid exceeding the point of 'peak ecological water.'

Since 1900, half of the world's wetlands have disappeared (Katz, 2006). The number of fresh water species has decreased by 50 per cent since 1970, faster than the decline of species on land or in the sea. River deltas are increasingly deprived of flows due to upstream diversions, or receive water heavily contaminated with human and industrial wastes.

Figure 5 is a simplified graph of the value that humans obtain from water plotted against the declining value of the ecological services that were being satisfied with this same water. The graph assumes that ecological services decrease as water is appropriated from watersheds (though in nature such declines may be non-linear).

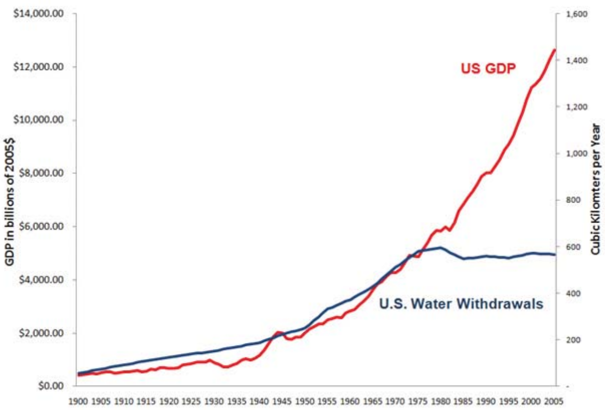

Figure 7. U.S. gross domestic product in 2005 dollars from 1900 to 2005 (left axis) plotted with total water withdrawals for all purposes in km3 per year (right axis). Source: Gross domestic product data, U.S. Department of Commerce (2011). U.S. Bureau of Economic Analysis , http://www.bea.gov/national/index.htm#gdp; water use data, Kenny et al. (2009).

The pace or severity of ecological disruptions increases as increasing amounts of water are appropriated. Because ecological services are not easily valued in financial terms, the y-axis should be considered the overall (economic and non-economic) 'value provided by water'.

At some point, the loss of ecological services provided by water is equivalent to the increased value of human services satisfied by using that same unit of water. After this point, increasing human use of water causes ecological disruptions greater than the value that this increased water provides to humans. Gleick and Palaniappan (2010) define this as the point of 'peak ecological water' – where society will maximise the total ecological and human benefits provided by water. The total value of water then declines as human appropriation increases (Fig. 6). While it is difficult to quantify this point because of problems in assigning appropriate valuations to each unit of water or each unit of ecosystem benefit in any watershed (Daily et al., 2000), the incorrect assumption that such values are zero has led to them being highly discounted, underappreciated, or ignored in 20th century water policy decisions.

Evidence for peak water in the US

Few countries or regions collect or release comprehensive data on human uses of water. Nevertheless, there is some strong evidence that some major regions of the world have already passed the point of 'peak water,' including all three of the concepts described above. Here we offer some examples from the US Figure 7 shows US gross domestic product (in 2005 dollars) plotted with total water withdrawals in the US, for all purposes, from 1900 to 2005, based on data from state and federal water agencies, compiled largely by the US Geological Survey's water use assessments (Kenny et al., 2009). These two curves grew exponentially, and in lockstep, through the first three-quarters of the 20th century. After the late 1970s, however, the two curves split apart, and total water withdrawals in the US are now well below their peak level. Per-capita water withdrawals have fallen even more, as the population has continued to grow. Some of the reasons for this dramatic change include improving the efficiency of water use, changes in the structure of the US economy, the implementation of the national Clean Water Act, which led to reductions in industrial water use and discharges, and physical, economic and environmental constraints on access to new supplies (Gleick, 2003).

Whether the US has truly reached a peak in water use is unknown. In theory, total water withdrawals could resume their rise again, but many factors suggest this is unlikely in the long run. Significant expansion of irrigated agriculture, which dominates US water use, seems improbable, especially in the western US where new land and water resources are simply unavailable to any significant degree or at an acceptable ecological and economic price. Almost all major rivers and aquifers are at the limits of their renewable and non-renewable supplies. Significant expansion of cooling water demand also seems unlikely because of physical constraints on water withdrawals (even in relatively well-watered regions), environmental restrictions on in-stream temperatures and flows, and because efforts to move from central water-intensive thermal plants to less water-intensive renewable systems are expanding.

Conclusions and recommendations

This paper presents three separate definitions of peak water – renewable, non-renewable and 'ecological' water – together with evidence that many regions of the world, including major portions of the US, have already passed the point of peak water. Peak water limits are far more worrisome than are constraints on petroleum, which has many substitutes. Water is fundamental for ecosystem health and for economic productivity, and for many uses it has no substitutes.

The concept of peak water does not mean we will 'run out' of water. Water is a renewable resource and is not consumed in the global sense; hence water uses within renewable peak limits can continue indefinitely. But not all water use is renewable; indeed some water uses are non-renewable and ecologically unsustainable. Ground water use beyond normal recharge rates follows a peak-oil type curve with a peak and then decline in water production. Such peak non-renewable water problems are increasingly evident in major ground water basins with critical levels of overdraft, such as the Ogallala and California's Central Valley in the US, the North China Plains, and in numerous states in India, such as Andhra Pradesh, Rajasthan and Tamil Nadu. 'Peak ecological water' limits are being reached where the cost of disruptions that occur in the ecological services that water provides exceeds the value ad provided by additional increments of water use by humans for economic purposes. Defined this way, many regions of the world have already surpassed 'peak ecological water' – humans use more water than the ecosystem can sustain without significant deterioration and degradation.

The concepts around peak water also lead to some important recommendations that result from new paradigm shifts in the use and management of water – what we call the "soft path for water." In regions approaching peak renewable and non-renewable limits, new efforts to rethink the concept of both water 'supply' and 'demand' are already underway in order to move back down the peak water curves to more sustainable levels. New 'supply' concepts, focused on expanding renewable limits, include recycling of water, tapping into salt water stocks through desalination, rainwater harvesting and new treatment techniques to permit new forms of reuse. Equally important are efforts at improving water use efficiency as a way to continue to meet current demands for food, industrial and commercial goods and services, and basic human needs with less water. These efficiency improvements permit withdrawals of renewable and non-renewable water to decrease, and in regions approaching peak constraints, such efficiency improvements are proving to be among the easiest, fastest and cheapest alternatives available (Gleick, 2002). Finally, in regions suffering from 'peak ecological water' limits, new efforts are underway to restore water for natural ecosystems – effectively moving back down the curve to the left in Fig. 6. Sometimes this takes the form of reducing human use of water or guaranteeing minimum ecosystem flows. These kinds of policies can be effective if we are willing to both identify peak limits and act to overcome them.

In conclusion, there are growing efforts to quantify peak ecological limits and to develop policies to restore water for ecosystem services in basins experiencing serious ecological disruptions. Regions that rely on ground water basins suffering from non-renewable withdrawals are under pressure to reduce withdrawals to more sustainable levels, or to better integrate surface and ground water management. The bad news is that we are increasingly reaching peak water limits. The good news is that recognizing and understanding these limits can lead to innovations and changes in behaviours that reduce water use and increase the productivity of water in a more sustainable way.

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HOW HORMONALLY ACTIVE SUBSTANCES IN OUR ENVIRONMENT AFFECT HUMANS AND WILDLIFE – WHAT DO WE KNOW AND WHAT CAN BE DONE?

Humans and wildlife face chronic exposure to contaminants such as pesticides, industrial and household chemicals, pharmaceuticals, personal care products and natural hormones. Some of these chemicals contain or present endocrine disrupting compounds (EDC). They can be detected in wastewater, surface and ground water, tap water and even in bottled water. EDCs cause effects at very low concentrations. The onset of effects may be delayed, occurring long after exposure, and sometimes only becoming apparent in the next generation. This makes their identification especially challenging. Effects in aquatic wildlife include reproductive disturbances, sterility and population decline. In humans, malformations, hormone-related diseases and abnormal gonadal development are considered to be possibly related to increased exposure to EDC's. Technologies, such as advanced wastewater treatment (for example with ozonation and activated carbon) can reduce the EDC concentrations in effluents. Also, measures that prevent the entry of these compounds into water bodies, provide options for reducing exposure concentrations.

Key words: endocrine disruption, environmental hormones, fish, effect, pharmaceutical- mitigation measures

Purpose and aim of the article

Aquatic ecosystems are especially prone to exposure to compounds with endocrine-disrupting activity, because a great variety of substances exhibiting such activity are intentionally or accidentally released into our surface waters. In this paper, background information on endocrine disrupting compounds and their sources will be presented and followed by an outline of several critical aspects, such as sensitive windows, and low-dose and mixture effects. Subsequently, some of the studied effects observed both in humans and in aquatic animals are summarised. Finally, potential mitigation measures including not only technological solutions, but also societal approaches, will be addressed and critically discussed.

Scientific relevance

What are endocrine disruptors and why are they problematic?

Endocrine disruptors – also named endocrine disrupting compounds (EDCs), endocrine active substances/agents or environmental hormones – comprise a multitude of chemicals, which affect the endocrine (hormone) systems of animals and humans. They are active ingredients in pharmaceuticals, but also include natural hormones (such as phyto- and mycoestrogens) as well as other compounds, many of which are used in industry, agriculture and households (Table 1).

The endocrine system releases hormones, which act as chemical messengers on receptors in organs and cells. These are under feedback control from external and internal stimuli. At critical periods during the development of an embryo (named 'sensitive windows') hormones set the course for the future. In several fish species for example, hormones determine the sex (organizational function) (Piferrer et al., 2001). Later in life hormones mainly have activating or inhibiting functions, such as stimulating the growth and activity of cells and organs. The former effects are mostly irreversible, while the latter are generally reversible.

Since many EDCs act via receptor binding, extremely low concentrations may be sufficient to exert a response, thus making them more problematic than compounds with a threshold for toxicity. For example, 17α-ethinylestradiol (EE2), the active ingredient in many contraceptive pills, induces the synthesis of the yolk protein precursor vitellogenin [a specific and sensitive indicator for exposure to (xeno)estrogens] in fish at concentrations 1'600'000-fold lower than the concentration necessary to cause the death of 50 per cent of the test fish population (LC50) (Sumpter and Johnson, 2005). In comparison with adults, embryos and foetuses are even more sensitive to compounds which cross the placenta or are transferred via the yolk into the embryo. This often results in delayed effects due to an early exposure (Segner, 2011). Furthermore, current research also indicates that transgenerational effects occur through an alteration of the developmental programming induced by endocrine disruptors. These are persistent, heritable changes of gene expression caused by alterations in the pattern of DNA methylation.

An emerging issue is the field of mixture toxicology: so far, studies have mainly concentrated on the effects of single compounds. However, different compounds in combination might show cumulative effects, regardless of the mechanism or mode of action of the individual compounds. Putting aside the joint actions of combined chemicals, even less is known about the combined effects of chemical and physical and/or biological stressors. Exposure of juvenile trout to 17-beta-estradiol (E2) in combination with the fish-pathogenic parasite Tetracapsuloides bryosalmonae, the etiological agent of the deleterious proliferative kidney disease (PKD), resulted in significant inhibition of both the rate and the magnitude of the biomarker vitellogenin response, while neither the parasite's nor the fish's response to the parasite was affected by the presence of estradiol alone (Burki et al., 2010).

This research topic has gained much attention in recent decades and will continue to do so in the future for several reasons. The number of synthetic chemicals is steadily increasing: more than 56 million organic and inorganic substances are registered worldwide and 12,000 substances are added every day (CAS Registry, 2010). The EU has listed more than 550 substances for which there is either clear evidence to prove that they are, or can be suspected to be, endocrine disruptors (European Commission DG ENV, 2007). In the US, 207 chemicals and substances have been identified as priorities within the Environmental Protection Agency's (EPA) drinking water and pesticides programmes (U.S. EPA, 2010). The demographic change, with increasing numbers of elderly people, goes along with a considerable increase in prescriptions and consumption of medication. In the US from 1993 to 2003, the purchase of pharmaceuticals increased by 70 per cent whereas the population increased by only 17 per cent (Ruhoy and Daughton, 2007).

Which are the best studied endocrine disruptors?

There exist large amounts of EDCs which have complex interactions and feedback mechanisms on various biological levels. Nevertheless, only few endpoints of endocrine disruption have been intensely studied, namely those of the estrogenic and the androgenic axis. Compounds interfering with these hormone systems are also named (xeno)estrogens and (xeno)androgens, respectively. Additional effects, for example on the thyroidal, the retinoid and corticosteroid systems (amongst others) have not been investigated systematically. It is important to note that the various compounds have different estrogenic potencies: for the (xeno)estrogens, estradiol serves as a reference (relative potency = 1). By contrast, most of the compounds studied so far have a lower relative potency (estrone: 0.3; 4-tert-nonylphenol: 0.0025; and bisphenol A: 0.0004) (Sumpter and Johnson, 2005).

Table 1. Endocrine disruptors, their use and examples of effects in humans and aquatic animals.

Class	Examples of substances	Use	Primarily affected hormone system in humans	Examples of negative endocrine effects on aquatic animals	Examples of negative endocrine effects in humans or mammals
Natural hormones and metabolites	17-ß-estradiol (E2) estriol (E3) estrone (E1) therapy	contraception & hormone replacement	estrogenic 2008)	spermatogenesis, vitellogenin (VTG) (Koerner et al.,	

Class	Examples of substances	Use	Primarily affected hormone system in humans	Examples of negative endocrine effects on aquatic animals	Examples of negative endocrine effects in humans or mammals
Synthetic hormones	17-ethinylestradiol (EE_2) diethylstil-bestrol (DES)	contraception & hormone replacement therapy	estrogenic	fertility, intersex (Laenge et al., 2001)	infertility, vaginal adeno-carcinomas in daughters, gender dysphoria (Kerlin, 2006)
Phyto- and mycoestrogens	isoflavones, lignans, coumestans stilbenes, zearalenone, genestein	hormone treatment, health	estrogenic	reproduction (Schwartz et al., 2010)	male fertility (West et al., 2005)
Veterinary growth hormones	anabolic steroids: trenbolone, acetate, melengestrol acetate	fast growth of meat producing animals	androgenic	reproduction, demasculization (Orlando et al., 2004)	affinity for human androgen receptor (Wilson et al., 2002)
Drugs with hormonal side effects	Ibuprofen diclofenac paracetamol	anti-inflammatory, painkiller	estrogenic	reproduction pattern, prosta glandin synthesis (Flippin et al., 2007)	effect on human receptor in in-vitro assay (Isidori et al., 2009)
	fibrates: bezafibrate, clofi-brate, gemfibrozil, fenofibrate	lipid regulator	estrogenic	VTG, sperm count and plasma androgen concentration (Runnalls et al., 2007)	effect on human receptor in in-vitro assay (Isidori et al., 2009)
	Atenolol metopropol propanolol	ß-blocker	estrogenic	number of eggs (Huggett et al., 2002)	weak effect on human receptor in in-vitro assay (Isidori et al., 2009)

Class	Examples of substances	Use	Primarily affected hormone system in humans	Examples of negative endocrine effects on aquatic animals	Examples of negative endocrine effects in humans or mammals
	oxytetracycline erythromycin sulfathiazole chlortetracycline	antibiotic	estrogenic steroidogenic	estradiol in plasma (Ji et al., 2010)	effect on human receptor in in-vitro assay (Isidori et al., 2009)
Pesticides, herbicides, fungicides & metabolites	DDT/DDE	pesticides	estrogenic anti-androgenic thyroid	VTG (Uchida et al., 2010)	female reproductive organs (Tiemann, 2008)
	Vinclozolin	fungicide	estrogenic anti-androgenic	steroidogenesis, spermatogenesis, fertility (Martinovic-Weigelt et al., 2011)	spermatogenesis, fertility in rats (Anway et al., 2005)
	endosulfan maneb, mancozeb, metiram, zineb (metabolites)	pesticide	estrogenic thyroid	thyroid hormone metabolism (Coimbra et al., 2005)	maturation of boys (for review Roy et al., 2009)
	tributyl tin and compounds	biocide	anti-estrogenic androgenic	fertility, imposex & intersex (for review Matthiessen and Gibbs, 1998)	testicular development and function in rats (Kim et al., 2008)
Industrial and household chemicals	PCB, PBB (brominated biphenyls), PBDE (brominated diphenyl esther) PHAH (poly halogenated aromatic hydrocarbon)	paints, furnishings, flame retardants	estrogenic thyroid	T3 and T4 levels (Brown et al., 2004)	toxic effect on thyroid, T4 levels (Kodavanti, 2006)
	furan, dioxins (e.g. TCDD)	byproduct in many industrial processes	estrogenic thyroid	T3 and T4 levels (Brown et al., 2004)	T4 levels, thyroxine agonist (for review Verma and Rana, 2009)

Class	Examples of substances	Use	Primarily affected hormone system in humans	Examples of negative endocrine effects on aquatic animals	Examples of negative endocrine effects in humans or mammals
	alkylphenols: propyl phenol, butyl phenol, nonyl phenol, octyl phenol, alkyl phenol derivates, (NP1EC, NP2EC)	surfactants	estrogenic androgenic	feminization, male fertility, gross morphology/ histology, VTG, spermato-oogenesis, (Harries et al., 2000)	progesterone receptor in human cells, mitotic activity in rat endometrium (Soto et al., 1991)
	bisphenol A	plasticisers	estrogenic androgenic	gross morphology/ histology, VTG, spermato-oogenesis, fertility (Sohoni et al., 2001)	testosterone & estradiol levels, ovarian morphology, fertility in rats (Fernandez et al., 2010)
	phthalates: butyl-benzylphthalate Di-(2-ethylhexyl) phthalate DEHP	plasticisers	estrogenic	VTG (Barse et al., 2007)	male reproductive system (Barrett, 2005)
	Perchlorate	solid rocket fuels	thyroid	reproduction, hermaphroditism, thyroid histology (Patino et al., 2003)	
	heavy metals: cadmium, lead mercury etc.	various	estrogenic, androgenic hypothalamic-pituitary adrenocortical axis	steroidogenesis, gametogenesis, ovulation, VTG, fertility (for review Tan et al., 2009)	fertility, endometrium, spermatogenesis, CNS effects, testes (for review Tan et al., 2009)
Personal care products	homosalate benzophenone-3 3-benzylidene camphor octyl-methoxy-cinnamate	UV screens	estrogenic reproduction	fertility, gonadal development, (Kunz et al., 2006)	estrogenicity in rat assay (Schlumpf et al., 2001)
	Parabens	cosmetics	estrogenic	VTG, histo-metabolic changes (Barse et al., 2010)	unclear (for review Boberg et al., 2010)

Policy relevance

Where do we find endocrine disruptors in the aquatic environment?

Endocrine disruptors are structurally very diverse, which makes a systematic search difficult, if not impossible. A major challenge is the detection of these compounds in the environment, where they are mostly present at fluctuating concentrations and often at concentrations close to the analytical detection limit (Snyder et al., 2006). For their identification, screening tests have been developed, standardised and validated in many countries (US EPA, 2010). National and regional screening programmes exist and the World Health Organization (WHO) evaluates EDCs worldwide (WHO, 2010).

Endocrine disruptors are present in surface waters, such as rivers, streams, lakes and oceans (for review: Burkhardt-Holm, 2010). The pharmaceuticals diclofenac, bezafibrate and clofibrate, for example, are found in the river Rhine in concentrations of tens to hundreds ng/L (Sacher et al., 2008). The highest concentrations are commonly detected in sewage treatment plant effluents (lower µg/L range for pharmaceuticals, lower ng/L range for estrogens; for review see Caliman, 2009; Schulte-Oehlmann et al., 2007; Johnson et al., 2005; Adler et al., 2001). EDCs have also been detected in drinking water (up to tens of ng/L; Adler et al., 2001), and even in some samples of bottled water (up to tens of ng/L; Wagner and Oehlmann, 2009).

What do they do?

Alterations in the endocrine system can lead to disturbances of homeostasis, ultimately leading to miscarriage, failures in development and reproduction, and even to death. Whereas effects in laboratory experiments are easy to demonstrate, clear cause–effect relations in humans or on the population level in wildlife are more difficult to establish. This is mainly due to a long delay in the occurrence of effects, the cumulative effects as well as the difficulty of distinguishing EDC effects from those of other relevant stressors, such as competition between species or habitat destruction (Burkhardt-Holm et al., 2008). The endocrine system is an evolutionary highly conserved system in vertebrates. Adverse effects observed in fish and other sentinel species are therefore also of great relevance to humans.

Effects on male fertility and diseases in humans

A considerable decrease in human sperm counts (which have fallen by nearly half in the last 50 years) has been attributed to EDCs in our environment (Sharpe and Skakkebaek, 1993; Carlsen et al., 1992). In several populations, sperm counts were only twice the number which is still considered normal (20 × 106 /ml) according to the WHO. Among young European men (18-25 years of age), 15-20 per cent exhibit sperm counts below this threshold (Andersson et al., 2008). However, differences with respect to geographical and ethnic variation, as well as differences in design and methodology between the studies, still cause controversial debates. There is a need for more standardised research approaches. The risk of environmental endocrine disruptors to disrupt spermatogenesis is assessed as low – in contrast to exposure in an occupational setting (for review see Sharpe, 2010).

Exposure to EDCs is also being discussed as a potential cause for testicular cancer, which is the most common cancer in young men. Incidences have almost doubled within recent decades, with annual increases of from 1 per cent to 2 per cent in Switzerland and Norway and 6 per cent in Spain (Bray et al., 2006).

Effects on female fertility, and on disorders and diseases in humans
Epidemiological studies indicate positive correlations between the levels of estrogenic compounds in tissue and the risk of breast cancer. Exposure to estrogenic disruptors during foetal and prenatal stages induces a premalignant and malignant transformation of adult mammary glands in rodents. Taken together, this strongly suggests that endocrine disruptors may account for the increasing incidence of breast cancer (1 per cent per year), which is the most frequent cancer in women and the leading cause of cancer death worldwide (Fenichel and Brucker-Davis, 2008).

Effects in aquatic animals

Aquatic animals are at risk due to their constant exposure to contaminated water and due to the ingestion of contaminated food. Reproductive and developmental impairments of various species in the wild are associated with exposure to endocrine active compounds (Segner, 2011; Scholz and Kluver, 2009; Sumpter and Johnson, 2005). As an example, population declines and limb malformations in amphibians have been found to be associated with pesticide exposure (Loeffler et al., 2001). In alligators in Lake Apopka and contaminated wetland sites, alterations of gonad morphology, steroidogenesis, and reduced penis size have been reported (Milnes and Guillette, 2008). Clear dose–response relationships between exposure to xenoestrogens or alkylphenols and feminization of fish or increase of vitellogenin in male fish were found in a great variety of fish species and under various experimental conditions (Schubert et al., 2008; Sumpter and Johnson, 2005). In addition, in-situ exposure to point-of-source pollution by endocrine disruptors, such as sewage treatment plant effluents and pulp and paper mill effluents, has been reported to be significantly associated with a range of deleterious effects on reproduction in fish (Laenge et al., 2001). The questions of greatest interest are which critical concentrations induce detrimental effects in fish and whether such concentrations are measured in the environment. Concentrations of from 1 to 3 ng/L EE2 induce measurable changes in fish reproduction under laboratory conditions (Koerner et al., 2008; Vermeirssen et al., 2005; Laenge et al., 2001) and correspond to the median concentration of some sewage treatment plant effluents in countries such as Germany, England, Netherlands and the US (Heberer, 2002).

Whether such alterations translate into changes in the recruitment in wild fish populations is rarely substantiated. The most convincing study is that of Karen Kidd et al. (2007) which showed that the long-term addition of ethinylestradiol to an experimental lake led to impaired reproduction or even to the near extinction of one fish species in that lake.

Invertebrates have been studied far less and their endocrine system deviates considerably from that of vertebrates, suggesting that their responses might be different, and probably less obvious. However, one of the best examples for an EDC-induced population decline was reported in marine molluscs. Exposure to very low concentrations of tributyltin (a biocide used for wood preservation and as an antifouling and antifungal compound in ship painting) caused irreversible reproductive abnormalities in several aquatic mollusc populations, in which female animals developed male sex characteristics, eventually leading to their mass extinction (Matthiessen and Gibbs, 1998). Even though much research has been done, many important questions, such as reversibility and the effects of endocrine disruptors in combination with other environmental stress factors, remain unanswered (Segner, 2011; Scholz and Kluver, 2009).

Risk assessment

Several national authorities have developed guidelines for risk assessments to predict the impact of endocrine disruptors. In Europe, an environmental risk assessment (ERA) is compulsory for a market authorization of pharmaceuticals (directive 2004/27/EC) and veterinary medicine (2004/28/EC). The consistent technical standard for implementing the ERA states that potential endocrine disruptors need to be addressed irrespective of the quantities released into the environment (EMEA, 2006). Although assessing the risks posed by chemical compounds is a standardised and formalised process that fills dozens of books and papers (e.g. Kendall et al., 1998), the evaluation of the reliability and relevance of the studies by various experts leads to extremely different outcomes in risk assessments (Beronius et al., 2010). A lack of knowledge of the mechanisms of action makes it difficult to extrapolate results from in vitro and animal experiments to human health risks. In conclusion, the lack of generally accepted criteria for the interpretation and evaluation of data from studies on endocrine disruptors for ERA is unsatisfying. Establishing causative links between exposure and adverse effects is difficult and many more epidemiological and eco-epidemiological studies are necessary to evaluate the potential risk associated with exposure (Daston et al., 2003).

What can be done?

Since EDCs are present in a great variety of products, contamination pathways are manifold, and responsibilities, regulations and potential mitigation measures must take this into account and be modified accordingly.

Technologies

Conventional water treatment plants use coagulation, flocculation, sedimentation and filtration techniques and can thereby only partly remove endocrine active compounds (Snyder et al., 2003). Biodegradation and sorption are the principal processes for removing estrogenic compounds. Removal rates for the most common (xeno)estrogens vary between 50 per cent to almost 100 per cent in activated sludge treatment, depending on the type of process, oxygen supply, hydraulic retention times and other factors (Koh et al., 2008). Effluent concentrations of specific estrogens may be higher than in the sewer, due to degradation and biotransformation of inactive conjugates excreted by humans (Panter et al., 1999). Advanced treatment processes consist of various additional oxidation processes (such as ozonation), sorption on activated carbon, biofiltration, membrane filtration (reverse osmosis, nanofiltration), aeration, chemical softening or ultraviolet irradiation, which are evaluated according to their performance to remove EDCs (Snyder et al., 2003).

While the incorporation of advanced technologies is often not feasible for sewage treatment operators, a simple process modification could help. Optimizing the activated sludge process (e.g. prolongation of the hydraulic retention time and sludge retention time) is recommended as a cost-effective measure, as is adding powder-activated carbon to conventional treatment plants during high risk periods of EDC occurrence in raw water (Koh et al. 2008; Synder et al., 2003).

Since about 50 per cent of excreted pharmaceuticals and their metabolites primarily enter the sewerage via urine, on-site technologies, such as urine separation, have great potential in separating compartments with critical loads of endocrine active agents. They can then be eliminated via adsorption processes, which are easier and more cost-efficient in undiluted urine than in highly diluted waste water (Larsen et al., 2009). However, urine separation has to be accepted by the user. Several studies have been carried out to improve the NoMix toilet technology and to raise the users' acceptance (Lienert and Larsen, 2006).

Societal change

In addition to the residues of consumed drugs that enter the environment (after excretion or bathing), drugs are commonly also directly disposed of in drains. This practice is widespread and causes serious concern (Table 2) (Tong et al., 2011). Programmes for the proper disposal are underway in various countries. According to §127b, EU directive 2004/27/EC, all member states are obliged to establish safe disposal schemes. As of 2010, 10 members have established obligatory take-back schemes. In addition, 16 other European countries have launched voluntary return programs (Vollmer, 2010). In Spain, for example, the pharmaceuticals collected in 2009 increased by 14.6 per cent compared to 2008 (Sigre, 2009). Disposal instructions (ONDCP, 2009) and multiple take-back programmes are in place in the USA, and in Canada, where there are a variety of disposal programmes at the provincial, municipal and community levels (Gagnon, 2009). To our knowledge, the legal regulation of drug disposal is missing in most countries of the world.

Table 2. Improper disposal of medication.

Country	Type	Disposed to of study /or toilet	Disposed sink and	Returned to to waste	Remarks pharmacy	References
UK	representative survey	12 per cent	63 per cent	22 per cent	8 groups of pharmaceuticals	Bound and Voulvoulis, 2005
UK	representative survey	0 per cent	75 per cent	25 per cent	hormone drugs	Bound and Voulvoulis, 2005
Kuwait	questionnaire	11 per cent	77 per cent	12 per cent		Abahussain and Ball, 2007
US	convenience sample of patients	54 per cent	n.a.	23 per cent		Seehusen and Edwards, 2006
Germany	representative survey	19 per cent	16 per cent	40 per cent	liquids; multiple entries possible; method used always or often	Goetz and Keil, 2007
Switzerland	questioned in a public library	1 per cent	13 per cent	76 per cent	return to pharmacy is proposed by federal agencies	Lienert et al., 2007
New Zealand	online survey	55 per cent	24 per cent	17 per cent	liquids	Braund et al., 2009
New Zealand	online survey	19 per cent	51 per cent	24 per cent	solids	Braund et al., 2009
California	random telephone survey	28 per cent	45 per cent	6 per cent		Kotchen et al., 2009
Sweden	random telephone survey	n.a.	3 per cent	43 per cent	survey 2007	Persson et al., 2009

Education plays a significant role in prevention: in the past counselling has resulted in significantly higher returns of medications to pharmacies (Seehusen and Edwards, 2006).

A reduction of endocrine substances in the environment could also be achieved via a decrease in the production and use of endocrine disrupting chemicals and pharmaceuticals. This would, however, require a fundamental change in the economy, health industry, politics and – ultimately – society.

'Green chemistry' can be defined as the "design, development, and implementation of chemical products or processes to reduce or eliminate the use and generation of hazardous and toxic substances" (Hjeresen et al., 2002). As an example, the endocrine disrupting pesticides DDT, lindane, aldrin and dieldrin were replaced by carbamate and pyrethroid which are less toxic and have a higher biodegradability. The endocrine disrupting antifouling agent tributyltin was replaced by the isothiazolone compound Sea-Nine (Jacobson and Willingham, 2000).

Green pharmacy' tackles the problem of pharmaceutical residues in the environment by developing green drugs, preventing their release into the environment and improving treatment in water purification plants (Sumpter, 2010). Special attention is given to product life cycle management ('cradle-to-cradle design', Daughton, 2003) which comprises an environmentally friendly manufacturing method, non-hazardous ingredients and good biodegradability. Changes in manufacturing are important because emissions through waste production during the manufacture of pharmaceuticals may traditionally exceed those of the pharmaceutical residues by a factor of 100 (Sheldon, 2007).

Legal regulations

Neither in Europe nor in the U.S. are threshold values regulated for human or veterinary pharmaceutical residues or EDCs in drinking water, wastewater effluent or natural water bodies. Some legislation exists at the state or regional level (e.g. perchlorate in some US States). Environmental impacts during the production phase of chemicals and pharmaceuticals in Europe are covered by the EU IPPC directive 96/61/EC on Integrated Pollution Prevention Control from Industrial Sources (Kampa et al., 2010).

Analysis

Regarding both the exposure and effects of EDCs, many scientists assume that we currently know only the tip of the ice berg. The European production of the estrogenic disrupting chemical bisphenol A, for example, has risen from 685,000 tonnes in the period 1996 to 1999 to 1.18 million tonnes in 2005/2006, whereas global production amounted to 3.8 million tonnes in 2006 (UBA, 2010; Munn et al., 2003). Ibuprofen tops the list of pharmaceutical sales in Germany at 345 tonnes per year (BLAC, 2003). However, no figures are available for the amount of personal care products which are used and have adverse endocrine disrupting effects (Ternes et al., 2003). In addition, there is no routine monitoring of the known compounds, while the endocrine potency of many of those sold and consumed is rarely studied.

Whether endocrine active compounds present in water cause adverse effects in human beings is controversial (Snyder et al., 2003). There are several pitfalls to the thinking: while fish are constantly exposed to EDCs in water, humans are mainly exposed to EDCs through the ingestion of water. However, some beverages contain more EDCs than pure drinking water (such as leachates from plasticisers, or disinfectant by-products). Furthermore, the contribution of exogenous hormones to reproductive disturbances and disease in humans is extremely difficult to prove, since EDCs are not only ubiquitous, but may also act jointly with other compounds or confounding variables and there is no unexposed control group. What makes it even harder is the long lag time between exposure and effect. Who knows what his or her mother might have been ingesting during the second or third month of pregnancy? In fact, the lack of exposure data during critical periods of development is one of the biggest hindrances to determining whether observed adverse effects have a causative link to such exposure (WHO, 2002).

Conclusions and recommendations

Extremely low concentrations of EDCs are sufficient to induce effects. However, measurements of such low concentrations are especially demanding. This is a great challenge, especially for densely populated regions or countries which cannot afford adequate monitoring and efficient mitigation measures. However, it has to be emphasised that optimization of existing treatment technologies, such as the prolongation of hydraulic retention time and sludge retention time, can contribute considerably to improved removal of at least some EDCs (Koh et al., 2008).

In the long term, measures at the source should be combined with advanced sewage treatment technologies, such as ozonation and use of activated carbon. However, such measures entail large financial investments and running costs, as well as increases in energy consumption and CO_2 emissions (Koh et al., 2008; Joss et al., 2008).

For the future, we are in need of enhanced sustainable water management and better protection of our water bodies. (1) We are confronted with a steadily increasing population and increasingly large urban agglomerations. The ageing of the human population and the increasing use of pharmaceuticals and other chemicals will contribute to increasing chemical contamination, especially in urban and peri-urban areas. (2) Other non-point sources, such as agriculture, contribute to environmental pollution, and all this is (3) accompanied by the need to re-use wastewater, due to climate change-induced water scarcity – an issue which is aggravated by the considerable amount of sewage water lost via leakage in many regions.

The risk for humans raised by exposure to endocrine disrupting compounds is difficult to assess. A lack of generally accepted criteria for the evaluation and the extrapolation of results from animals shows the need for a transparent and open discussion and the application of the precautionary principle.

To conclude, attention should be directed to:

- Improving wastewater technology to reduce the input of EDCs into surface and ground water systems.
- Raising awareness, improving education and communicating issues related to risk assessment, sustainable production and the use of chemical compounds which might harm humans and the environment. Such programs should be directed at various stakeholders, including professionals ranging from engineering authorities, industries, health care and consumers.
- Promoting personalised medicine and pharmacogenomic research and promoting 'green chemistry' and 'green pharmacy'.
- Allowing the recycling of unused medicine and leftover drugs and household products and establishing and improving take-back programmes for which harmonization and standardization is necessary.

Acknowledgement

I would like to thank Susanne Wolfer for her thorough literature work and Nadia von Moos for her linguistic support.

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GLOBAL CHALLENGES TO WASTEWATER RECLAMATION AND REUSE

Water pollution control efforts in many countries have made reclaimed water from municipal wastewater suitable for what is an economical augmentation of existing and future water supplies, compared to the increasingly expensive and environmentally destructive development of new water resources, such as dams and reservoirs. The trend is to consider wastewater reclamation and reuse as an essential component of sustainable and integrated water-resource management. In this paper, global challenges to wastewater reclamation and reuse are examined, focusing on significant developments worldwide.

Key words: integrated water-resource management, public acceptance, public health, treatment, wastewater, water reuse.

Wastewater reclamation and reuse

'Wastewater reclamation' is the treatment or processing of wastewater to make it reusable, while 'wastewater reuse' is using wastewater in a variety of beneficial ways. In addition, 'reclamation' or 'reuse' of water frequently implies the existence of a pipe or other water conveyance facilities for delivering the reclaimed water. The foundation of water reuse is built upon three principles: (1) providing reliable treatment of wastewater to meet strict water quality requirements for the intended reuse application, (2) protecting public health, and (3) gaining public acceptance. Whether water reuse is appropriate for a specific locale depends upon careful economic considerations, potential uses for the reclaimed water and the relative stringency of waste discharge requirements. Public policies can be implemented that promote water conservation and reuse rather than the costly development of additional water resources with considerable environmental expenditures. Through integrated water resources planning, the use of reclaimed water may provide sufficient flexibility to allow a water agency to respond to short-term needs, as well as to increase the reliability of long-term water supplies (Asano et al., 2007; US Environmental Protection Agency, 2004; Asano, 2002).

The development of wastewater reclamation and reuse in many countries is related to looming water scarcity, water pollution control measures and protection of the aquatic environment. There is also the need to obtain alternative water resources for a growing population. In cities and regions of developed countries, where wastewater collection and treatment have been the common practice, wastewater reuse is practised with proper attention to sanitation, public health and environmental protection (Jimenez and Asano, 2008).

In the planning and implementation of water reuse, the intended applications govern the degree of wastewater treatment required and the reliability of wastewater treatment processing and operation. In principle, wastewater or any marginal quality waters can be used for any purpose, as long as adequate treatment is provided to meet the water quality requirements for the intended use. The dominant applications for the use of reclaimed water include agricultural irrigation, landscape irrigation, industrial recycling and reuse and groundwater recharge. Among them, agricultural and landscape irrigation are widely practised throughout the world, with well-established health protection guidelines and agronomic practices.

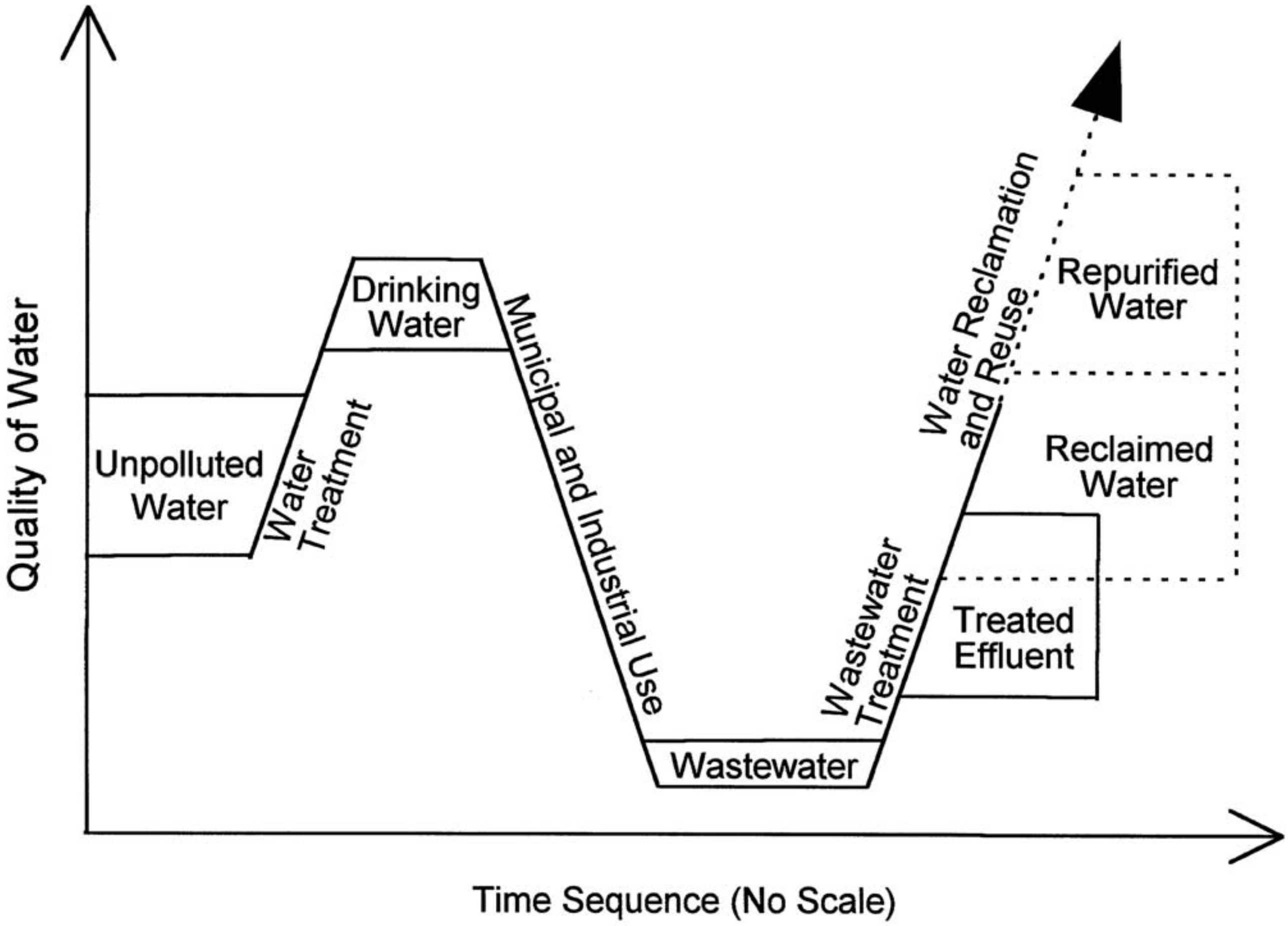

Figure 1. Water quality changes during municipal uses of water in a time sequence.

Spectrum of reclaimed water quality

As water is used for various applications, the quality changes due to the introduction of various constituents. A conceptual comparison of the extent to which water quality changes through municipal applications is shown schematically in Fig. 1. Today, technically proven water reclamation or water purification processes exist to provide water of almost any quality desired.

Significant developments worldwide

The desirability and benefits of wastewater reclamation and reuse have been well recognised by most States in the United States. For example, in the California State Water Code it is clearly noted that "it is the intention of the Legislature that the State undertake all possible steps to encourage development of water recycling facilities so that recycled water may be made available to help meet the growing water requirements of the State".

Examples of wastewater reclamation and reuse in the United States

Irvine Ranch water district, Irvine (IRWD), CA. Reclaimed water now makes up 20 per cent of IRWD's total water supply, reducing the need to import expensive water and helping to keep water rates low. The reclaimed water is delivered through a completely separate distribution system that includes more than 394 km of pipeline, eight storage reservoirs and 12 pumping stations. The system provides reclaimed water to approximately 405 ha of fields and orchards planted with a variety of fruits, vegetables and nursery products. Eighty per cent of all business and community landscaping (parks, school grounds) is irrigated with reclaimed water. A few estate-sized residential lots also use this water for front and backyard irrigation. Many water features such as fountains and the lake at Mason Park are filled with reclaimed water. Reclaimed water is currently used for toilet flushing in IRWD's facilities as well as in several high rise office buildings constructed with dual piping systems. Potable or drinking water demands in these buildings have dropped by as much as 75 per cent due to the reclaimed water use. There are four primary uses for reclaimed water within IRWD. (1) Landscape irrigation – parks, golf courses, school playfields, athletic fields, and many common areas maintained by homeowner associations. Over 2818 landscape meters receive reclaimed water, providing irrigation to over 2287 ha of landscaping. (2) Agricultural irrigation – reclaimed water is used to irrigate most crops grown in this area. The District provides reclaimed water to 44 agricultural users, irrigating over 405 ha of crops. (3) Industrial uses – some industries use reclaimed water in their production processes. One carpet mill converted its carpet dyeing process from domestic to reclaimed water. This one conversion alone saved from 1892 m3/d to 3785 m^3/d of drinking water. (4) Toilet flushing – reclaimed water is used to flush toilets in a few dual-plumbed high-rise and other commercial buildings. In a typical office setting, approximately 80 per cent of the water is used for toilet flushing. By using reclaimed water instead of drinking water to flush toilets, major savings can be realised.

City of St. Petersburg, FL. Development of St. Petersburg's reclaimed water system owes largely to the Wilson-Grizzle Act as well as the 1972 decision by City Council to implement a recycling and deep injection well system to achieve zero-discharge to surface waters. The Wilson-Grizzle Act "mandated wastewater treatment plants discharging to Tampa Bay and its tributaries to treat their wastewater to that of drinking water standards or cease discharging to surface waters altogether." The pilot study concluded that spray irrigation using treated wastewater was more feasible and considerably more cost-effective than advanced wastewater treatment followed by discharge to Tampa Bay and that it would reduce the total quantity of water to be imported for potable use. The approach adopted was to reclaim the wastewater to a sufficient degree that it would be suitable for the irrigation of parks, schools and golf courses within the city. Since the inception of the reclaimed water system, annual demand for potable water has been stabilised while the demand for nutrient rich reclaimed water has steadily increased. Several potable water system projects, such as additional treatment units at the Cosme Water Treatment Plant, a booster station on the 122 cm inch water transmission main in the Safety Harbor area and the south-side booster station and storage facility, have all been delayed indefinitely. The cost for these projects would have been in the range of US$25 to US$30 million. Economic savings have also been realised at the treatment plants by avoiding the need to install expensive nutrient removal wastewater processing systems. The Reclaimed Water System Master Plan Update recognised that the system had continued to expand and change in character from an alternate mode of wastewater disposal to a full operation as a third element of the city's Public Utilities Department. This has made St. Petersburg the first major municipality in the US to achieve zero discharge of wastewater effluent into surrounding surface

The wastewater reclamation and reuse activities in the countries belonging to the European Union (EU) are heavily influenced by the EU Water Framework Directives promulgated in 2000. In the European Communities Commission Directive (91/271/EEC), "treated wastewater shall be reused whenever appropriate", and that "disposal routes shall minimise the adverse effects on the environment" (EEC, 1991). More substantial pan-European guidelines for wastewater recycling and reuse have been proposed and are being studied, but no actions have been taken (Bixio and Wintgens, 2006). The World Health Organization (WHO) published in 2006 the "Guidelines for the safe use of wastewater, excreta and greywater", Volume II of which dealt with "Wastewater use in agriculture" (WHO, 2006).

Several Mediterranean countries in Europe, particularly Portugal, Spain, the southern provinces of France and Italy, and Greece have been in the vanguard in wastewater reclamation and reuse for agricultural and landscape irrigation.

Integrated water resources management program in Vitoria, Spain

Wastewater reclamation and reuse has been the final corner stone of an ambitious integrated water resources management program for the City of Vitoria (250,000 people, located in the Basque Country, northern Spain) that began in 1995. The wastewater reclamation and reuse project implemented in Vitoria includes a wastewater reclamation facility with a capacity of 35,000 m^3/day (expandable to 3 additional modules), that satisfies the water quality requirements specified by Title 22 of the California Code of Regulations, and an elaborated pumping, conveyance and storage system. The project objectives are (1) to supply reclaimed water for the spray irrigation of 9500 ha during the summer, (2) to provide storage capacity for 7 hm^3 of reclaimed water during the winter for agricultural irrigation in the summer. Ultimately, the project could supply up to 27 hm^3/yr of reclaimed water for stream flow augmentation at the discharge base of the drinking water supply reservoir. Construction of the reservoir's earth dam began in 2002 and was completed in June 2004, becoming one of the largest reclaimed water reservoirs in the western Mediterranean basin. Although agricultural irrigation around the city of Vitoria was the main driving force of the project, the city is planning to use reclaimed water for irrigation of the urban landscape (3 hm^3/year) and for an industrial water supply to a new industrial park. The initial commitment of the project to produce high quality reclaimed water (suitable for unrestricted irrigation) has been instrumental in its success and its wide acceptance among current and potential users.

Israel is the pioneer in intensive use of reclaimed municipal wastewater in agriculture as well as such large scale groundwater recharge and high quality irrigation projects as the Dan Region project. Reclaimed water is used predominantly for agricultural irrigation. As a result of increasing water demand for domestic and industrial uses, the supply of freshwater to the agricultural sector has decreased from about 77 per cent in the 1960s to about 60 per cent at present. Of the 410,000 m^3 of wastewater generated from urban centres, 265,000 m3, or 65 per cent, is reused for irrigation. Currently, an estimated 300,000 m3 (25 per cent) of total water supplied for irrigation is reclaimed water. This volume is expected to double by 2020.

In addition, Portugal and Tunisia have well-established agricultural and landscape irrigation programs using reclaimed wastewater (Lazarova and Bahri, 2005).

Most of the significant developments in wastewater reclamation and reuse have occurred in arid regions of the world including Australia, Israel, Middle East, Spain, Tunisia and the west and south western United States. In Windhoek, Namibia, because of extreme drought conditions, extensive research was conducted in 1968 on direct potable reuse technology and an epidemiological study was conducted to assess the health effects of reclaimed water consumption. Highly treated wastewater has been commingled with other drinking water sources. In Singapore, wastewater reclamation and reuse has been implemented for industrial water supply as well as a source of raw water to supplement Singapore's water supply reservoirs. Newer technologies, such as membrane bioreactors, membrane filtration, advanced oxidation and ultraviolet disinfection, are important in the production of high quality reclaimed water reliably (Khan, et al., 2007; IWA Specialty Conference, 2005).

Dan Region project, Tel Aviv, Israel

The Dan Region project (DRP) is the largest water reclamation scheme in Israel. Domestic and industrial wastewater from the Tel Aviv metropolitan region is treated, recharged into a confined aquifer, and subsequently withdrawn and distributed for wastewater reuse. The DRP treats about 110,000 m3 of wastewater annually. Stage one of the reclamation system has a treatment capacity of 20,000 m3/yr and has been in operation since 1977. Treatment in stage one consists of a facultative oxidation pond with recirculation, and polishing ponds for ammonia stripping and re-carbonation. Groundwater recharge in stage one is accomplished via surface spreading at four spreading basins with a total area of 24 ha. Stage two has a capacity of 80,000 m3/yr and has been in operation since 1987. Secondary treatment in stage two consists of mechanical-biological treatment by activated sludge operated for nitrification/de-nitrification. Stage two has two spreading basins with a total area of 42 ha. After treatment and recharge to the groundwater, reclaimed water is withdrawn through a ring of recovery wells, located between 350 m and 1500 m from the nearest recharge basin. The reclaimed water is pumped to southern Israel for use in non-potable applications. The main application for water reuse is unrestricted agricultural irrigation.

Planned direct or indirect potable water reuse in Windhoek, Namibia, and Singapore

Windhoek's Goreangab water reclamation plant

Namibia's capital city, Windhoek, has been practicing direct potable reuse since 1968. The Windhoek water reclamation plant serves a population of 220,000. Domestic wastewater from the city is first treated in a conventional biological wastewater treatment plant; the treated wastewater then flows through a series of maturation ponds to a water reclamation plant. The reclamation plant has undergone many re-configurations and upgrades since 1968, most recently with the construction of the new Goreangab water reclamation plant (WRP) in 2002. Industrial effluents in the city are diverted to a separate sewer and treatment system. Goreangab WRP has a capacity of 2.1 million m3, and it is internationally renowned as the first in the world to reclaim municipal wastewater to potable water quality as a supplement to Windhoek's very scarce water source. The treatment train consists of dissolved air floatation, sedimentation, rapid sand filtration, ozonation, carbon adsorption (both granular and powdered), ultrafiltration and chlorine disinfection. After treatment, reclaimed water is mixed with water from other sources, so that reclaimed water makes up at most 35 per cent of the city's drinking water. Potable reuse, despite its potential difficulties elsewhere, is an indispensable element of the Windhoek water system and has proven to be a reliable and sustainable option for over 40 years.

Singapore

Singapore being a small city-state that has one of the highest population densities in the world, now buys more than half of its water from neighbouring Malaysia under decades-old treaties, which start expiring in 2011. The water trade has sparked occasional disputes between the two nations over pricing and other issues. The Singapore water reclamation study (NEWater Study) was initiated in 1998 as a joint initiative among the Public Utilities Board (PUB), the Ministry of the Environment and the National University of Singapore. The primary objective of the joint initiative was to determine the suitability of using NEWater as a source of raw water to supplement Singapore's water supply. NEWater is reclaimed water that has undergone stringent purification and treatment processes using advanced dual-membrane (microfiltration and reverse osmosis) and ultraviolet disinfection. The NEWater factories at Bedok and Kranji water reclamation plants were commissioned at the end of 2002. Since February 2003, NEWater has been supplied to wafer fabrication plants at Woodlands and Tampines/Pasir Ris and other industries for non-potable use. In January 2004, another milestone in the NEWater initiative was accomplished with the commissioning of the third NEWater factory at Seletar water reclamation plant, which began supplying NEWater to the wafer fabrication plants at Ang Mo Kio. The total capacity of the three NEWater factories is 92,000 m3/day. Besides supplying to industries, NEWater is also available for indirect potable use. This involves pumping NEWater into the reservoirs to be mixed and blended with raw water. The mixed water undergoes a process of naturalization before being treated again in conventional waterworks to produce drinking water. PUB introduced 13,500 m3/day of NEWater, about 1 per cent of the amount of water consumed daily, into the raw water reservoir in 2003 with considerable fanfare. The amount will be increased progressively to about 2.5 per cent of the total daily water consumption by 2011. The country's target is to obtain, by the year 2012, 25 per cent of water supply from non-traditional sources – 15 per cent from NEWater, 5 per cent from sea water desalination and the remaining 5 per cent from industrial water.

Wastewater reuse in developing countries

Urban growth impacts on infrastructure in developing countries are extremely pressing. In many cities of Asia, Africa and Latin America, engineered sewage collection systems and wastewater treatment facilities are often non-existent. For developing countries, particularly in arid areas, wastewater is simply too valuable to waste. It contains scarce water and valuable plant nutrients, and crop yields are higher when crops are irrigated with wastewater than with freshwater. Farmers use untreated wastewater out of necessity and, unfortunately, it is a reality that cannot be denied or effectively banned.

Where wastewater collection systems are available, they often discharge untreated wastewater to the nearest drainage channel or water course. Because alternative low-cost sources of water are generally not available for irrigation of high value market crops near these cities, the common practice is to use untreated wastewater directly or to withdraw from nearby streams that may be grossly polluted with untreated municipal and industrial wastewaters. The contamination of food crops causes a high level of enteric diseases in the area and has serious impacts on visitors to these cities (WHO, 2006). The major health concerns make it imperative to governments and the United Nations agencies to implement public health and environmental protection measures.

Sanitation and wastewater reuse in Ghana

In Ghana, urban sanitation infrastructure is poor. Less than 5 per cent of the population has sewerage connections and only a small share of the wastewater is treated (Keraita and Drechsel, 2004). Twenty per cent of households do not have access to any form of toilet facility; about 31 per cent relies on public toilets, while 22 per cent has access to pit latrines. About 7 per cent of households use KVIP (Kumasi ventilated improved pit) latrines and 9 per cent has access to water closets. Access to water in rural and urban areas has generally improved, gradually resulting in increased generation of faecal sewage and wastewater with increasing waterlogging and stagnant pools of water in many towns and cities because of a lack of drains. Inadequate water and sanitation have a significant impact on public health and contribute to 70 per cent of the diseases in Ghana (WaterAid, 2001). About 20 per cent of the 44 existing wastewater treatment plants are functional, and these are usually below design standards. Waste stabilization ponds and trickling filters are some of the common systems. Very little extension of the sewerage network has taken place since its construction in the early 1970s. Due to the limited number of sludge treatment sites and their poor accessibility and/or status, more than 60 per cent of all collected excreta are dumped into the ocean.

Studies have been carried out to improve sewerage effluent disposal and sanitation through off-site and on-site sanitation facilities. The Accra Sewerage Improvement Project will provide two new sewage treatment plants, based on waste stabilization ponds, with outfalls discharging into the sea and into watercourses (AfDB, 2005). Transfer of sanitation and sewerage functions from central Government agencies to the Assemblies is considered in the National Environmental Sanitation Policy, which is, however, not automatically combined with a corresponding transfer of capacities and operational funds.

Urban and peri-urban agriculture is developing wherever land is available close to streams and drains (Obuobie et al., 2006). Around Kumasi, informal irrigation, which often uses polluted stream water, is estimated to cover 11,500 ha (Keraita and Drechsel, 2004). Typical concentrations of faecal coliforms in the irrigation water ranges from 104 to 108 CFU/100 ml (Keraita et al., 2003). Watering cans are the most common irrigation method used in the country. Buckets, motorised pumps with hosepipe and surface irrigation are also used to fetch, pump and water crops. In Accra, between 800 and 1000 farmers irrigate more than 15 kinds of vegetables (including lettuce, cabbage, spring onions, cauliflower, cucumber, tomatoes, okra, eggplants and hot pepper). All-year-round irrigated vegetable farming can achieve annual income levels of between US$400 and US$800 per actual farm size. The annual value of the production, a significant part of which is irrigated with wastewater, has been estimated by Cornish et al. (2001) for dry-season farming as US$5.7 million around Kumasi (Keraita and Drechsel, 2004) and for year-around production as US$ 14 million in case the same crops have to be imported from neighbouring countries with safer water sources (Drechsel et al., 2006).

Every day, about 200,000 urban dwellers from all classes of the capital Accra benefit from this production when consuming raw salads as part of urban fast food, but the same number is also at risk due to vegetable contamination. Irrigated vegetables sold in the markets showed faecal coliforms and helminth eggs (> 103 FC/g fresh weight and up to 3 helminth eggs per gram of vegetables) (Keraita et al., 2003). Both municipal food supply and safety are therefore significantly affected by the urban sanitation situation. This is a major concern of the authorities who tried to ban the use of polluted water for irrigation purposes, with the same degree of success that they had with stopping water pollution. Alternative interim health risk reduction strategies are currently explored as proper wastewater collection and treatment infrastructure is not yet available and the existing one is not functional.

Intermediate steps to mitigate the negative impacts should be undertaken, such as introducing crop restrictions and standards for effluent reused for irrigation and other uses, applying source control of contaminants, using appropriate irrigation, agricultural, post-harvest and public health practices that limit risks, improving extension and outreach activities to all stakeholders, and upgrading the effluent quality from treatment plants. The medium-term goal should be to prohibit the use of untreated wastewater for irrigation purposes.

One of the challenges in the World Health Organization's (WHO) guidelines for the use of wastewater for agriculture is to address protection of public health in these situations. In 2006, the WHO developed realistic health guidelines for the use of wastewater in agriculture. In addition, the Stockholm International Water Institute has been addressing these water and sanitation issues in developing countries since 1991 at its annual World Water Week in Stockholm, Sweden.

Challenges for expanding wastewater reclamation and reuse

With many communities approaching the limits of their available water supplies, wastewater reclamation and reuse has become an attractive option for conserving and extending available water supply by potentially (1) substituting reclaimed wastewater for applications that do not require high-quality drinking water, (2) augmenting water sources and providing an alternative source of supply to assist in meeting both present and future water needs, (3) protecting aquatic ecosystems by decreasing the diversion of freshwater, reducing the quantity of nutrients and other toxic contaminants entering waterways, (4) reducing the need for water control structures such as dams and reservoirs, and (5) complying with environmental regulations by better managing water consumption and wastewater discharges.

Wastewater reclamation and reuse is particularly attractive in the situation where available water supply is already overcommitted and cannot meet expanding water demands in a growing community. Increasingly, society no longer has the luxury of using water only once. Producing reclaimed water of a specified quality to fulfil multiple water use objectives is now a reality due to the progressive evolution of water reclamation technologies, regulations and environmental and health risk protection. However, the ultimate decision to promote wastewater reclamation and reuse is dependent on economic, regulatory, public policy and, more importantly, public acceptance factors reflecting the water demand, safety, and need for reliable water supply in local conditions.

Important issues related to the expanding wastewater reuse and some of the foreseeable impediments are summarised below (Asano et al., 2007).

Implementation hurdles

While wastewater reclamation and reuse is a sustainable approach and can be cost-effective in the long run, the additional treatment of wastewater beyond secondary treatment for reuse and the installation of reclaimed water distribution systems can be costly compared to such water supply alternatives as imported water or groundwater. Like the development of any other utilities, the implementation of wastewater facilities generally requires a substantial capital expense. In the context of integrated water resources management of the region, government grants or subsidies may be required to implement wastewater reuse. Unfortunately, institutional barriers, as well as varying agency priorities, can make it difficult to implement water reuse projects in some cases.

Public support

The public's awareness of sustainable water resources management is essential. Thus, planning should evolve through a community value-

based decision-making model involving all stakeholders from the start in water reuse operations and ensuring multi-stakeholder platforms to facilitate dialogue, participatory technology development, innovation uptake and social learning. Thus, water reuse is placed within the broader context of water resources management and other options in the region to address water supply and water quality problems. Community values and priorities are then identified to guide planning from the beginning in the formulation and selection of alternative solutions.

Acceptance varies dependent on necessity and opportunity

To date the major emphasis of wastewater reclamation and reuse has been on non-potable applications, such as agricultural and landscape irrigation, industrial cooling and in-building applications, such as toilet flushing, in large commercial buildings. Indirect or direct potable reuse raises more public concern because of real or perceived perception of aesthetics and long-term health concerns. In any case, the value of water reuse is weighed within a context of larger public issues of necessity and opportunity. The water reuse implementation continues to be influenced by diverse debates, such as drought and availability of water; growth vs. no growth; urban sprawl, traffic noise and air pollution; perception of reclaimed water safety and public policy governing sustainable water resources management for the future.

Public water supply from polluted water sources

Due to land use practices and the increasing proportion of treated wastewater discharged into receiving waters, freshwater sources of drinking water are containing many of the same constituents of health concern that are found in reclaimed water. Much of the research that addresses direct and indirect potable water reuse is becoming equally relevant to unplanned indirect potable reuse that occurs naturally when drinking water supply is withdrawn from polluted water sources. Because of the research interest and public concerns, emerging pathogens and trace organic constituents, including disinfection by-products, pharmaceutically active compounds and personal care products, have been reported extensively. The ramifications of many of these constituents in trace quantity are not well understood with respect to long-term health effects.

Technological advances

As technology continues to advance and the reliability of wastewater reuse systems is widely demonstrated, wastewater reclamation and reuse will continue to expand as an essential element in sustainable water resources management. Several innovative and advanced technologies, including membrane bioreactors, ultraviolet disinfection, ozonation and advanced oxidation, have been incorporated in the current design of wastewater reclamation and reuse in several locations. Cost-effective treatment of wastewater and less energy intensive wastewater reclamation and reuse systems need be developed in the context of sustainable water resources management.

Examples of advanced technologies for reliable wastewater reuse operations in Kuwait and Arizona

The Sulaibiya wastewater reclamation and reuse project, Kuwait

The entire wastewater system has been upgraded and a new plant has been constructed in Sulaibiya to allow unrestricted non-potable uses. It is a 30-year concession from the Kuwait government to a consortium to design, build, own, operate and maintain the facility. The plant treats in a first stage 375,000 m3/d of wastewater and will be extended to 600,000 m3/d. The facility applies advanced treatment processes – ultra-filtration and reverse osmosis. The plant delivers water of potable water quality at approximately US$0.65 per m3 with US$0.40 per m3 for conventional wastewater treatment and pipeline costs, while producing tertiary treated wastewater costs US$0.38 per m3. Reuse options include mixing reclaimed water with brackish water and supplying the brackish water system, unrestricted irrigation and groundwater recharge.

City of Scottsdale's water campus, Arizona

Water campus is a state of the art water and wastewater treatment complex located on a 57 ha site in Scottsdale, Arizona. It includes a 204,000 m3/d surface water treatment plant, a 45,000 m3/d water reclamation plant; a 38,000 m3/d advanced water treatment plant including microfiltration and reverse osmosis along with 27 vadose zone injection wells. At the heart of the complex is a major indirect potable reuse programme with an annual groundwater recharge target in excess of 19 million m3. Tertiary effluent from the water reclamation plant (WRP) enters a distribution system delivering water to 17 golf courses in north Scottsdale to meet their irrigation demands. The advanced water treatment plant (AWT) includes continuous microfiltration units and three stage reverse osmosis (low-pressure thin film composite elements) trains set in a 24-10-5 array with a target of 85 per cent recovery. The design provides flexibility to operate the entire microfiltration plant with either wastewater effluent or CAP (Central Arizona Project) water. This is determined based on wet weather conditions, golf course irrigation demands and the targeted recharge credits. The AWT was designed and constructed to further treat WRP effluent that is not used for golf course irrigation. A chlorine contact basin provides disinfection for the WRP effluent prior to flow equalization. In a parallel microfiltration system, the plant will treat wet weather flows from the WRP that exceed the capacity of the AWT microfiltration system. During dry weather, surface water from the Colorado River (transported via the Central Arizona Project Canal) will be treated and recharged through these units. The water campus is the cornerstone of the city's integrated wastewater/water reclamation programme towards compliance with the State of Arizona's 1980 Groundwater Management Act, which requires either natural or artificial recharge to equal groundwater withdrawals.

Conclusions and policy recommendations

The growing trend in wastewater reclamation and reuse is to consider wastewater reuse practices as an essential component of sustainable and integrated water resources management. The development of wastewater reclamation and reuse in many countries is related to looming water scarcity, water pollution control measures and protection of the aquatic environment, and to obtaining alternative water resources for the growing population. In the cities and regions of developed countries, where wastewater collection and treatment have been common practice, wastewater reuse is practised with proper attention to sanitation, public health and environmental protection. When planning and undertaking wastewater reclamation and reuse, the seven key policy recommendations in the box below may be considered. As technology continues to advance and the reliability of wastewater reuse systems is widely demonstrated, water reclamation and reuse will continue to expand as an essential element in sustainable water resources management.

Seven key policy recommendations

1. Wastewater should be considered as a potential resource in the overall water budget
2. An integrated framework should be adopted to manage water supply, storm water, wastewater, non-point source pollution and water reuse
3. Wastewater reclamation and reuse should be incorporated into sustainable development, climate change adaptation and integrated water resources management strategies
4. The various reuse options should be considered from the outset in the design of treatment plants, as well as in their operation, with corresponding criteria and standards
5. Guidelines and policies that encourage communities to determine the most appropriate and cost-effective wastewater treatment solutions, based on local capacities and reuse options, should be adopted
6. All stakeholders should be involved from the start in water reuse plans, and multi-stakeholder platforms should be created to facilitate dialogue, participatory technology development, innovation uptake and social learning
7. Financial stability and sustainability should be ensured by (a) linking waste management with other economic sectors for faster cost-recovery, risk reduction and sustainable implementation; (b) developing mixed public/private, public/public sector solutions for investment, service delivery and operation and maintenance; and (c) considering social equity when defining cost-recovery mechanisms.

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PEAK PHOSPHORUS AND THE EUTROPHICATION OF SURFACE WATERS: A SYMPTOM OF DISCONNECTED AGRICULTURAL AND SANITATION POLICIES

That phosphorus rock is being depleted from commercial fossil deposits and ends up in lakes and oceans remains of little interest to most governments. Concerns about eutrophication are centered around overzealous use of fertiliser, erosion losses from farms and non-existent or poorly functioning sewage treatment. Waste and sanitation systems have solutions to prevent eutrophication, but not linked to reuse in agriculture, nor to management of limited phosphorus mineral supplies. Most phosphorus in the world is produced by China, US and Morocco/Western Sahara, which may contain about 75 per cent of global reserves. No UN agency monitors phosphorus rock mining and no independent source of data exists. Countries need to optimise phosphorus use in agriculture and its reuse from manure, sludge, sanitation and solid waste. This paper calls for a global governance system ensuring sustainable management of phosphorus from both fossil and recycled sources providing long-term food and political security to the world.

Key words: peak phosphorus, agriculture, eutrophication, sanitation, policies.

Introduction

Shifting the focus away from just eutrophication

Phosphorus is a limited, non-renewable, but recyclable resource fundamental to all forms of life and to our food systems (Tiessen, 1995). The fact that commercially viable phosphorus rock is being depleted from available fossil deposits and is ending up at the bottom of lakes and oceans, unavailable for reuse, continues to be of little or no concern to most governments around the world. The concerns centred around water quality and eutrophication are not connected to finite resource depletion, but only to the overzealous use of fertiliser, subsequent erosion losses from arable land and non-existent or poorly functioning sewage treatment in cities. Sophisticated scientific efforts around the world led, for example, by the institutions for limnology and oceanography that assess lake, river and coastal eutrophication, remain fixed on monitoring and ecosystem changes. They are, apparently, less concerned by the call for integrated water resources management (IWRM), land-based preventive approaches including the need for radical changes in agricultural practices, sanitation and solid waste systems and a wiser use of dwindling fossil fertiliser resources.

Eutrophication of surface waters continues to be one of the most common water quality problems around the world (World Water Assessment Programme, 2009). There is extensive literature describing the eutrophication of freshwater and coastal marine zones spanning, for example, Vollenweider (1968), Schindler (1977) and Carpenter et al. (1998). Knowledge of the role played by phosphorus as a limiting factor for growth in aquatic systems led to legislation in many parts of the world to control the use of phosphate in detergents and to reduce the discharge of phosphorus from effluents, mainly municipal sewage (Dolan, 1993). To some extent, this has also had an impact on reducing fertiliser use and has changed agricultural practices along certain sensitive shorelines or coastal zones, but runoff remains a major source of phosphorus in, for example, the Baltic Sea drainage area (HELCOM, 2008).

But the driver behind all this interest for the past 40 years has been water pollution and the risk of algal growth, fish kills and anoxic lake bottoms. Much of the response, therefore, has been at the 'end of the pipeline', to remove phosphorus, and not the sustainable use of a limited natural resource. The challenges have been immense, especially when the ecosystem has not been properly the focus of clean-up strategies. Most marine systems are considered to be nitrogen limited, but when it comes to the Baltic Sea, this brackish water system can support the growth of toxic blue-green algae (Cyanobacteria) that can fix atmospheric nitrogen, thus rendering them phosphate limited (HELCOM, 2009). So to control eutrophication in the Baltic, it is necessary to manage nitrogen and phosphate from both the atmosphere and from land sources (Conley et al., 2009).

The case of the North Sea also illustrates the dangers of policy disconnections. The eutrophic and polluted rivers of northern Europe were cleaned up mainly by removing phosphorus in sewage treatment plants during the 1970s and 1980s. But even though phosphate levels decreased, eutrophication in the coastal area increased (Cadée and Hegeman, 1993). The water quality of the rivers improved with increased oxygen levels and the recovery of fish populations, but the previously polluted rivers with anaerobic zones were carrying out significant denitrification – removing nitrogen from the water phase and releasing it to the atmosphere. With improved oxygen conditions following phosphorus removal, the rivers were no longer reducing the nitrogen, but became efficient nitrate pumps from the agricultural lands to the North Sea, thus causing eutrophication of the North Sea instead. The disconnection between sanitation engineering pushing for only phosphorus removal, agricultural practices creating excess nitrate runoff and the lack of integrated management approaches illustrates why IWRM is needed.

The removal of phosphate from municipal sewage effluent, most often through flocculation of phosphate with iron chloride or aluminium sulphate, has been the priority in developed countries. Re-use and recycling have not been a central part of the pollution abatement strategy, as witnessed by the fact that the standard practice renders the phosphorus in the sludge less available for plants (Kyle and McClintock, 1995). Only recently has this been the focus of new developments to produce more plant-available products, like struvite, by using magnesium (Ashley et al., 2011).

The objective of this paper is to create interest and generate discussion about the limited mineral sources of phosphorus, their management in human systems, the respective flows and net losses and the need for increased efficiency and recycling. The paper explores the policy and technology disconnections between the practices in using phosphorus fertiliser in agriculture, the control of phosphorus in effluents, the management of the mineral reserves and products therein and the need for environment-friendly recycling systems.

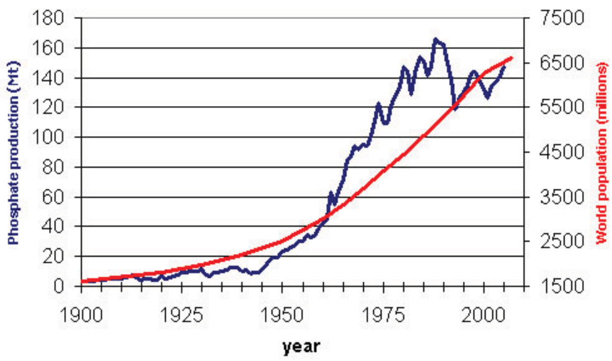

Figure 1. Trends in global extraction of phosphate rock from 1900 in relation to population growth. In 2010 almost 180 Mt of rock was extracted and the world population neared 7 billion. Source: Déry and Andersson, 2007..

Problem analysis

Phosphorus: a limited resource

Historically the main source of phosphorus in agrarian communities was manure. Eventually when agriculture became more intensive, bone-meal and guano were used as rich sources of phosphorus. But it was not until the 1900s that significant amounts of phosphorus were mined for fertiliser production. Once the Haber-Bosch technique became streamlined and produced essentially unlimited amounts of ammonia for fertiliser production, phosphorus mining became much more intensive in order to match the growth in nitrogen fertiliser products. Indeed the population explosion since then has been fuelled by abundant and relatively inexpensive fertiliser and food (Fig. 1).

The 'Green Revolution' created a mindset that there was apparently no practical limit to the availability of fertiliser and, if a country was undernourished, that food could be shipped there from the bread baskets of the world. But the number of undernourished in the world is still increasing and is now greater than one billion. We also know that the world will have to double the amount of food it currently produces if we are to support 9 billion people by 2050 (WFP, 2009). One might ask: what are the planetary limits for the production of fertiliser, knowing that we have already exceeded the safe operating space for nitrogen through the production of ammonia (Rockström et al., 2009)?

More than 80 per cent of the phosphorus mined is used in fertiliser, but there are many other important functions served by phosphorus including detergent, fire retardants, pesticides, food additives, explosives, etc. But there are signals now that commercially viable mined phosphorus sources are dwindling and these call for a more sustainable approach to exploiting this precious resource (Schröder et al., 2010). Peak phosphorus has been suggested as a possible threat to food security and human development by several authors (Cordell et al., 2009; Rosemarin et al., 2009; Déry and Andersson, 2007). There is some controversy about exactly when such a peak could occur (Van

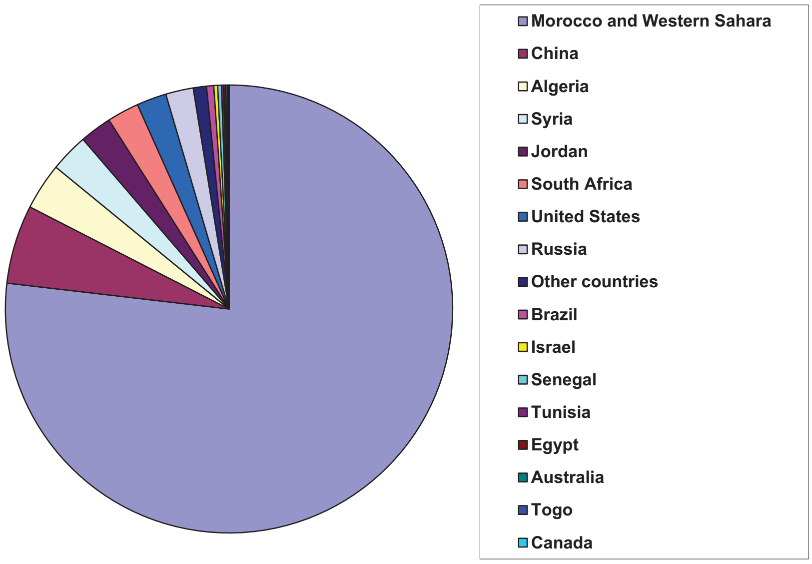

Figure 2. Relative distribution of phosphate rock reserves in 2010. In total, there are an estimated 65 Gt of rock containing 20 to 30 per cent P2O5. Source: USGS, 2011.

Kauwenbergh, 2010) although the U.S., which for many decades was the world's largest producer, peaked already in the mid-1990s (USGS, 2011; Vaccari, 2009; Déry and Andersson, 2007). Exactly how much rock there is left to exploit depends of course on what the price is. What is of interest is that, up to 2009, the US Geological Survey (USGS) provided two classes of rock – one that was commercially viable (reserves) and one that also included what was currently non-viable (reserve base), based on, for example, a technology constraint or low ore content level. But this was abandoned and, along with a new revision, brought on by the International Fertiliser Development Center (IFDC) report (Van Kauwenbergh, 2010) sponsored by USAID, the base reserves have been in effect incorporated into the classification 'reserves'. Thus, Morocco's rock reserves were increased from 5.7 Gt to 50 Gt without any substantive international review. The raw data and assumptions regarding commercial viability made by both the IFDC and USGS are unavailable for scrutiny. The IFDC revised estimate was based on theoretical calculations using areal data from a geological survey from 1989 and the phosphate content of the rock is not provided. No UN agency is involved in monitoring the resource, so the only open and published source of data is that from the USGS. The present data (USGS, 2011) provide an estimate of the reserves at 65 Gt of rock of which Morocco/W. Sahara stand for 75 per cent (Fig. 2).

The USGS also provides extraction data (Fig. 3). In total there were 176 Mt of rock extracted during 2010, with China dominating at 65 Mt, followed by the U.S. and Morocco/W. Sahara at 26 Mt each.

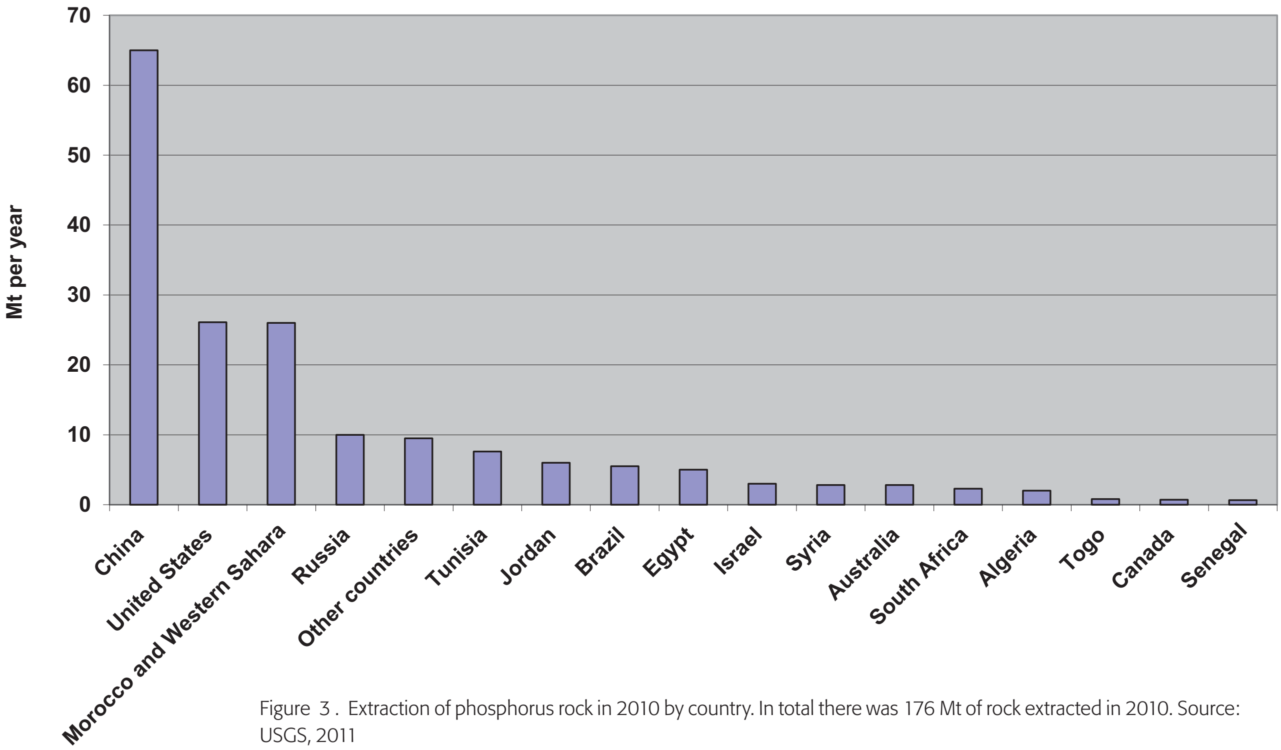

Figure 3. Extraction of phosphorus rock in 2010 by country. In total there was 176 Mt of rock extracted in 2010. Source: USGS, 2011

Table 1. Prognoses for depletion of phosphorus at the global level and for Morocco, China and the U.S., the three largest producers
Source: USGS, 2011

	P-rock		Years to depletion			Current annual increases (%)
	Extraction 2010 Mt	Commercial reserves Gt	Zero annual increase	1 per cent annual increase	2.5 per cent annual increase	
World total (rounded)	176	65	369	155	93	6.02
Morocco & Western Sahara	26	50	1 923	300	156	13.04
China	65	3.7	57	45	20	7.97
United States	26,1	1.4	54	43	34	-1.14

At current rates of extraction, both China and the U.S. would deplete their commercially viable reserves within 40 to 50 years (Table 1). Globally, depletion could occur within 155 years assuming a compounded annual growth of 1 per cent. Population growth is at present running exponentially at 1.18 per cent (UN-DESA, 2011), so a 1 per cent exponential increase in phosphorus consumption to 2050 or 2060 is not inconceivable. Even with zero growth, China and the U.S. would deplete their reserves within 55 to 60 years.

The question is whether other limiting factors will come into play, such as fertiliser or agricultural production capacity or even fertiliser and fossil fuel affordability. Other compounding factors that can also come into play are those relating to geopolitics, recognizing that Morocco's monopoly role will have significant global market effects. Morocco has recently announced that it will significantly increase its capacity to produce phosphorus rock and respective products by about 70 per cent within the next 4 to 5 years (Ghanmi, 2010). So Morocco's role of taking up the slack left by the US and China will become central to global food security strategies. That the world should be already aiming for zero or even negative growth within this sector would appear to be the wisest approach. But this, surprisingly, is not yet on the UN or EU agenda, nor is there a single government in the world that has taken the lead in taking up this critical question. This inconvenient truth still has yet to come to the surface and remains one of the most important neglected sustainable development issues of our time.

Cadmium: a natural contaminant

As phosphorus mineral reserves dwindle and the quality of the available apatite ore diminishes, the issue concerning the relatively high levels of cadmium in phosphate fertiliser will raise its head. Relatively high levels of natural cadmium are present in the sedimentary phosphate rock that is used to produce fertiliser (Oosterhuis et al., 2000). The levels for the rock available from the mines in Morocco range from 55 to 120 mg Cd/kg P_2O_5 (Demandt, 1999). The EU has been considering a 15 year programme to reduce cadmium in phosphate fertiliser in an attempt to bring it down to approximately 20 mg Cd/kg P_2O_5, which is considered a safe level (EU, 2003). Anything above 60 mg Cd/kg P_2O_5 is considered unsafe. Removal of cadmium from the fertiliser is conceivable at additional costs. What is of interest is that sludge and organic sources that can be rendered recyclable often have lower levels of cadmium than the fertiliser sources. Human urine contains around 0.5 mg Cd/kg P_2O_5 (Kirchmann and Pettersson, 1995).

Global trends in fertiliser use

Fertiliser consumption has been dropping since the 1990s in the EU and most of the OECD countries and this has resulted in major water quality improvements in these countries. But agricultural practices using excessive amounts of fertiliser leading to runoff losses to both fresh water and coastal zones remain a problem in many other parts of the world (Fig. 4). Fertiliser use has increased in Asia, Africa and South America over the past several decades.

As populations continue to increase, especially in the developing countries, food production and fertiliser availability will need to increase accordingly. What agricultural policies, therefore, are being currently put forward to ensure food security within the confines of sustainability? Which countries will be feeding the world and increasing their requirements for fertiliser? The OECD countries do not have obvious action plans for sustainable agriculture. The EU subsidises agriculture to the tune of €1 billion each week as part of the CAP (Common Agricultural Policy) (EC, 2010). The result is overproduction and over-consumption of food with the ensuing environmental and health impacts. Similar trends can be seen in the U.S. It appears China, Malaysia, Brazil, Vietnam, Chile and South Africa are expanding their capacity to grow food and at significant growth rates – currently between 2 and 3 per cent per year (Global Harvest Initiative, 2010). Sub-Saharan Africa is still falling behind, but can be expected to grow over the next few decades.

Global phosphorus flows

Bennett et al. (2001) reviewed the literature on the global phosphorus cycle and concluded that phosphorus applied as fertiliser accumulates in the soil and eventually becomes eroded creating nutrient loading to

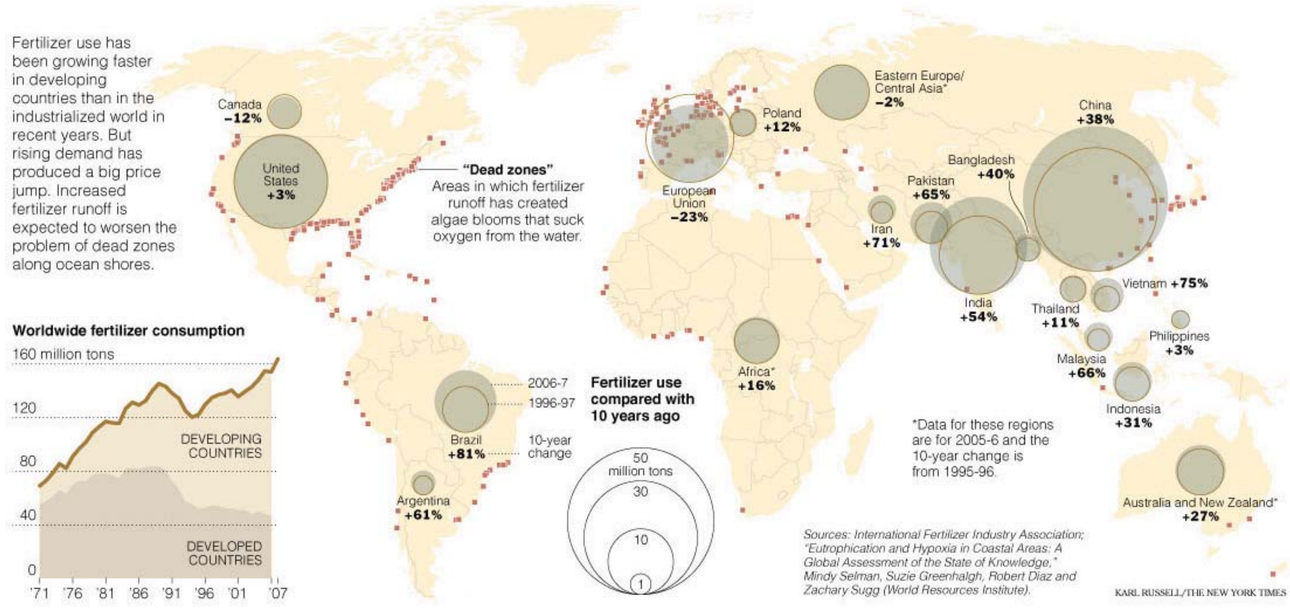

Figure 4 . Global trends in fertiliser use including the 'dead zones' in coastal areas due to excessive nutrient runoff and discharge
Source: New York Times, 2008.

receiving water bodies. Cordell et al. (2009) also estimated the global flows of phosphorus (Fig. 5), showing that of the 15 Mt of phosphorus that is used each year in fertiliser, only 3 Mt ends up being consumed in the form of prepared food. Significant losses to the soil and erosion amount to approximately 8 Mt. Domestic farm animals produce about 15 Mt of phosphorus in the form of manure and about half of this is added back to arable lands to grow crops. The bulk of the phosphorus in the manure (12 Mt) is from grazing natural vegetation and only about 2.5 Mt enters from feed. The grazers therefore are an important source of phosphorus for agriculture and, as mineral sources become more depleted and more expensive, the role of grazers, especially on rain-fed, natural grasslands, may become even more important also as a source of food protein.

The largest losses are from agriculture, which uses and loses the most phosphorus. Reforms are necessary to reduce the erosion losses and optimise the amounts used as fertiliser. Losses from manure handling also need to be reduced. Waste and sanitation systems are presently not designed for reuse and recycling. Source separation of organic fractions is necessary both in food processing and preparation. Nutrient capture from sludge and wastewater systems plus onsite collection of solid waste and latrine fractions will become more and more economically attractive as the price of fertiliser increases. Poor countries will be able to close the loop on phosphorus faster than the rich countries – since they are less locked into the large mixed waste and sanitation systems that developed countries have adopted (Rosemarin et al., 2008). These, unfortunately were designed to get rid of waste and not to refine, recycle and reuse it as a valuable, readily available resource. The present tendency is to continue building and expanding these mixed waste systems as the world becomes more and more urbanised (now over 50 per cent of the global population). Urban agriculture in an ideal world would be receiving nutrients from the cities it supports. But there is a long way to go before such systems are put into place. At the present time, over 700 million people in 50 countries consume food from 20 million ha of land irrigated with untreated sewage (Scott et al., 2004). This practise will increase as cities become larger and the need to produce food increases. If such systems had been designed from the start for agricultural reuse, the spreading of pathogens and parasites could have been reduced.

Market response to high oil prices and production of biofuels

Phosphate prices are set essentially by only three countries – the U.S., China and Morocco – that produce the bulk (almost 70 per cent) of the product for fertiliser use (Fig. 3). Phosphate fertiliser prices soared in 2007/2008 (600 per cent increases in product and 800 per cent in rock) (Fig. 6) when oil prices were over US$100 per barrel and the U.S. and other countries increased the use of food crops to produce ethanol as a liquid fuel. After the economic crash of 2008, prices are gradually increasing again. Triple superphosphate increased by 100 per cent in price during 2010 (World Bank, 2010).

Globally, food prices rose 40 per cent in 2007 and even in the poorest countries, the food index rose 25 per cent. For rural smallholder farmers in developing countries, chemical fertilisers are still no longer affordable even following the global economic collapse of 2008/2009. The relative price hike in food was the highest in over 100 years, exceeding the peaks during the oil crisis of the early 1970s and the two world wars. (Fig. 7).

The UN held three food security summits following this rapid increase in fertiliser and food prices, but only recommended short-term remedies, like increased food aid to poor countries unable to afford the high costs of chemical fertiliser. No systems or integrated view was taken questioning the excessive use of chemical fertilisers, the need for eco-friendly and climate-smart agricultural practices or examining the world's limited fertiliser resources. Phosphorus was not

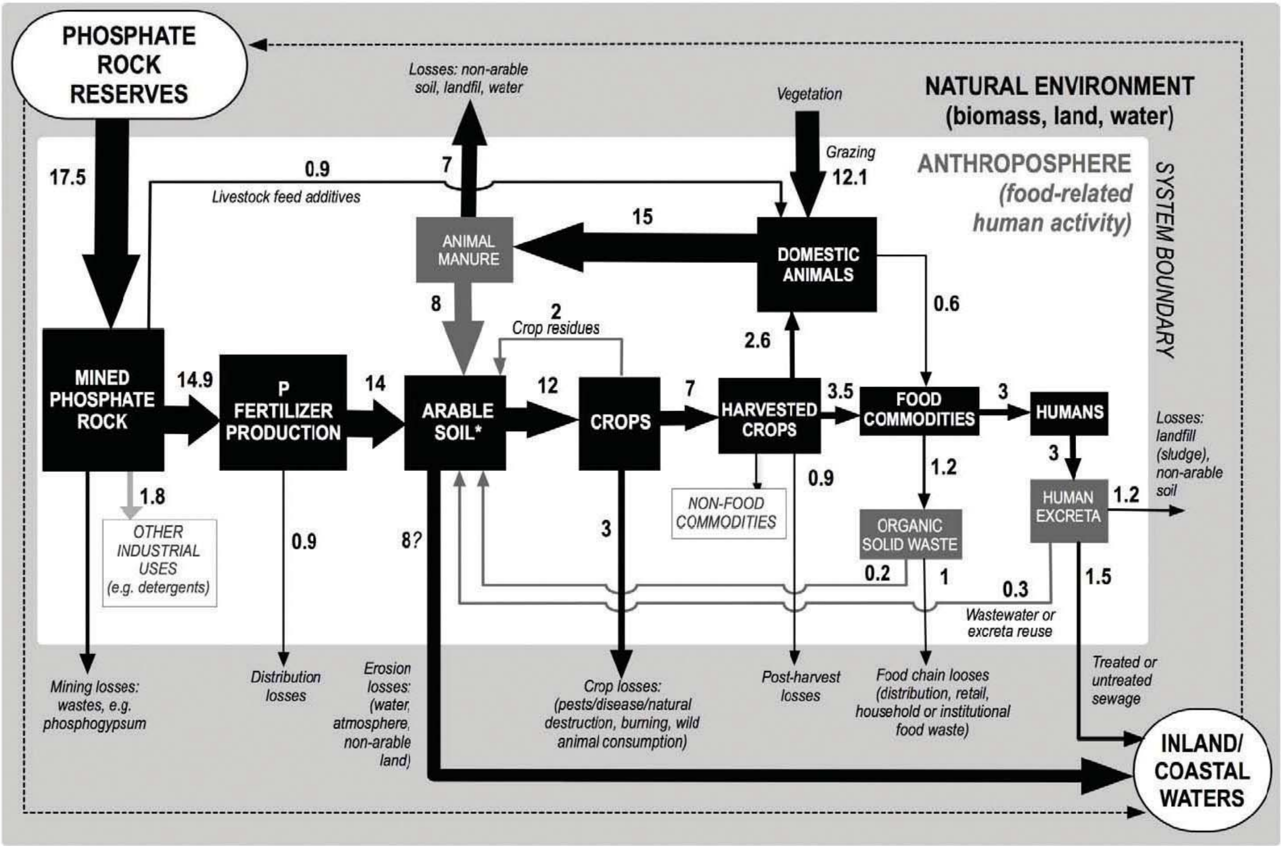

Figure 5. Global flows of phosphorus (Mt). Source: Cordell et al., 2009

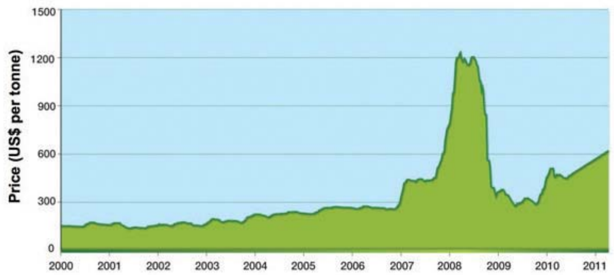

Figure 6. Trends in the world price of diammonium phosphate to 2011 (Bulk FOB US bulk US$ per tonne). Source FMB Weekly Phosphates Report, May 2011.

Figure 7. Trends in the FAO food price index to 2008.
Source: World BankUNEP, 2009.

recorded as an issue of long- or medium-term concern in the resolution of June 2008 (FAO, 2008). A new form of global governance of phosphorus is thus called for. Phosphorus reserves are limited and will become more expensive as the high-grade commercially viable rock becomes depleted. The geographic distribution is highly skewed, which can lead to shortages caused by unpredictable political turmoil in some of the larger producer countries. A governance capacity is needed to provide global fertiliser and food security by monitoring rock extraction and the size of reserves, promoting more efficient agricultural practices and reuse from manure and waste sources.

Conclusions and recommendations

Closing the loop between agriculture and sanitation

The agriculture challenge

The agriculture challenge is truly gargantuan when one sees that nearly one billion people living in 46 countries are malnourished (FAO, 2010), 40,000 die every day of hunger and hunger-related diseases and famine remains a threat in at least nine African countries where the lives of 20 million people are at risk. Some 75 to 80 per cent of Africa's farmland is degraded. Africa loses between 30 and 60 kg of nutrients per ha per year – the highest rate in the world. In 2002/2003 sub-Saharan Africa used 8 kg of fertiliser per ha compared to South America (80 kg/ha), North America (98 kg/ha), Western Europe (175 kg/ha), East Asia (202 kg/ha), South Africa (61 kg/ha) and North Africa (69 kg/ha). The cost of fertiliser prior to 2007 in the U.S. was US$150/t, but in landlocked African countries it was as high as US$600/t largely as a result of the severe underdevelopment of the transport infrastructure – rail and road. Phosphorus fertiliser, although produced on the African continent, is not available to African smallholder farmers. Reforms within the sector are necessary in order to make use of alternative sources of fertiliser and even alternative agricultural practices. In order to cope, more sustainable conservation agricultural practices are necessary, such as strategic cropping and low- or no-tillage practices, water harvesting and recycling of nutrients from various organic sources including manure and humanure.

The sanitation challenge

While the agriculture challenge is daunting, the human sanitation challenge remains (Rosemarin et al., 2008). Currently 5000 children die every day in the world from water-borne diseases linked to a lack of basic sanitation; 700 million people in 50 countries eat food from crops irrigated with untreated sewage; 60 million DALYs (disability-adjusted life years) are lost due to diarrhoea every year; 3.5 billion people are infected with helminth worm parasites; and half the world lacks basic sanitation systems. Meeting this, the largest MDG target, will have a cross-sector social impact by improving livelihoods and general productivity. Productive sanitation linked to agriculture can provide new growth opportunities for poor countries. So, in order to meet the MDG target for sanitation coverage, the question of disposal and reuse should be put clearly into focus especially knowing that the potential fertiliser capacity from these systems can be a significant contribution towards fertiliser and food security.

Linking sanitation and agriculture

A closer look is necessary to understand how sanitation and agriculture can be linked. The concept of ecological sanitation seeks to develop sanitation systems for human excreta that close the nutrient and water cycles. For example, nutrient recycling from human waste can be achieved by using soil composting and urine-diverting dry toilets (Morgan, 2008). Such systems are particularly appropriate in rural and peri-urban areas of developing countries where farmers cannot afford chemical fertilisers. Ecological sanitation has the potential to be a useful alternative to generate fertiliser in subsistence farming (Rosemarin et al., 2008).

The average human produces 500 L of urine and 50 L of faeces per year. This is equivalent to about 5.5 kg of NPK (4 kg of nitrogen, 1 kg of potassium and 0.5 kg of phosphorus) per capita per year varying from region to region depending on food intake (Jönsson et al., 2004). The rule of thumb is that one day's urine from an adult is sufficient to fertilise a square metre of cropped area for each cropping period. This means one year of urine from a person can support agriculture over an area of about 300 to 400 m2. If used mainly as a phosphorus fertiliser (i.e. requiring a supplement of nitrogen), one person's urine over a year can support even larger areas of between 500 and 600 m2. Calculations show that sub-Saharan Africa could become self-sufficient in fertiliser supply if it were to adopt productive or ecological sanitation practices (Rosemarin et al., 2008). This would provide the necessary supply of nutrients to smallholder farmers and provide food security and new opportunities for income.

In trials in seven villages in Niger, Dagerskog and Bonzi (2010) found that ten persons (the average family size is nine) annually excrete in their urine the equivalent of about 50 kg of urea in purchased chemical fertiliser. In their faeces and the non-nitrogen part of the urine they excrete about 50 kg of prepared NPK fertiliser (14-23-14), worth about US$80. Plots using urine as a fertiliser produced comparable or 10 to 20 per cent higher yields of sorghum and millet compared with plots receiving chemical fertiliser at the same nitrogen application rate. In trials with tomato, onion, cabbage, lettuce and pepper, urine, which contains potassium, phosphorus and nitrogen, acted as a complete fertiliser producing consistently 20 to 45 per cent higher yields in comparison to urea alone. The objective in this IFAD project was to encourage farmers to use urine instead of the expensive synthetic urea. The rule of thumb from this project was that one person excretes in urine and faeces per year on the average 2.8 kg N, 0.4 kg P and 1.3 kg K and this is sufficient to fertilise a cereal or vegetable crop covering 300 m2. To avoid loss of ammonia from stored urine, sealed containers are used. Responding to the increasing interest in recycling of phosphorus and other nutrients from sanitation systems, WHO, UNEP and FAO developed guidelines for the safe reuse of human excreta in agriculture (WHO, 2006). Struvite is now being produced using urine as the sole source of phosphorus in villages of Nepal (Gantenbein and Khadka, 2009). The phosphorus loop for rural populations can therefore be closed without too much change in the make up of the present systems. For urban systems the challenge is much larger since the waste systems have not been designed with agricultural reuse in mind. For those cities with sewage treatment systems, the sludge is a significant source of phosphorus. The organic fraction of municipal solid waste is also a significant source of phosphorus since this constitutes between 50 and 70 per cent of the waste produced (UNEP/GRID-Arendal, 2004).

In order to make this jump to sustainable or productive sanitation requires a paradigm shift in the way we design and use sanitation and solid waste systems. Mixing reduces the quality of the various products. So this calls for source separation of urine, faeces and greywater, containment of the various fractions, treatment (e.g. through composting of the faeces fraction) and then reuse of the nutrients in agriculture of various kinds. In urban settings where sludge can be collected from pit latrines, septic tanks and sewage treatment plants, considerable amounts of phosphorus can be collected and made available for agricultural reuse. For EU-27, it is estimated that one-third of the phosphorus used as fertiliser can be obtained from the sludge in sewage treatment plants (based on data from an EU assessment by Milieu Ltd. et al., 2009). If the manure from domestic farm animals is included, then the entire fertiliser requirement can be covered through recycled sources (Haarr, 2005). In Sweden, with improved fertiliser and manure practices, municipal sludge could, within a decade, replace 50 to 65 per cent of the P originating from chemical fertiliser (Finnson, A., 2011).

As fertiliser prices continue to increase, the economic value of urine and composted organic wastes and faeces from both livestock and humans will make these products more and more attractive alternatives. And there will be more pressure to develop these options. There are major stumbling blocks preventing widespread development in these directions resulting from general ignorance and cultural taboos and attitudes about human excreta. There is a serious lack of capacity in the world today to carry out large-scale productive sanitation with agricultural applications. Policies and regulations are also lacking to help promote and main-stream these practices. So much work through extension services and training is required before we can make the leap to close the loop on nutrients to benefit mankind.

The urgent need for policies and governance

The above discourse identifies gaps in policies and governance that may already be jeopardizing the food security of several nations. There is an acute need for a directive and governance capacity to dictate policy on the sustainable management and use of phosphorus. A global convention and implementation commission are required in order to secure the limited supply of commercially viable phosphorus and to begin using it in a much more conservative manner than up to now. The commission would fulfil the need for an independent monitoring capacity in order to increase transparency about the extent of viable phosphorus reserves. The commission would also promote more efficient agricultural practices, both in the use of chemical fertiliser (e.g. through better fertiliser placement and reduced applications) and in the use and storage of manure in order to minimise losses. Implementation in developing countries could be catalyzed through FAO and IFAD extension interventions. There is also a need to develop new recycling systems from waste and sanitation sources that are designed around agricultural requirements (e.g. to produce floc in sewage treatment plants that is crop-available and to introduce source separation of waste components in order to optimise fertiliser quality). Implementation could be catalyzed through UN Habitat and UNEP, which has already shown an interest in the phosphorus question (UNEP, 2011). Tax incentives could be introduced to promote investments in closed-loop systems. It is of prime importance that the various waste and sanitation sectors better integrate themselves in the agriculture sector to provide new and more sustainable solutions that will secure a high level of efficiency in the use and reuse of phosphorus.

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POLICY COCKTAILS FOR PROTECTING COASTAL WATERS FROM LAND-BASED ACTIVITIES

This article explores how comprehensive, continuing and adaptive governance and management reforms that link watershed and coastal area management – an integrated ecosystem approach from Hilltops-2-Oceans (H_2O) – should be proactively designed and implemented to address cumulative threats to ecosystem services in coastal areas. Such reforms, comprising dynamic policy and institutional combinations, must be multi-disciplinary and cross-sectoral and should involve a tailor-made balance of command-and-control instruments, voluntary approaches and market-based instruments.

The article highlights that governance and management reforms seeking to transform behaviour across multiple sectors while integrating freshwater and coastal/marine management require sustained leadership, multi-stakeholder participation, certainty for investors and high-profile initiatives that generate multiple benefits. It recommends that governments explore, even experiment with, reforms or policy cocktails that are integrated with elements of the broader governance environment, such as planning, energy, transport, agriculture, forestry, tourism, development aid and taxes.

Key words: governance, ecosystem, policy, pollution, Hilltops-2-Oceans approach, Global Programme of Action (GPA).

Introduction

The well-being of humanity "ultimately depends on the health of the ecosystems" (UNEP, 2009a). We exploit ecosystems for resources and depend on ecosystem processes to regulate natural cycles and eliminate pollutants. We also "rely on them for recreation, instruction and mental and spiritual enrichment". In this context, humanity has for millennia congregated in urban and rural settlements where both freshwater and marine resources are proximate and readily accessible. Loosely labelled 'coastal areas', with unclear boundaries, these locations are characterised by dynamic natural ecosystems that form the defining feature of planning and economic development.

Often endowed with reliable rainfall and fertile soils, juxtaposed with aquatic corridors for transport and trade, food supply and recreation, the services provided by coastal ecosystems ensure that economic activity is vibrant. For example, both subsistence and broad-scale agriculture flourish on productive coastal floodplains – 25 per cent of global primary production takes place in the coastal zone and 90 per cent of the world's fish is either caught or farmed in coastal waters. Approximately 3.4 billion people – more than half the world's population – currently live in coastal areas, accounting for only 5 per cent of inhabited land. By 2025, as much as 75 per cent of the global population will live in the coastal fringe with the majority of the balance living in vast watersheds that drain to the coast. In South East Asia, more than 70 per cent of the population already live in coastal areas. Currently, of the 33 largest megacities across the globe, 22 are located in coastal areas, while rapid population growth is also expected in the many mid-sized urban centres in coastal areas.

These anthro-magnetic coastal ecosystems include seas (bays, gulfs, enclosed and semi-enclosed seas), the adjacent watersheds (low-lying alluvial pans, coastal floodplains and deltas), estuaries, lakes (including the Great Lakes), lagoons and sandy, muddy or rocky shorelines. They are dynamic complexes comprising plant, animal and microorganism communities and the non-living environment. They vary enormously in size.

Importantly, humans are an integral part of these ecosystems. Indeed, the magnetism of coastal ecosystems is perhaps their greatest threat. As much as 91 per cent of all inhabited coasts will be heavily impacted by development by 2050, while more than 80 per cent of pollution in coastal waters stems from land-based activities in cities, towns and farms. Key threats to coastal ecosystems include untreated sewage and industrial wastewater, nutrient enrichment, invasive species, persistent organic pollutants (POPs), heavy metals, oil spills and radioactive substances, litter, overfishing and heavy siltation. Poorly planned or unchecked development can result in the physical alteration and destruction of critical coastal habitats (mangroves, wetlands, foreshore dune systems, coral reefs and seagrass meadows) that provide important and valuable ecosystem functions, including the sequestration of carbon (note: tidal salt marshes and mangroves have extremely high carbon accumulation rates compared to terrestrial habitats such as tropical and temperate forests) (Laffoley and Grimsditch, 2009). Yet these habitats are being lost four times faster than our rainforests and the rate of loss is accelerating. While humanity extends its love affair with the coast, the ecosystems services that are the very foundation of development are showing signs of stress and fatigue, putting at risk our livelihoods, our security and our quality of life – in short, our future.

Jeffrey Sachs (2008) reports (p. 28):

> "My colleagues at The Earth Institute have calculated that roughly 10 per cent of the world's population lives in low-lying coastal zones (within 100 km of the coast and at less than 10 m above sea level), though such areas constitute a mere 2.2 per cent of the Earth's land area. This implies, of course, that such low-lying coastal settlements are roughly five times more densely populated than the average land area on the planet. Of the people living in low-lying coastal zones, about 60 per cent are in coastal cities. As the Earth's climate changes in future decades, rising sea levels and increasingly intense tropical storms will threaten these coastal settlements around the world. The New Orleans tragedy of Hurricane Katrina could be replayed many times."

However, these threats and the associated reduction in resilience to climate change are symptoms, not the root illness. The real failing relates to the lack of ecosystem approaches to governance and management across the entire waterscape. The very ecosystem services upon which coastal populations are so dependent are threatened with 'death by a thousand cuts' because of humanity's failure to govern river basins and groundwater aquifers, i.e. fresh water systems, and coastal ecosystems as interconnected systems.

Thia-Eng (2006) reports (p. 104):

> "Existing policies and management strategies in most parts of the world … are insufficient and ineffective in arresting or reducing the rapid rate of coastal degradation, especially transboundary degradation …. The costs of coastal degradation, and threats to food security, employment and public health, are often very high."

In reference to the East Asia region, Thia-Eng continues:

> "Many status reports document slow progress in improving coastal environments and often paint a gloomy picture. Coastal governance efforts trail sadly behind environmental degradation."

An integrated Hilltops-2-Oceans (H_2O) approach to governance and management

Addressing these longstanding shortcomings in governance and management requires a radical paradigm shift towards a more holistic view of the links between ecosystem service delivery and human needs, i.e. an ecosystem approach to the governance and management of river basins and coastal ecosystems. To achieve this, it is important for policymakers and practitioners to understand two important concepts. The first relates to the difference between 'governance' and 'management'.

Coastal governance "refers to the process by which the full range of laws, policies, plans, institutions and legal precedents address the issues affecting coastal areas. Governance sets the framework within which management can proceed as it establishes the fundamental goals, institutional processes and structures that are the basis of planning and decision making (see Box 1). Governance in this context does not rest solely on government and politics. It stems also from the other communities of stakeholders." (Thia-Eng, 2006; p. 104).

Olsen et al. (2009) states:

> "Management is the process by which human and material resources are harnessed to achieve a known goal within a known institutional structure. We therefore speak of business management, park management, personnel management or disaster management. In these instances the goals and the mechanisms of administration are well known and widely accepted. Governance, in contrast, addresses the values, policies, laws and institutions by which a set of issues are

addressed. It probes the fundamental goals and the institutional processes and structures that are the basis for planning and decision making. Governance sets the stage within which management occurs." Governance, as opposed to management, is about leadership and vision. A governance framework is constitutional in nature, in that it articulates rules or conventions governing relations and practice. It defines expectations, grants power and influences standards of behaviour and the exercise of authority. It embodies the laws, policies, organizations and social norms in which management occurs.

The fundamental importance of governance in protecting and maximizing ecosystem services is highlighted by Paul Collier (Collier, 2010) in his recent book 'The Plundered Planet'. Collier proposes two alternative formulas for anticipating the long-term social and economic implications stemming from a nation's natural assets:

nature + technology – regulation = plunder

or

nature + technology + regulation = prosperity

The determining factor between a future of plunder or prosperity, according to Collier, is the presence, or not, of adequate regulation, with Collier arguing that the key failures have been due to the lack of regulation. He suggests that, "Without regulation the potential of natural assets cannot be realised" and is quick to point out that, "Regulation requires good governance". He notes that, "the world's 194 governments … vary greatly in their competence and their accountability to citizens" and in his analysis of the so-called 'resource curse' he contends that, "the resource curse is confined to countries with weak governance" and that, "the evidence suggests that the endowment of natural assets has ambiguous effects, which depend upon the initially prevailing level of governance."

Understanding the difference between governance and management is important for those concerned about the conservation of coastal ecosystem services because it is the governance framework, not only the managers, which will determine success or failure, prosperity or plunder. Indeed, it can be argued that no one actually manages coastal ecosystems. Billé (2008) contends that the concept of a 'coastal manager' is a myth and prefers to label such individuals as coastal practitioners, professionals or facilitators. He suggests:

"There is truly a 'coastal management' associated with any given coastal region (the way it is managed, its actual management), but there are numerous managers with none having, nor being able to exercise leadership over the other a priori. In other words, one can say that the management of coastal areas is a process without a pilot, a management without a manager."

This distinction between governance and the heterogeneous nature of coastal management, emphasises that coastal practitioners will always be influenced or constrained by the prevailing winds and currents of the governance framework in which they operate.

Box 1 Protecting the Bohai Sea

The Bohai Sea is an enclosed water body in north-west China and covers an area of 77,000 km2. As many as 40 rivers flow into the Bohai Sea which drain an area of approximately 1.4 million km2, supporting a population of 445 million people. Tackling pollution was problematic because the Bohai Sea borders different administrative and jurisdictional boundaries – namely three of China's provinces (Shandong, Hebei and Liaoning) and the municipality of Tianjin.

In response to the Bohai Sea's growing environmental problems, the State Oceanic Administration, in conjunction with the coastal provinces and municipality, agreed to manage the Sea and to protect the marine environment collaboratively. Subsequently China launched its Bohai Sea Sustainable Development Strategy to foster improved long-term governance and management of the region, as well as its Bohai Blue Sea Action Plan in association with several key ministries and administrations. The Chinese government has committed US$18.5 billion to the implementation of the Bohai Sea Action Plan which runs to 2020. This includes The Blue Fund established to collect endowments which are invested in pollution reduction and capacity building initiatives.

An overall plan for the Environmental Protection of the Bohai Sea (2008–2020) was submitted to and approved by the State Council at the end of 2008. The plan aims at:

- Promoting marine pollution control and prevention
- Ecological rehabilitation
- Better control and treatment of land based sources of pollution
- Improved management of water sources and river basins
- Increasing scientific and technological support for environmental protection and marine monitoring
- Establishing marine pollution reduction technical working groups for key river basins in partnerships with local governments and the State Oceanic Administration

As part of the governance reforms, an institutional management body was established – 'the Bohai Sea Integrated Management Committee (BSIMC)' – comprising 11 national government agencies as well as four coastal provincial and municipal governments. The BSIMC adopted a mechanism to develop integrated and cross-sectoral approaches linking all responsible government departments and agencies. The change from a previous sector management approach to the new multi-sectoral, integrated governance approach enables local governments to adopt integrated management approaches and mechanisms which include pollution risk assessments, waste reduction programmes and cross-sectoral pollution monitoring. The Bohai Sea Management Law further codifies these reforms and provides the legal basis for the implementation of various activities pertaining to the development, management, protection and rehabilitation of the Bohai Sea. The signatory partners, namely the State Oceanic Administration, the three provinces and a municipality, are all responsible for the enforcement of this law.

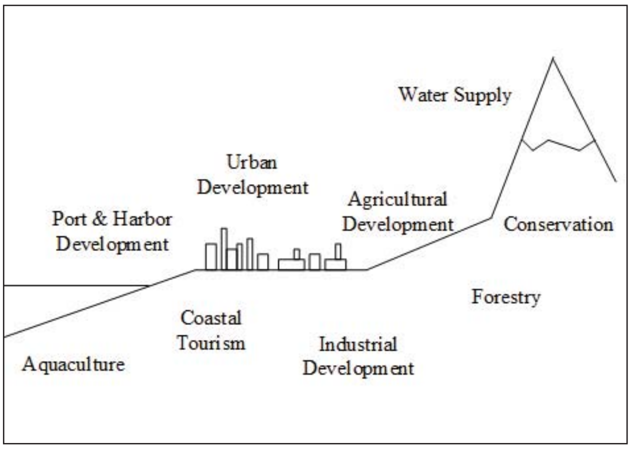

Figure 1. The Hilltops-2-Oceans (H2O) approach links multiple sectors.

Figure 2. National action as the central feature of the GPA.

Governance mechanisms and reforms can help or hinder coastal practitioners, depending on the extent to which they reflect the interconnected and interdependent nature of freshwater ecosystems and coastal ecosystems.

This leads to the second important concept for policymakers and coastal practitioners to understand. It is an important fact of physics, namely 'water runs downhill'. While appearing facetious, this simple fact of nature is often overlooked in the maelstrom of policies, laws and institutions that crowd and confuse the protection of coastal ecosystems. While water runs downhill, the governance and management mechanisms frequently do not.

The 'water runs downhill' phenomenon means that the effects of upstream decisions in multiple sectors (e.g. agriculture, forestry, urban and industrial development) reach their cumulative climax in downstream coastal ecosystems. However, as highlighted above, many different sectors and societal groups, each with their own interests and objectives also come together in these 'receiving' ecosystems to capitalise on the multitude of ecosystem services provided. The protection and sustainable development of coastal ecosystems therefore demands a cross-sectoral response, linking development activities in the river basin with those linked to the coastal ecosystems, i.e. an integrated ecosystem approach from 'Hilltops-2-Oceans' (Fig. 1). More often than not, this requires fundamental changes in the policies, laws, institutions and practices underpinning both governance and management.

Global Programme of Action

In an attempt to actively promote governance reforms linking river-basin and coastal governance, the global community adopted the Global Programme of Action (GPA) for the Protection of the Marine Environment from Land-based Activities in Washington, D.C. in 1995. It was reviewed in 2001 and 2006 in Montreal and Beijing respectively.

The GPA "aims at preventing the degradation of the marine environment from land-based activities by **facilitating the realization of the duty of states** to preserve and protect the marine environment" [emphasis added]. At the national level it calls upon states **"to develop comprehensive, continuing and adaptive programmes of action** within a framework of integrated coastal area management". National actions are complemented and supported at the regional level, where the GPA calls on states "to strengthen and, where necessary, create new regional cooperative arrangements and joint actions". Many of the respective regional seas have also negotiated legally-binding protocols on land-based activities/land-based sources of marine pollution, paralleling the GPA. Similarly, at the global scale the GPA calls for states "to strengthen existing international cooperation and institutional mechanisms and, where appropriate, to establish new arrangements, in order to support states and regional groups to undertake sustained action" (Fig. 2).

At the 2nd Intergovernmental Review (IGR2) of the GPA in Beijing in 2006, governments determined that the period 2007 to 2011 would "focus on mainstreaming the implementation of the GPA in national development planning and budgetary mechanisms". Governments indicated that "mainstreaming will require integration of the GPA across sectors and ministries and also integration into domestic and international aid budgets, development plans, strategies and actions." In this context, mainstreaming is "the informed inclusion of relevant environmental concerns into the decisions of institutions that drive national, local and sectoral development policy, rules, plans, investment and action" (Dalal-Clayton and Bass, 2009).

The mainstreaming of ecosystem-based (Hilltops-2-Oceans) governance and management reforms into national development frameworks has three main aspects:

1. Developing processes that are not a bound to a specific sector, but rather relate to aspects of a wide range of sectors – agriculture, water management, fisheries, tourism, transport and industrial development
2. Reconciling processes that focus on stimulating growth and development with measures that protect coastal ecosystems

3. Establishing the policy and institutional mechanisms to make those processes work.

Mainstreaming the GPA follows the 'sustainable development' view that economic development and conservation goals are mutually supportive under the right circumstances.

While many multilateral initiatives seek to mainstream their respective objectives, the GPA is unique in that it is the only global initiative directly addressing the connectivity between terrestrial, freshwater, coastal and marine ecosystems. The mainstreaming process can provide the 'glue' that brings together the various sectors operating in these interconnected ecosystems. Importantly, the GPA recommends that States undertake activities to protect the marine environment, recognizing the affect on food security and poverty alleviation, public health, coastal and marine resources, ecosystem health, and economic and social benefits and uses.

Furthermore, the GPA represents an explicit understanding by the international community that the degradation of coastal ecosystems frequently "results from multiple assaults rather than a single factor", meaning that "multiple interventions are typically required to restore a degraded ecosystem" (Sachs, 2008; pp. 74-75).

As stated above, the GPA calls upon States "to develop comprehensive, continuing and adaptive programmes of action" that effectively reform the governance framework in which coastal practitioners, agriculturalists, urban planners and developers will operate. In this context, the three adjectives – comprehensive, continuing and adaptive – provide a good model for ecosystem-based governance reforms from Hilltops-2-Oceans.

Comprehensive ecosystem-based governance reforms will provide a framework and incentives for the setting and achievement of targets across the Hilltops-2-Oceans landscape addressing the broad suite of pollutant categories impacting coastal ecosystems. These include nutrients (agriculture, sewage and atmospheric), POPs, heavy metals and hydrocarbons, litter, radioactive waste and sediment loads. Such targets may include total maximum daily loads (as used in the USA), or 'fit for use' water quality standards (as used in Europe). Targets should also be set to prevent or reduce the physical alteration and destruction of habitat and may involve the designation of coastal and marine protected areas.

The term 'comprehensive' applies not only to the range of pollutants addressed, but also the extent to which communities, non-governmental stakeholders and the market are integral to governance reforms and implementation, and the extent to which institutional collaboration is facilitated. In this context, institutional collaboration refers to "the pooling of appreciations and/or tangible resources (e.g. information, money and labour), by two or more stakeholders to solve a set of problems which neither can solve individually" (Grey, 1985).

Given that it is precisely the uncoordinated nature of governance across the waterscape that threatens coastal ecosystems, institutional collaboration has much to offer to the realm of ecosystem-based governance reforms. Unfortunately, little is known about the difference between strategic, policy-level collaboration and the relatively well-understood community-based efforts, or how the efforts of informal collaborative networks to develop, implement and adapt policy-level changes affect formal collaborative arrangements, i.e. bottom-up collaboration (Robinson et al., 2010). More work is required at global, regional, national and sub-national scales to get policy collaboration right (this is discussed further below).

Continuing ecosystem-based governance reforms will ensure that policies and institutions are appropriately financed for long-term sustainability (see Box 2). Sources of funding include domestic revenues, such as tariffs and taxes, as well as subsidies, bonds and multilateral finance. In this context, market-based instruments can be utilised to 'institutionalise' good practice through both economic incentives and penalties.

To ensure the continuity or sustained implementation of ecosystem-based governance reforms, reporting and accountability frameworks must be established and implemented. Ideally, these should be codified into national law and supported by systems of transparency, probity and enforcement.

Adaptive ecosystem-based governance reforms will be science-based, but not science-dependent, recognizing that policymakers and practitioners must frequently make decisions despite incomplete data, imperfect models and scientific disagreement. Policies, laws and institutions will be responsive to changes in the biophysical environment and will ensure monitoring of subsidiary management actions aimed at achieving pre-determined targets. Periodic reviews are programmed and governance institutions are structured and empowered to make changes based on real outcomes.

Adaptive reforms provide a flexible environment for positive change. For example, as a part of the shift to a greener economy, adaptive reforms will encourage the public and private sectors to be more proactive in funding wastewater management. Wise investments in wastewater management will generate significant returns, as addressing wastewater is a key step in reducing poverty and sustaining ecosystem services. Instead of being a source of problems, well-managed wastewater will be a positive addition to the environment which in turn will lead to improved food security, health and economic activity.

Consistent with the call for comprehensive, continuing and adaptive action, the joint UNEP/UN-Habitat report entitled 'Sick Water? The central role of wastewater management in sustainable development' (UNEP/UN-Habitat, 2010) made the following recommendations:

- Countries must adopt a multi-sectoral approach to wastewater management as a matter of urgency. This must incorporate the principles of ecosystem-based management from the watersheds to the sea, connecting sectors that will reap immediate benefits from better wastewater management

- Successful and sustainable management of wastewater requires a cocktail of innovative approaches that engage the public and private sector at local, national and transboundary scales. Planning processes should provide an enabling environment for innovation, including at the community level, but require government oversight and public management
- Innovative financing of appropriate wastewater infrastructure should incorporate design, construction, operation, maintenance, upgrading and/or decommissioning. Financing should take account of the fact that there are important livelihood opportunities in improving wastewater treatment processes, whilst the private sector can have an important role in operational efficiency under appropriate public guidance
- In light of rapid global change, communities should plan wastewater management against future scenarios, not current situations
- Solutions for smart wastewater management must be socially and culturally appropriate, as well as economically and environmentally viable into the future
- Education must play a central role in wastewater management and in reducing overall volumes and harmful content of wastewater produced, so that solutions are sustainable.

Policy cocktails

Experiences from around the world demonstrate that the comprehensive, continuing and adaptive ecosystem-based reforms envisaged by the drafters of the GPA must not rely on a single governance tool, but rather incorporate a cocktail of policies, laws and institutional mechanisms (see Box 3). These may range from exhortation, e.g. market-based instruments such as tradable pollution permits; to standing back, e.g. voluntary self-regulation agreements; to coercion, e.g. command-and-control legislation. The cost of enforcement and the impossibility for government to be everywhere may mean that exhortation measures are preferred to more coercive measures.

Irrespective of the cocktail ingredients, ecosystem-based governance reforms must seek to provide certainty for investors and set the prevailing winds in which long-term decisions and behaviour are determined (see Box 4). Murphy (1997) states:

"Relative to the problem of the pollution of rivers, lakes, and seas the key large investment decisions include choices among different designs and different locations of sewage and waste disposal systems, industrial plants, and refineries whose effluent may enter the waters. Key decisions also include … investment decisions regarding designing and marketing fertilisers and pesticides used on lands that drain into water…. Even the most significant of these decisions can be shaped by the governmental and intergovernmental regulatory environment simply because wise firms (whether public or private) always take projections about the regulatory environment into account before making investments."

Though an infinite number and combination of strategic governance reforms may exist for slowing down, halting or even reversing the pollution and destruction of coastal ecosystems, they are of course subject to political and economic constraints. Enhancing traditional command-and-control legislation with the best combination of legal, educative, economic and social approaches is a difficult task and must be tailored to the respective circumstances of governments, cultures, economies and ecosystems. No two national approaches to protecting coastal ecosystems will have quite the same appearance, scope or focus.

Box 2 The River Thames – comprehensive, continuing and adaptive reforms

During the 1950s pollution levels in the River Thames were so bad that it was declared 'biologically dead' – there was simply not enough oxygen in the river water to support life and residents often complained that its mud-banks reeked of rotten eggs. Sixty years later the Thames is teeming with life: there have been 125 species of fish including salmon and sea trout recorded and more than 400 species of invertebrates. Birds have returned including ducks, waders, sea birds, and even seals, dolphins and otters are now regularly spotted.

It has taken thousands of people many decades to restore the Thames to this point. It has included tighter regulation of polluting industries and working with farmers, businesses and water companies to reduce pollution and improve water quality. Since 2005, 393 habitat enhancement projects have been completed and nearly 70 km of the river have been restored or enhanced. The chemical quality of the majority of the rivers in the Thames catchment is now classed as 'Very Good' or 'Good'. This has improved from 53 per cent in 1990 to 80 per cent in 2008 while the estuary supports viable shellfisheries and is a nursery ground for commercial sole and bass (fish) stocks.

The UK's Environment Agency has publicised five innovative projects that have significantly helped to improve the quality of the Thames and its tributaries:

1. Working with farmers, which has helped to reduce pollution from nutrients and pesticides
2. The Jubilee River Flood Alleviation Scheme, which created a new 11 km stretch of natural river and habitats and at the same time delivered flood protection o 5,500 homes
3. The implementation of the London Rivers Action Plan which is helping to restore London's urban rivers (tributaries to the Thames) with 58 new river restoration projects in progress since its launch in 2009
4. The London Tideway Tunnels project – a £3.6 billion (US$5.7 billion) scheme to tackle the 39 million tonnes of storm sewer overflows that enter the tidal Thames annually
5. Thames Estuary 2100 – a 100-year adaptable plan to ensure the future sustainable management of tidal flood risk in the Thames estuary which seeks to protect over 1.25 million people and £200 billion (US$320 billion) in property value.

Box 3 A policy cocktail for the Great Barrier Reef

Australia's Great Barrier Reef Marine Park is a World Heritage Site. It covers almost 350,000 km2, an area bigger than the British Isles. Its significant contribution of US$5.4 billion a year to the Australian economy comes primarily through fisheries and tourism. Decades of research has suggested that the reef is in decline, largely as a result of land-based sources of coastal and marine pollution. Human activities, particularly agriculture (livestock grazing, sugar cane and banana farms, the application of fertilisers and pesticides), have significantly increased pollution with a detrimental effect on the reef and adjacent coastal ecosystems, such has estuaries, sea grass beds and mangroves.

A Reef Water Quality Protection Plan (Reef Plan) was introduced by the State (Queensland) and Federal governments in 2003 in an attempt to address the threats to the Great Barrier Reef from diffuse pollution sources. The innovative idea behind Reef Plan was that it viewed the sustainable growth of agricultural industries as an integral and vital element to the future well being of the Great Barrier Reef – what's good for agricultural business must also be good for the marine environment.

In 2009 a revised programme building on the lessons learned during the previous five years was adopted and backed by increased state and federal funding. The short-term goal of the new Reef Plan is to halt and reverse the decline in water quality entering the reef by 2013. The longer term goal is to ensure that by 2020 the quality of the water entering the reef from adjacent catchments has no detrimental impact on the health and resilience of the reef. The Reef Plan measures are cleverly designed in that they improve productivity by way of better soil, fertiliser and pesticide management, so that farmers actually make money which they can then re-invest for sustainable production and improved land management.

Smaller producers are asked to maintain records and assess risks, for example from herbicide run-off. Larger producers are asked to adopt environmental risk management action plans. Regulations complement these measures, for example better protection for 720,000 ha of riparian vegetation and wetlands. Science plays its part by informing the process.

Key messages include:

- Publicizing a threat to an iconic resource can help achieve the critical political and institutional reform required to tackle the issues threatening that very resource
- Involve industry and community organisations in generating solutions and implementing reforms
- National and local government worked together to create the right enabling environment
- Voluntary codes should be supported with fiscal investment and where necessary underpinned by incentives, regulatory and enforcement measures.
- Targets must be set
- Implementation must be informed by best available science.

Box 4 Certainty in the Philippines

Puerto Galera is a town of 30,000 permanent residents who are heavily dependent on tourism, the main source of income for residents and a major source of revenue for the local government. Tourist numbers rose dramatically from 138,000 in 2002 to reportedly more than one million in 2004. The increase in tourist numbers has been proportional to increasing discharges of sewage pollution, so wastewater treatment therefore became a priority action. However, Puerto Galera was a small municipality so the immediate issue was not building wastewater treatment plants, but rather making sure the prevailing governance environment was right. Political leadership and vision were vital ingredients for the success of the project. The mayor of Puerto Galera, Hon. Hubbert Christopher Dolor, was the 'champion' of this cause and pushed forward in partnership with the private sector and rallied constituents to support the scheme.

Key factors included:

Strong local government commitment and accountability: The establishment of a sewerage system is not just a public works project, but also involves political will, policy reforms, capacity building and social acceptability. Institutional capacity development was key for strengthening institutions and strong leadership helped drive top-down and bottom-up transformational processes.

Clear legal and institutional framework and regulatory capacity: A firm legal basis for financing and partnership arrangements created a more reassuring environment for investors.

Support and involvement of stakeholders: Strong community demand and support was critical to achieve successful implementation. Awareness needed to be raised and knowledge increased to stimulate demand. Asking people to pay for environmental services proved contentious and required a series of consultations and awareness/consensus-building exercises.

A systematic and transparent procurement process: Rigging of bids and corruption are issues that have been raised in many projects, thus transparency and a formal public process were used in the screening and evaluation of the proposals.

Cost-recovery/revenue-generating mechanisms: Consumers needed to be made aware why they should pay an environment-user fee and not simply receive the service for free. At the same time, the government and its private sector partner had to ensure the quality and timely delivery of service to encourage people to pay. To this end, effective project design and business planning were essential for the project to succeed.

Of course, not all cocktails are good cocktails. The various policy/institutional combinations may be complementary, neutralizing, redundant, counterproductive, antagonistic, or dysfunctional, purely as a result of the context in which they are applied. Finding the right balance for an integrated policy cocktail is therefore an iterative and adaptive process. Not all combinations will be accepted by stakeholders, and policymakers must be prepared to make timely changes as appropriate. Afsah et al. (1996) suggest that appropriate governance reforms should incorporate five key features. These are:

- Information intensity (reliable data, integrated information systems and the capacity to set priorities which reflect comparative benefits and costs)
- Orchestration, not dictation (taking into account indirect
* influences on polluters and using high-leverage non-regulatory programmes)
- Community control (strengthening central regulatory agencies should not empower them to impose uniform standards on heterogeneous communities)
- Structured learning (rather than pre-committing to broad-based programmes, agencies should initiate a variety of pilot projects and build larger programmes as lessons are absorbed)
- Adaptive instruments (regulators should be empowered to minimise disruption for investors and to counter environmental degradation by tightening existing instruments).

A key to avoiding ineffective or counterproductive reforms is to shake, not stir, i.e. integrated, but not confused, policy reforms. Pollution control instruments that are carelessly superimposed on each other are more likely to be incompatible and dysfunctional than complementary or sequential instruments designed to shake polluters into or out of certain behaviour.

Furthermore, it is important that any governance or management reform pertaining to the protection of coastal ecosystems is integrated with elements of the broader governance environment. An integrated approach recognises that, in addition to legal, fiscal and organizational reforms, widespread (and often enshrined) ethical, information, economic, moral, administrative and enforcement factors all affect behaviour in freshwater and coastal ecosystems. It recognises that negotiation, bargaining and compromise are inherent in ecosystem-based governance, and that the success or failure of policy alternatives is influenced by systemic synergies or limitations of legislative and institutional construct.

Integrated policy-making is important for at least three reasons (UNEP, 2009b):

1. A policy that addresses one issue can affect other issues, which may not be less important
2. Synergies among different issues exist and a policy intervention can be designed to achieve multiple benefits
3. Successful implementation of a policy relies on the support from a range of stakeholders who may have diverse values and interests that need to be harmonised.

Consistent with the objective of 'sustainable development', governance reforms aimed at protecting coastal ecosystems must be integrated with areas such as planning, energy, transport, agriculture, forestry, tourism, development aid and taxes. The objective should be seamless regulation and broad-based economic incentives that encourage, not diminish, inter-sector cooperation.

Regional and transboundary governance frameworks

The transboundary nature of many of the world's river basins means that the integration of governance reforms should also occur at multilateral or regional scales, the result being a nested governance framework reflecting a Hilltops-2-Oceans approach (see Box 5).

VanDeveer (1997) suggested:

> "Much of the transnational activity associated with the protection or restoration of environmental quality of coastal seas such as the Baltic, Mediterranean, and Black Seas and major lakes such as the Great Lakes evokes relatively new issue areas for international relations, involving concerns once considered the sole purview of domestic or internal authorities such as resource use, development planning, regulatory structure, and waste disposal and treatment. Many coastal seas protection regimes have moved from the regulation of a common resource to advocating, facilitating, and at times requiring fairly extensive changes in land use policies, scientific research and monitoring, economic development, and other states and societal practices on land….Thus, many states and sub-national governments are becoming increasingly bound by transnational norms associated with certain practices which have acquired normative force; that is, they are viewed as the ways in which regional seas research, monitoring, management, or administrative enforcement should be accomplished."

In this context the respective regional seas organizations have emerged over the last quarter-century as inspiring examples of how to craft a regional approach to protecting the environment and managing natural resources. There are now a total of 18 regional seas organizations across the globe. Many are guided by legally binding conventions, including specific protocols on the protection of the marine environment from land-based activities, while others are guided by non-binding action plans. Contracting parties or participating states should be guided by these governance frameworks in setting domestic governance frameworks for their constituents and companies operating within their borders. Similarly, many countries have built strong collaboration around projects funded by the Global Environment Facility and other donors that concentrate on the protection of large marine ecosystems. These initiatives address multiple threats, including land-based sources of marine pollution.

Another example of regional or transboundary governance frameworks guiding domestic policy comes from Europe, where the Water Framework Directive establishes a legal framework to protect and restore clean water across the continent and to ensure its long-term and sustainable use. It sets the 'good status' of freshwater and coastal waters as its core objective. Based on the natural geographical and hydrological units of river basins, the directive sets specific deadlines for EU Member States to achieve ambitious environmental objectives for aquatic ecosystems. Similarly, the new Marine Strategy Framework Directive establishes a framework for the protection and management of Europe's seas. It calls on EU Member States to ensure the 'good environmental status' of all of Europe's marine regions and sub-regions.

Conclusion

Coastal communities are increasingly threatened by climate change, burgeoning populations, unchecked development and widespread pollution, 80 per cent of which comes from land-based activities. The effective and efficient protection of coastal ecosystems therefore requires the freshwater community and the coastal/marine community to increase collaboration around holistic, ecosystem approaches (Hilltops-2-Oceans) to governance and management. It also requires far more than having tough sanctions to punish the environmental 'bad guys'. Most pollution and habitat destruction is not caused by a small number of criminal stereotypes, but by 'respectable' industries, government-sponsored or -initiated development, consumer choices and the community at large. Pollution and habitat destruction is a by-product of the market, driven by our consumer lifestyles. Governance reforms must, therefore, incorporate market-based instruments, voluntary agreements and social change agendas. Pollution and habitat destruction is something in which everybody is implicated to varying degrees.

As articulated by governments in the 1995 GPA for the Protection of the Marine Environment from Land-based Activities, these ecosystem-based governance and management reforms must be comprehensive, continuing and adaptive. Governments should explore, even experiment with, governance reforms or policy cocktails that are integrated with elements of the broader governance environment, such as planning, energy, transport, agriculture, forestry, tourism, development aid and taxes.

Ultimately, policy cocktails can and should be used expeditiously to generate …

…. the political will to DO IT
…. the capacity to DO IT RIGHT and
…. the resources to DO IT RIGHT NOW

Box 5 Regional cooperation on the Rhine

The European economic boom of the 1950s and 1960s led to the pollution of many waterways in Europe and the Rhine was no exception. Draining parts of Italy and Switzerland, the Rhine stretches for over 1200 km through the middle of Germany and enters the North Sea in the Netherlands. Altogether the Rhine's basin extends into Austria, Belgium, France, Germany, Italy, Lichtenstein, Luxembourg, Netherlands and Switzerland.

The Rhine was a major conduit for sewage and pollution from all the above countries where the wastewater treatment plants only first appeared in the 1970s. Following an accident in 1986, when 20 tonne of highly toxic pesticide entered the Rhine near Basel, Ministers from the Rhine countries approved the Rhine Action Programme (RAP) in Strasbourg in 1987. Key targets of the Rhine Action Programme were to reintroduce extinct fauna, return the river water to drinking water quality; and to reduce pollutants entering the river. In 1988 Ministers adopted further measures to combat accidents, specifically targeting industries situated along the river which use hazardous substances. In response to large algal blooms in the North Sea in 1988, Ministers added the 'protection of the North Sea' to the targets of the RAP, where nutrients entering the Rhine were to be reduced by 50 per cent by 1995.

Inputs of most priority substances have been significantly reduced by between 70 and 100 per cent or are no longer detectable. Of the population in the Rhine catchment, 96 per cent are connected to municipal wastewater treatment plants. In 2000 the Rhine transported 7000 tonne of ammonium nitrogen, compared to almost 40,000 tonne in 1985. The concentrations of heavy metals, such as chromium, copper, nickel and cadmium, have also fallen distinctly.

The results demonstrate what can be achieved when nine countries cooperate with one another. Specifically:

- Implementation was supported by the regional integration organisation, the EU where the European Commission launched legislation which complemented improvements, such as regulations/directives on municipal waste, agriculture, water and also specifically targeting single species such as salmon and eel
- A key factor was political momentum in the form of Ministerial-level participation which was highly active for the 15 years of the RAP, i.e. the RAP had significant cross-political party support in all nine countries
- The work of the International Commission for the Protection of the Rhine (ICPR) which coordinated meetings and kept the public informed, included NGOs and industries and reported results as well as shortcomings.

Now there is a new vision for the Rhine: a green strip of floodplains along the edges of the river which can absorb floodwater and are teeming with amphibian life. The diversity of fauna and flora species typical of the Rhine continues to increase. Salmon migrate upstream as far as Basel and maintain their stock without artificial stocking measures. Fish and crustaceans from the Rhine are known for their 'purity' and quality and are very much in demand.

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PATHWAYS TO IMPROVED WATER QUALITY

Global water challenges are as much about availability as they are about quality. Water quality is on the decline largely as a result of population growth, urbanization, industrial production and environmental degradation. Business has a vested interest in improved water quality. While business is often blamed for negative impacts on water quality, it can be part of solutions to improve it. Business efforts to improve water quality require a combination of measures, including managing water quality risk within business's own operations, external risks and developing and implementing innovative technological and other solutions – 'thinking outside the box'. The following article explores the most pressing water-quality issues of the day and possible business actions to overcome them, including a focus on hitherto little-explored options, such as the ecosystem approach.

Key words: water quality, innovation, natural capital, markets for eco-system services, regulation

Water: it's about quantity and quality

Concerns about water are not new. There have been issues surrounding this all-important resource for several decades, with much of the global focus on water scarcity and availability. Water quality is often a poor second, yet it is equally important. Similarly, the onus has been on household water rather than on water for business, except where business impacts negatively on the resource. Yet good water quality is as important to business as it is to the daily life of people.

Many in business do recognise the water quality challenge. For some sectors – like the food and beverage or pharmaceutical industries that rely on clean water as an input, or the water utilities sector – the importance of water quality is clear. For others, the link may be less apparent, though no less important. Poor water quality can result in major costs for business, as well as presenting health and environmental risks to its operations, employees and contractors. Of equal concern, poor water quality has a direct impact on water quantity. Polluted water effectively reduces the availability of usable water in a given area. In a world in which only 2.5 per cent of the water supply is fresh water – and unevenly distributed at that – this has serious implications.

Water quality on the decline

Global water quality is rapidly declining as a result of population growth, urbanization and industrial activities. At the same time, climate change and ecosystem degradation are adding to the problem. Recent data from some areas has revealed that sometimes these declines are greater than originally thought. In early 2010, China's government unveiled its most detailed survey ever of the pollution plaguing the country, revealing that water pollution in 2007 was more than twice as severe as what was shown in official figures, which had long omitted agricultural waste (New York Times, 9 February 2010).

Population growth and increasing urbanization (over half of the world's population now lives in towns and cities) are putting pressure on water and sanitation infrastructure, especially in developing countries. If development and improvement of this infrastructure fails to keep pace with demographic change, the result will be increased pollution and contamination of water sources. In addition to carrying health and social implications, this will also lead to reduced fresh water. As it is, 2.5 billion people worldwide are without adequate sanitation – more Indians have access to a mobile phone than a toilet! (UNU-INWEH 2010).

At present, over 80 per cent of sewage in developing countries is discharged untreated directly into water bodies. Faecal contamination of drinking water is a major contributor to diarrhoeal disease which kills millions of children every year and causes illness in even greater numbers of people. Besides the enormous human suffering , this places this places aheavy burden on struggling public health systems; the fallout in economic terms – lost days of productivity, work and schooling – is even greater. But the problem is not confined to developing countries. In developed countries too, aging infrastructure and lack of investment in its replacement are also resulting in freshwater losses and contamination.

Growing levels of industrial activity to fuel our global economy are a major cause of poor water quality. Worldwide, industry is responsible for disposing an estimated 300-400 million tons of heavy metals, solvents, toxic sludge and other waste into waters each year (UNEP and The Pacific Institute, 'Clearing the waters', March 2010).

When added to accidental spills of hazardous materials, chemicals, oil and plastics, this compromises water quality further. Even if spills occur at a distance from open waters, such discharges can move through porous limestone soil and reach open waters or canals. Equally, airborne pollution that falls back to earth as acid rain serves to further spread the pollution. Compounding this, are the growing numbers of emerging pollutants being detected in the world's waterways. These include substances that contain endocrine-disrupting compounds, such as pharmaceutical products, steroids and hormones, industrial additives and agents, as well as gasoline additives. They represent a new challenge to water quality management as data on their eco-toxicology and associated risks are lacking. Also of concern is thermal pollution wherein warm water discharged into rivers and waterways, particularly from power plants, raises the temperature of the receiving waters thereby potentially endangering biodiversity. Threats to local fauna and flora can come from physiological changes caused by warmer water; equally, they may come from invasive species that are attracted by the warmer temperatures.

While efforts to tackle point source pollution (industrial discharge and urban wastewater treatment) in developed countries have paid off with improvements in surface water quality, the same cannot be said of many developing countries where more lax environmental regulations or lack of enforcement have not resulted in the same improvements. Contaminants find their way into ground water which represents about 90 per cent of the world's readily available freshwater resources and upon which nearly 1.5 billion people depend for their drinking water. Equally, managing diffuse pollution, caused by daily use of certain products (e.g. fertilisers) and airborne pollutants is much more challenging.

This is particularly obvious in the agricultural sector. Agriculture is an important source of water contamination; runoff from livestock manure and fertiliser can be a great source of water pollution. The resulting nutrient enrichment leads to an overgrowth of algae which eventually die off and decompose, absorbing all the dissolved oxygen in the water, thus preventing growth and development of other aquatic species. Eventually this may lead to dead zones and further degradation of freshwater ecosystems.

> The 2003 heat wave in France meant high air temperature leading to increased demand for cooling, including air conditioning, as well as high temperature of the water in the rivers used for cooling nuclear power plants. For environmental reasons, even after the government softened water-temperature regulations, the generation from nuclear power plants had to be reduced (around 25 per cent) and compensated by electricity importation. The average electricity price spiked 1300 per cent on the spot market and the electricity supplier EDF lost approximately 300 million Euro.

The degradation and loss of ecosystems and biodiversity are a growing challenge to water quality and quantity. Although this is obvious in the case of freshwater ecosystems, what is less evident is the impact of the deterioration of other ecosystems on water quality. Ecosystems provide a whole host of important services including water purification, rainfall regulation e.g. through evapotranspiration, surface soil runoff prevention, watershed protection, often at lower costs than human-engineered solutions. Damage to ecosystems prevents them from being able to fully deliver their products and services thereby further compromising water quality. According to the 2005 Millennium Ecosystem Assessment (MA), the most comprehensive study of its kind ever undertaken, two-thirds of the ecosystems and their services that were assessed were severely degraded or compromised; that change, the result of human activity, has been faster in the last 50 years than in the preceding 150 years.

Compounding all these challenges is the problem of climate change, which has several implications for water quality. Carbon dioxide (CO_2) being emitted to the atmosphere as a result of human activities is being absorbed by the oceans. This is making them more acidic (lowering their pH). According to a report by the Royal Society, "Evidence indicates that emissions of carbon dioxide from human activities over the past 200 years have already led to a reduction in the average pH of surface seawater of 0.1 units and could fall by 0.5 units by the year 2100. This pH is probably lower than has been experienced for hundreds of millennia and, critically, at a rate of change probably 100 times greater than at any time over this period" (Royal Society, "Ocean acidification due to increasing atmospheric carbon dioxide", June 2005).

The report notes that some of the impacts being observed as a result of CO_2 absorption will be greater for some regions and ecosystems. Coral reefs in the southern oceans will be particularly affected; the impacts on other marine organisms and ecosystems are much less certain. Uncertainty is a major risk, especially for business.

But acidification is far from the only climate change impact likely to affect water quality. Sea-level rises are resulting in saline intrusion in coastal groundwater and wetlands. Growing incidence of flooding is increasing the risk of water source contamination from sewage overflows and runoff from agricultural land and urban areas. Likewise, physical damage to dams and water operations, especially treatment facilities, will also threaten water quality. At the other extreme, where drought becomes more common and stream flows and lake levels decline, nutrients and contaminants will become more concentrated. Interestingly, it is telling that engineered efforts to improve water quality or mitigate some of the impacts of climate change on water, e.g. desalination or water purification activities, could themselves become a source of climate-changing emissions as they are typically very energy intensive processes.

Water quality: why it's important to business

For some industry sectors, notably the beverage sector, which relies on clean water as a key input to its products, the importance of clean, uncontaminated water, is evident. The same is true of the food and pharmaceutical sectors many of whose products require clean water for their end use (e.g. medicines that are dissolved in water). For these sectors, the importance of high water quality is evident. For others, whose reliance on water may be less direct, the importance of good water quality may seem a more remote concern. Yet, these industries too are heavily reliant on sound water quality.

Poor water quality can result in increased costs and operational risks for business. Companies may find themselves faced with escalating production costs as a result of the decreasing quality of their water supply which may force them to pre-treat their water input to make it safe for use. Similarly, reduced quantities of clean water may result in water allocation restrictions and prioritization. At times of clean water shortages, it is unlikely that business will figure close to the top of the human–agriculture–industry–nature hierarchy. This could pose even greater risks further along companies' supply chains than in their own operations.

Closer to home, poor water quality poses risks to the health of employees and customers. The greatest asset any company has is its people so a healthy and productive workforce is key. Days of absence due to sickness represent an important financial burden for business. Similarly, business also needs a healthy customer base.

Where people are vulnerable to hunger and poor health, due to a lack of safe drinking water and sanitation, enterprise will not prosper. Business cannot survive in a world that fails.

For many companies, their license to operate is underpinned by access to water supplies and good practice in the area of environmental performance, notably where water is concerned. Deteriorating water quality therefore poses reputational and regulatory risks. Increasing numbers of companies are finding themselves embroiled in disputes either relating to competing uses (the abovementioned human–agriculture–industry–nature hierarchy) or, equally worryingly, pollution allegations. Increasingly stringent water discharge quality standards expose companies to new fines, fees and lawsuits (see EC Water Framework Directive, 2000).

Coca-Cola, which operates 39 bottling plants in China, has joined forces with the environmental organisation WWF to improve the water quality of the upper reaches of the Yangtze River, one of the top 10 most-threatened rivers in the world. In one project, Coca-Cola is working with rural farmers to reduce the runoff of animal waste into the river by turning pig waste into biogas, a type of fuel that can be used for cooking and heating. The company has also launched a communication program to educate communities along the river basin about environmental issues.

Coca-Cola's involvement has helped WWF play a bigger role at the Yangtze River Forum, a bi-annual conference for various stakeholders. One result was that the companies agreed on a united recommendation to deliver to the Chinese government for implementing pollution regulation. Regulation of polluters in China is fairly uneven. It is such a nascent regulatory structure and there is some concern about how new laws could be applied.

Crucially, water quality is also a competitive issue. As customers and clients become more aware and concerned about their own environmental impacts, and especially water footprints, companies face the risk of losing out to other suppliers that offer products with lower water/ecosystem impacts.

Finally, as investors become more aware of potential risk exposure to water-related challenges, they will seek to assess companies' abilities to anticipate and respond to these challenges and convert them to opportunities. This is particularly the case in the current global economic climate where investors are becoming increasingly cautious. Companies without sound measures in place to manage water use sustainably are likely to suffer restricted access to capital, high loan rates and inflated insurance premiums.

Pathways to sustainable water quality

Know your risks

The first step for any business seeking to manage and improve water quality is to understand the risks posed by water quality. Broadly speaking, there are three categories of risk, those associated with the business' own operations, at sites along the supply chain and regulatory risks. Beyond the immediate control of business are risks associated with climate change and environmental factors.

'Inside the Fence' operational related business risks are among the least difficult to assess. Supply chain-related risks are more complex. As part of efforts to address this, in 2007 WBCSD members developed the Global Water Tool (www.wbcsd.org/web/watertool.htm). This is a free and easy-to-use tool for companies and organizations to map their water use and assess risks relative to their global operations and supply chains. It compares a company's sites with validated water and sanitation data on a country and watershed basis. It also helps companies to understand their own water needs in relation to local conditions, addressing such issues as water availability (current and projected), water scarcity, access to safe drinking water sources and sanitation, and population and industrial growth. Now in its second edition, the Global Water Tool has proved to be a popular mechanism. Knowledge of local water quality conditions and risks is the first step towards developing strategies to manage them.

Assessing water-related climate change and ecosystem risks to business is currently complex. At present, data and information about water-related climate change impacts remains inadequate. Although some progress has been made, there is a need to improve understanding and modelling of climate changes in relation to the hydrological cycle at scales that are relevant to decision-making. This deficiency of information poses a significant risk to long-term planning and business cycles. Fortunately, a bit more is known about the role of ecosystems in improving water quality, thanks in no small measure to the MA. Ecosystems provide vital services including water purification, rainfall regulation, watershed protection and soil runoff protection, among others. Despite this, relatively little remains known about the impacts to business on ecosystem deterioration, and especially of the economic impacts of such deterioration.

As part of efforts to address this, WBCSD, in collaboration with the World Resources Institute and the Meridian Institute, has developed the Ecosystem Services Review (ESR) [Clearing the Waters, A Focus on Water Quality Solutions, UNEP and The Pacific Institute March 2010]. This is a guide to assist business to assess its ecosystem-related risks, uncover ecosystem-related business opportunities and develop strategies to manage them. Consisting of a five-step easy-to-follow methodology, the ESR can either be implemented as a stand-alone process or incorporated into existing environmental management strategies. It is relevant to all sectors and all industries. The methodology was road-tested by five members of the WBCSD – Akzo Nobel, BC Hydro, Mondi, Rio Tinto and Syngenta. Since its release in March 2008 more than 300 companies have used it.

Regulation poses an altogether different level of risk to business in particular. Growing concerns surrounding water are resulting in increasing regulation on the part of local, national and international government authorities. A modern society cannot be without (formal) regulation, in particular when it concerns a resource like water. However, this is not without its challenges. As water and environmental issues increase in urgency, regulations change, sometimes at short notice. Lack of transparency, consistency, poor enforcement, frequent changes in regulation and corruption can cause difficulties for business with longer planning – and particularly investment – time-lines. The effect is to discourage business investment in new technologies. It can also compromise investment in research and development.

Similarly, uneven regulation among countries can discourage business action and result in competitiveness issues. While some governments have put in place stringent regulations others, especially in developing countries, lag behind. In addition, in some countries the legislation exists, but its implementation is weak. The impacts of this will be felt most keenly among companies with long international supply chains. Equally, some governments have established incentives to encourage business to adopt more water-friendly policies and practices and to increase levels of investment. In other countries, such incentives are lacking. This creates an uneven playing field for business and can result in unfair competition. The net effect can be to a disincentive to business, discourage the adoption of more environmentally-friendly practices, resulting in harm to the environment and ultimately to business.

International failure by some governments to agree on water quality standards also poses a risk to business. This is especially true in the case of trans-boundary water resources or shared watersheds. For example, the Guarani aquifer in South America straddles Brazil, Argentina, Uruguay and Paraguay. Near the Brazil–Uruguay border, sewage is threatening to contaminate this aquifer. This creates risks for operations across this shared water resource. Greater international efforts are needed to protect shared water resources. However, even where treaties are in place, issues may remain. For example, a 1929 treaty forbids any country south of Egypt from taking measures which limit Egypt's annual water consumption from the River Nile without its consent. This same treaty stipulates that tributaries feeding the Nile also cannot be used for irrigation or hydroelectricity. Parties to this treaty, including Kenya, Uganda, Tanzania and Ethiopia, are considering abrogating the treaty to access water required for households, irrigation and electricity generation. Egypt has threatened to use military force to enforce the provisions of the treaty and has stated that it will view as a hostile act any attempt to pull out.

Innovate for improved water quality

Faced with the challenge that declining water quality presents, there are several actions that a business can implement to reduce its exposure to water-related risks and at the same time gain a competitive advantage.

Recover, reuse and recycle

Within its own operations a business can lessen its impact on water quality by implementing measures to recover, reuse and recycle wastewater. According to recent figures presented in the Suez Environment's Contribution to Action to Fight Climate Change (Dec. 2009), of the 165 billion m3 of wastewater collected and treated worldwide, only 2 per cent is reused. This speaks volumes about the unused potential. Reusing wastewater translates as increased efficiency – and cost savings – in water use because the same water can be used several times before being discharged into the natural environment. Of course, not all uses lend themselves to recycled water. Therefore, water quality standards should be adapted to the desired end use (fit for purpose).

Develop new and innovative products

Declining water quality offers business opportunities to develop new solutions and technologies. There are business opportunities to be seized in developing innovative wastewater treatment devices, new irrigation techniques to minimise pesticide and fertiliser runoff, and water-saving information processing technologies.

Similarly, opportunities exist for the development and deployment of new infrastructure for water including for sanitation, especially in developing countries, or for the collection, treatment and distribution of water and the disposal of solid waste.

Use nature's own resources to improve water quality

Ecosystems provide a whole host of water-related services including water purification, rainfall regulation, watershed protection, soil run-off prevention, among others, sometimes at lower costs – and with lower rates of carbon emission – than engineered solutions. For example, desalination through industrial facilities is both energy- and carbon-intensive. Protecting ecosystems so that they can continue to offer such services may be less costly and at the same time yield benefits beyond water purification, e.g. by reducing or acting as a sink for carbon emissions.

To date, the role of ecosystems in protecting and promoting improved water quality has been largely overlooked. This is in part because ecosystem services are not priced and, as yet, have no established market – though this is slowly beginning to change. Corporate Ecosystem Valuation (CEV) offers one approach to address this by extending the scope of economic analysis beyond its conventionally narrow focus on marketed commodities to more inclusive calculations that also factor in non-market ecosystem service values. Valuing ecosystems and the services they deliver can offer incentives for their protection and restoration. In this, WBCSD's Guide to Corporate Ecosystem Valuation provides useful guidance.

CEV seeks to have nature's services recognised as an integral part of corporate planning and decision-making by offering guidance to companies on how to account for appropriate ecosystem benefits and services. It shows how economic tools can be applied to valuing the products and services provided by nature, and can assist managers with calculating trade-offs and designing the most cost – and environmentally – efficient solutions.

So, for example, appropriate pricing of water and wastewater can help provide incentives for water efficiency improvements, thereby reducing water contamination. Creating markets for water-related ecosystem services similar to current carbon markets can also offer a potential mechanism for protecting and enhancing nature's capital. Other mechanisms include the establishment of tradeable permits for the use of ecosystem services or the creation of markets similar to current carbon markets. Water resource allocation permits, for example, could be traded between users. Such mechanisms could be voluntary. Alternatively, they could be established through regulation. A concrete example is the development of mitigation banking in the U.S., which is a new way to foster biodiversity conservation initiatives in very large land areas and represents business opportunities for companies that own land as part of their business activities.

As the ecosystem approach to environmental challenges – including water and climate change – gains in popularity, there is every chance that ecosystem services will be regulated. Business can keep ahead of the curve by anticipating this and developing innovative ecosystem-based mechanisms that enhance ecosystems so that they can continue to provide their range of goods and services.

Veolia Water has implemented a 100 per cent energy self-sufficient wastewater treatment plant in Germany. The quality of the incoming wastewater is monitored, which guarantees the quality of the produced sludge. The quantity of sludge is then reduced through thermophilic digestion and provides 60 per cent of plant electricity (other energy source includes biogas from landfill). The digested sludge and treated wastewater are sprayed as irrigation and fertiliser in nearby fields.

Dow Chemical's site in the Netherlands collaborated with local authorities and local water producer to accept more than 9,800 m3 of household wastewater to be converted into industrial water to be used as feed water for several plants. In turn, wastewater from these processes is treated and used as feed water for the cooling tower. Three million tons of water per year that were previously discharged into the North Sea are now used two more times, reducing wastewater generation by 38 per cent and energy use by 90 per cent.

In order to reduce the sulfur content of its refined diesel fuel to 15 parts per million and be in line with new federal regulations, Suncor's Edmonton refinery (located in Alberta, Canada), needed additional hydrogen and steam. Making more hydrogen and steam would have required an additional withdrawal of up to 5 million litre of water per day from the river. Instead, Suncor partnered with the municipalities(City of Edmonton and Strathcona County) to install an enhanced treatment capability and built a pipeline to the refinery to supply it with municipal wastewater as feed water for the plant thus eliminating the need for additional freshwater withdrawal. In 2009, approximately 48 per cent of the water used at the Edmonton refinery was recycled wastewater supplied from the Gold Bar Wastewater Treatment Plant.

Weyerhaeuser has signed an agreement to conduct wetlands mitigation of an area of 130 ha in St Tammany Parish, Louisiana, U.S. Restoration was started in 2008 and will end in 2023. Credits were calculated through a model which determines the degree of rehabilitation. The Nature Conservancy will be the holder of the conservation servitude agreement

Enter into partnerships for improved water quality

Public information campaigns organised or supported by companies in partnership with NGOS, to educate and inform local populations – and particularly their own workforces – in good sanitation and hygiene practices can prove very effective as part of the efforts to improve the quality of wastewater in the community. They yield the twin benefits of improving the health of members of the community while contributing to protecting water resources.

Partnerships may also prove an effective instrument in efforts to manage risks posed by uneven regulation. Managing regulatory risks can be achieved through partnerships with policy makers and regulators at several levels. Business can engage with municipal water authorities for the provision of water technologies and infrastructure, for example. Similarly, it can use its technological expertise to deliver sanitation facilities and wastewater treatment technology. Equally, business can engage with local and national authorities to help define modalities and criteria for water use and to shape its operational environment. Another option would be to engage with governments, scientific organizations and civil society, including NGOs, to help define the criteria governing the use and disposal of harmful or toxic products, or to help set standards for volume and content (e.g. chemical content and heavy metals) of industrial effluent discharged into the environment. Partnerships offer several very real opportunities for businesses seeking to manage water quality-related challenges.

Reporting results and sharing information

One of the most effective tools for generating improvements in water management, and indeed in other areas too, is through reporting of results and sharing of information. Many leading companies report on successful water quality management initiatives and share their findings and examples of best practice with their industry peers, with policy makers and the public at large. The Global Reporting Initiative (GRI) also offers a pathway to achieve this. Starting from the premise that 'what doesn't get measured doesn't get managed', GRI was established to provide indicators to manage sustainable development performance. Indicators have been developed by consensus by participants drawn from business, government and civil society. In addition to the practical benefits that such reporting and information-sharing can generate, it can also enhance the business license to operate, particularly in areas where water quality challenges are especially acute.

Many water systems are extensive networks of rivers, canals, pumps, pumping stations, locks, dams and reservoirs. The total length of the Dutch waterways is about 2200 km, transporting roughly 120 trillion litres of river and rain water each year. IBM is collaborating with the University of Delft to apply analytics and high performance computing to the vast amounts of data gathered from across this system. Researchers expect to identify patterns and trends that will enable improvements in overall water management with benefits including reduced flooding and improved water quality.

In India, PepsiCo has worked with farmers to implementan agronomic practice in paddy cultivation called 'direct seeding'. Rather than growing the seedlings in a nursery, planting them, and then flooding their fields, direct seeding allows the seed to be planted directly into the ground, bypassing the nursery. This also removes the need for flood irrigation, reducing water use by as much as 30 per cent. In 2009, direct seeding was extended to 6,500 acres of paddy fields, saving more than 5 billion litre of water. There is also a reduction in greenhouse gas emissions in excess of 70 per cent using direct seeding, versus conventional methods.

Diarrhoea causes over 3million deaths a year worldwide yet can easily be prevented through better hygiene and sanitation. To address this, Unilever's Sustainable Living Plan commits to helping more than a billion people improve their hygiene habits by 2020. Unilever's Lifebuoy soap has already reached 130million people with hygiene education programmes since 2002. The programmes, delivered through advertising plus schools, doctors and mothers programs all focus on the importance of washing hands with soap at key occasions – before eating, during bathing and after using the toilet. When children wash their hands with Lifebuoy soap, diarrhoea is reduced by 20 per cent, acute respiratory infections by 19 per cent and up to 40 per cent more children attend school everyday*. Programmes are currently running in 19 countries including India, Pakistan, Vietnam and Indonesia.
* Randomised clinical trail on 2000 families in Mumbai 2007-8

Procter & Gamble (P&G) developed PUR – Purifier of Water® – to help address the issue of the lack of safe drinking water in developing countries. This product is a simple, effective and low cost technology, treating water for drinking in households not served by a safe water supply system, or for use in disaster relief. Each sachet of PUR powder treats 10 litre of contaminated water and turns it into clean, clear and safe drinking water. Since 2004, P&G and their partners (> 100, including NGOs and government agencies) have provided over 3 billion litre of safe drinking water by providing 300 million packets of the PUR Purifier of Water product in 63 countries.

Conclusions

Global water challenges are as much about water quality as about water quantity. Poor water quality poses as great a risk to business as it does to society at large. Meeting this challenge will require a range of different solutions. It will also necessitate action by all concerned stakeholders including governments, business and civil society.

From a business perspective, there are several actions that companies can take as part of their efforts to meet the water quality challenge. These include assessing water-quality related risks by gathering relevant data which can subsequently be used for corporate planning. Based on the best available information, business can implement individual actions within its own operations (within the business 'fence line'); devise strategies to manage external risks (beyond the 'fence line'), such as those posed by climate change and environmental concerns, and engage with stakeholders, including civil society and government authorities, to help shape the operational environment. Crucially, water quality challenges require integrating wider environmental considerations into business planning and action. This is a relatively new field, which implies considering nature's capital – especially nature's services – as assets that carry a market value that can be realised, traded and included in company and country balance sheets. Companies that succeed in internalizing the value of ecosystem services will gain a competitive advantage. It is through a combination of all these different actions and approaches that the necessary incentives can be put in place to work towards protecting and enhancing water quality.

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CONTROLLING CONTAMINANTS IN URBAN STORMWATER: LINKING ENVIRONMENTAL SCIENCE AND POLICY

A knowledge of sources of pollutants in stormwater is needed to develop source control policies for reducing or eliminating the presence of harmful contaminants in urban stormwater. For this purpose, it is useful to divide the sources of pollutants into three categories (atmospheric deposition, catchment surface and land-use activities) and to apply appropriate measures to each category. Two pollutant source control policies – phasing lead out of gasoline and removing copper and other contaminants from automobile brake pads – effectively reduced stormwater pollution and are discussed in detail. Further advances in understanding and implementing source controls are needed to improve urban stormwater runoff quality and protect the aquatic environment.

Key words: Urban stormwater, pollutant sources, heavy metals, environmental policies, pollution prevention, source controls

Introduction

Historically, interest in urban stormwater runoff was driven by the need to remove stormwater from urban areas and prevent local flooding. An empirical formula for calculating runoff flows was introduced in the mid-1800s and formed the basis for drainage design during the following one hundred years. Concerns about stormwater runoff quality are much more recent and started to emerge only during the last 50 years (Weibel et al., 1966). During this period, great progress has been achieved in understanding and modelling urban runoff flows, but the progress in assessing stormwater quality, its impacts on receiving waters and the means of mitigating such impacts, has been much slower. This follows from the complexity of stormwater quality processes and the ever-changing nature of stormwater pollution reflecting newly identified or released environmental contaminants.

The early exploratory studies of stormwater quality focused on identifying conventional or priority pollutants (also called micropollutants) in urban stormwater (Marsalek and Schroeter, 1989; US EPA, 1983). Subsequent analyses of the observed data indicated that a relatively small fraction of constituents (< 10 per cent) could be described as contaminants occurring at levels potentially causing human health or aquatic life effects (Makepeace et al., 1995). However, this issue may need to be revisited in light of the latest research findings (Becouse et al., 2010). The early studies provided general data adequate for the planning and design of stormwater management facilities, with the exception of those handling winter runoff and snowmelt, but did not address the specific sources of pollutants and the strengths of such sources. Interest in pollutant origins was stimulated by proposals to model and control stormwater quality (Field, 1987; Malmquist, 1983; Malmquist and Svensson, 1978). In the latter case, past experience indicates that pollution control measures applied at or near the source are both very practical and highly cost-effective, when compared to typical structural measures involving the containment and removal of pollutants after their release (and dispersal) in the environment (ASCE, 1998). Recognizing that source controls are generally mandated by environmental policies, the following paper focuses on identifying sources of stormwater pollution discharged from storm sewers in separate sewerage systems and the mitigation of such pollution by source control policies. This approach is documented by two examples – phasing lead (Pb) out of gasoline and reducing copper in automobile brake pads.

Sources of pollutants in urban stormwater

In urban areas, three main categories of pollutant sources can be identified: (1) atmospheric deposition (wet and dry), (2) catchment surface attrition/elution, and (3) urban land use activities, recognizing that boundaries among these categories are not always well defined. In the following section, the relative strengths of such sources are estimated for selected constituents and discussed with the objective of identifying the types of source control which would effectively limit such constituents in receiving environments.

Atmospheric deposition as a source of pollutants in stormwater

Atmospheric wet deposition includes particulates and dissolved chemicals resulting from a scavenging of the air by rainwater drops and dry atmospheric deposition represents the materials landing (depositing) on urban surfaces. The main source of deposition is air pollution, which may originate from both local and remote sources.

The literature on the atmospheric deposition of pollutants in urban areas is rather extensive and covers numerous constituents, geographical regions and types of urban areas (e.g. Pitt et al., 2004; Malmquist, 1983; Malmquist and Svensson, 1978; Barkdoll et al., 1977). To illustrate the potential contributions of atmospheric deposition to selected pollutant concentrations found in urban runoff, an illustrative example is given in Table 1 and Fig. 1. Towards this end, annual deposition rates were adopted from two recent references and converted into concentrations in runoff from a unit impervious area (m2), considering an annual runoff of 0.8 m (generated by precipitation of 1.0 m). Such concentrations were compared to the concentrations in a large database with stormwater quality data (Fuchs et al., 2004) and expressed as a fraction of the database values.

Finally, the ratios Cdeposition/Cdatabase were plotted (Fig. 1). The data in Table 1 and Fig. 1 illustrate the relative significance of atmospheric deposition with respect to constituent concentrations in urban stormwater, for the adopted assumptions. Among the constituents considered, total nitrogen (TN), total suspended solids (TSS), copper (Cu) and zinc (Zn) concentrations were affected significantly by atmospheric deposition; in the remaining two cases, Pb and total phosphorus (TP), atmospheric deposition contributions were negligible. However, atmospheric deposition is a major source of less common contaminants which are imported from outside of the urban catchment studied (Becouse et al., 2010).

In the urban environment, dry atmospheric deposition is combined with inputs from other sources (e.g. land use activities) and contributes to a material build up on the catchment surface (Deletic and Orr, 2005). In wet weather, such deposits are fully or partly washed-off and transported by surface runoff to receiving waters. There are two options for controlling these constituents in stormwater: (1) by controlling sources of air pollution on a large spatial scale that may fall outside the jurisdiction of local water managers, or (2) by controlling deposition on the catchment surface by street sweeping (Rochfort et al., 2009 8 ;German and Svensson, 2002).

Constituent	Annual deposition rate	Deposition concentration (C) in assumed annual runoff (mg/L)	Concentration (C) in stormwater database (Fuchs et al., 2004) (mg/L)	C deposition /Cdatabase
Total suspended solids (TSS)	30 g/m2/ya	37.5	141	0.27
Total nitrogen (TN)	0.8 g/m2/ya	1.0	2.36	0.42
Total phosphorus (TP)	7.6 mg/m2/ya	0.010	0.42	0.024
Cu	6.5 mg/m2/yb	0.008	0.034	0.235
Pb	4.1 mg/m2/yb	0.005	0.118	0.042
Zn	47.2 mg/m2/yb	0.059	0.275	0.215

Table 1. Contributions of atmospheric deposition to urban stormwater pollution.

a Urban data (Reinfelder et al., 2004)
b Urban data (Davis and Birch, 2011)

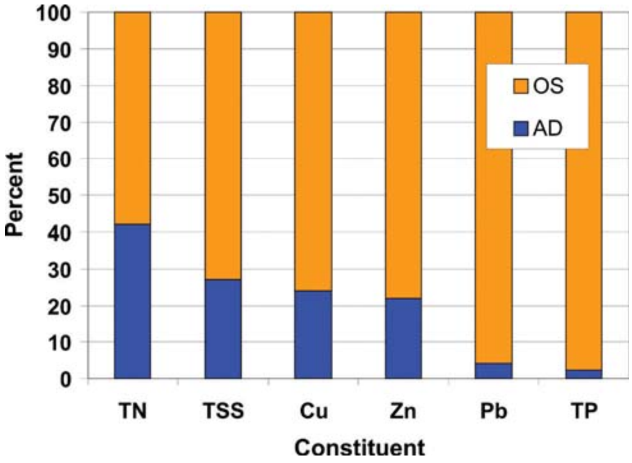

Figure 1. Example of estimated contributions of atmospheric deposition to stormwater quality (AD = atmospheric deposition, OS = other sources).

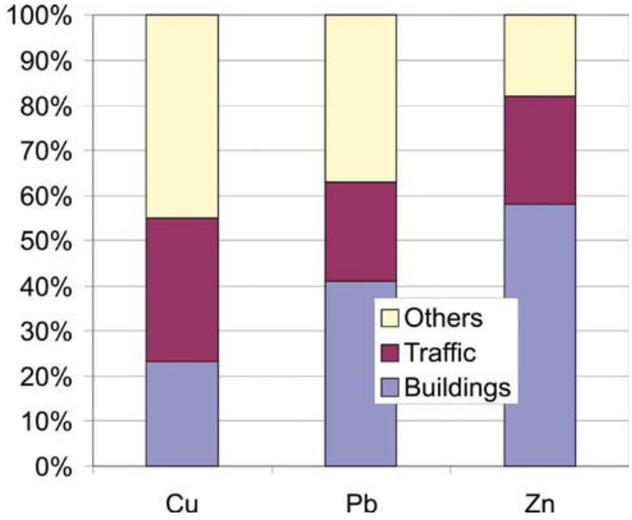

Figure 2. Main sources of Cu, Pb and Zn in urban stormwater Source: Fuchs et al. (2006).

Catchment surface attrition/elution sources

The catchment surface sources are defined here as the materials forming the catchment surface (including soils and any structures in the catchment exposed to rainwater or stormwater). The processes releasing surface materials include erosion (e.g. on soil surfaces), attrition (e.g. of pavements by vehicular traffic), and corrosion/elution (e.g. from the surfaces of buildings or other structures).

Soil erosion is a major source of TSS in urban runoff, particularly in new developments with exposed bare soils. Although soil erosion is a natural process, concerns are caused by the intensification of this process in urbanizing areas. During construction, large tracts of land are stripped of vegetative cover, which is eventually replaced with man-made covers (e.g. pavements and rooftops) or re-vegetated. Large increases in erosion rates result from two factors, the exposure of bare soils to rain drops (also referred to as sheet erosion) and increased runoff flows, which cause scouring in unlined channels and also provide increased capacity for transport of the eroded material to downstream areas. High rates of soil erosion then contribute to increased concentrations of TSS in the receiving waters. Observations from Maryland (USA) indicated that the sediment yields from natural catchments were as low as 100 t/km2/y, but increased to values as high as 50,000 t/km2/y during catchment urbanization (Wolman and Schick, 1962). After completion of the urban development, and establishment and consolidation of surface cover, the sediment yields may drop to the predevelopment (100 t/km2/y) or even lower values (10 t/km2/y) (Marsalek, 1992). Thus, excessive soil erosion in urban areas is a transient process, which should be mitigated by implementation of erosion and sediment control programmes (MOE, 2003).

At small sites, soil erosion is typically evaluated by the universal soil loss equation (Wishmeier, 1976) suitably adjusted to urban conditions. The equation includes a control practice factor C, which reflects a combination of control measures including surface stabilization, runoff reducing practices, sediment trapping measures and restriction of the spatial and/or temporal exposure of soils to the erosion. Consequently, it is important to have in place appropriate soil erosion and sediment control policies to control this source of TSS in urban runoff (MOE, 2003). Other sources of solid materials include pavement attrition (asphalt and concrete, products of their decomposition and aggregate materials) (Marsalek, 1992).

Corrosion/elution of catchment surfaces and buildings/structures is an important source of chemicals in stormwater, particularly heavy metals. Early studies by Malmquist and Svensson (1978) demonstrated that corrosion was an important contributor of Cu and Zn, with monthly corrosion rates in the range 80 to 390 mg/m2/month for Cu and 200 to 750 mg/m2/month for Zn. Fuchs et al. (2006) estimated that building surfaces account on average for about one-third of the heavy metals load in urban stormwater (Fig. 2). Other papers on this topic confirmed that metal roof runoff was a strong source of Zn and Cu (Gouman, 2004; Ristenpart, 2003; Malmquist and Svensson, 1978). Copper was also found in washoff from building facades, originating either from architectural Cu or facade materials, to which Cu is sometimes added as a biocide, preventing biofilm growth (Steiner and Boller, 2001). Finally, Zn is released by corrosion of galvanised metal surfaces (e.g. highway guard rails, sign structures on highways).

Davis et al. (2001) conducted experiments on extracting metals from building materials by washing their surface with synthetic rainwater and noted extremely high concentrations of Zn (practically from all siding materials, brick, painted wood, concrete, metals and unpainted wood, but not from vinyl siding), followed by Pb (one order of magnitude smaller), and Cu representing less than half the Pb concentrations. Vinyl sidings produced the lowest metal concentrations. In any case, substitution of low metal content materials offers an opportunity for reducing metal input into urban stormwater and has been practiced in some countries (Gouman, 2004; Ristenpart, 2003).

Urban land use activities

This last category contains sources activated by urban land use activities, including those related to residential land use (applications of garden chemicals, grass clippings, litter, pets), open spaces/parks (applications of fertilisers and pesticides, and pets), traffic (heavy metals, oil and grease, polycyclic aromatic hydrocarbons (PAHs) and chemical spills), and winter road maintenance in cold climates (sand and salts). Concerning specific pollutants or their groups, much attention has been focused on heavy metals, PAHs, chloride and indicator bacteria. In some cases, land use sources are hard to distinguish from atmospheric deposition and catchment surface sources, but were introduced here because they involve 'additions' of materials to the catchment surface and are thus amenable to somewhat different control measures. These materials can be controlled, to various degrees, by reducing their applications (e.g. fertilisers and road salts) or uses. Some pollutants from these sources accumulate on the catchment surface and are released during wet weather, when dry deposits are eroded by rainfall drops as well as by overland and gutter flows. The strength of this pollution source depends not only on the pollutant availability, but also on the transport capacity of runoff, which in turn is controlled by rainfall characteristics.

Perhaps the most potent and difficult to control pollutant sources in this category are those related to traffic, even though some control measures are available (e.g. reducing the kilometres driven, substituting materials which may be releasing specific contaminants and immobilizing pollutants on highway verges; Berbee et al., 2004). Only the traffic-related sources are briefly discussed below.

Extensive studies indicate that traffic produces significant quantities of heavy metals (Viklander 1998a, 1998b). Fuchs et al. (2006) estimated that this source accounts for about one-third of the heavy metals load in urban stormwater (Fig. 2). With respect to traffic, the primary sources of metals and other constituents were identified: Cd – tyres and brakes; Cr – car frames and tyres; Cu – brakes and tyres; Fe – car frames and litter; Pb – brakes, tyres, wheel balancing weights and fuel; Ni – brakes and tyres; and Zn – car frames, brakes and tyres. In cold climates, the high use of road salts in winter road maintenance (millions of tonnes annually) causes environmental concerns about toxic levels of chloride in road snowmelt and winter runoff. The information on traffic sources of pollutants is summarised in Table 2.

In regions with snowfall, where the policy of 'bare pavement' is practiced, large amounts of road salts are applied annually, with many environmental effects on soils, vegetation, infrastructure, processes in receiving waters and biodiversity (Environment Canada and Health Canada, 2001). The annual use of road salt was estimated at 5 million

Table 2. Sources of pollutants in highway runoff (• = primary source , ∘ = secondary source).

Constituent	Source							
	Traffic (vehicle operation)				Pavement		Litter	De-icing
	Frame/body	Brakes	Tyres	Fuel, automotive liquids	Asphalt	Concrete		
Solids – organic			•		•			
Solids – inorganic					•	•		•
P								•
Hydrocarbons				•	∘			
Cd		∘	•					
Cu		•	•					
Fe	•	∘	∘				•	
Pb		∘	∘	∘				
Zn	•	•	•					
Chloride								•

t/y in Canada (Environment Canada and Health Canada, 2001) and 18 million t/y in the USA (Corsi et al., 2010). During the periods of snowmelt and winter runoff, chloride concentrations may reach levels in excess of 20,000 mg/L (Marsalek, 2003) and exceed water quality guidelines, which were defined as 230 and 860 mg/L, for chronic and acute fresh water toxicities, respectively (US EPA, 1988). Thus, there is a need to identify chloride-sensitive receiving waters and limit chloride inputs to such waters by controlling salt applications, or considering alternative de-icers (Hellsten and Nysten, 2003).

Policy implications of the knowledge of pollution sources

Environmental issues follow a specific life cycle, starting with observation. This is followed by investigation, analysis, advocacy and argument; decisions and actions; and, finally, feedback and revision (Holtz, 2006). The same tendencies can be observed in the case of stormwater pollution, though there seems to be a significant time lag between the research stage and regulatory actions (Field, 1987). This time lag can be explained by numerous challenges encountered in developing pollution control policies for stormwater, because of the following factors:

- Multifaceted nature of stormwater impacts, comprising physical, chemical, biological and combined impacts on the environment
- Pollutant sources and impacts caused by stormwater are typically distributed throughout the urban environment
- Broad variation in the magnitude of stormwater pollution impacts ranging from negligible or minimal impacts to severe impacts, depending on specific conditions
- The non-homogenous nature of the urban drainage infrastructure characterised by the simultaneous existence and interaction of drainage elements ranging from conventional drainage without stormwater controls (i.e. designs 40 - 80 years old) to the most modern 'green' infrastructure following low-impact development principles.

While the physical impacts of stormwater discharges are typically controlled by municipal policies or local regulations and such controls consist in restricting runoff generation and its export from the areas where it was generated, controls of stormwater quality are much more challenging. At present, there is a good opportunity for advancing the understanding of sources of priority pollutants in stormwater under the European Water Framework Directive (EC, 2000). The Directive requires a progressive reduction of discharges of priority substances into water bodies, and this includes stormwater which was identified as one of the major pathways for conveying diffuse pollutants in the urban environment (Becouse et al., 2010). The supporting research should lay a foundation for further management controls of stormwater quality.

Past experience indicates that good understanding of sources and pathways of environmental pollutants contributed to the successful development of source control policies. Some of such policies are rather broad and concern stormwater as one of the pollution vectors (e.g. phasing Pb out of gasoline). Other policies are more focused on stormwater quality:

- Substitution of low Cu content materials in brake pads
- Elimination of Pb weights from car wheel balancing
- Reduction of road salt use in winter road maintenance and substitution of other (less harmful) de-icing materials in salt-sensitive areas
- Implementation of public awareness/education/participation programmes emphasizing source controls (e.g. taking care of pet faeces, responsible use of home and garden chemicals, banning cosmetic pesticides and recycling)
- The protective coating of metal surfaces to avoid elution of heavy metals, e.g. protective coating by plastics eliminates Zn export from Zn roofing materials (Gouman, 2004; Ristenpart, 2003).

Two of these examples are discussed here in more detail – phasing Pb out of gasoline and reducing Cu in automobile brake pads.

Phasing Pb out of gasoline

Until the early 1970s, Pb was added to all gasoline used around the world as a low-cost octane enhancer, at rates as high as 0.4 g/L. Health concerns, including the Pb impacts on the early development of children, and the need to operate vehicles equipped with catalytic converters, which eliminate other important pollutants, but are rendered inoperative by Pb, resulted in a policy decision to phase Pb out of gasoline. This has been achieved in most countries through a series of international agreements adopted between 1994 and 1999 (OECD and UNEP, 1999). The octane rating of the unleaded gasoline was maintained by modifying the refining process and/or by adding alternative octane enhancers. Concerning policy approaches, individual countries decided as to what policy instrument(s) to use to execute this change and the speed of implementation. In terms of policies, taxation which made unleaded gasoline less expensive than leaded gasoline was highly effective in achieving a quick conversion to unleaded gasoline and also contributed to minimizing the deliberate use of leaded gasoline in cars with catalytic converters. With respect to scheduling, most countries moved to implement the new policy quickly, in some cases in as little as three years (OECD and UNEP, 1999). Finally, it was important to adopt a comprehensive fuel strategy, which would: (1) prevent any increase in fuel toxicity caused by switching from leaded to unleaded fuels, (2) promote other fuel improvements as well, e.g. lowering volatility or sulphur levels to improve air quality, and (3) protect catalytic converters (this requires Pb concentrations in unleaded gasoline to be ☒ 0.013 g/L).

Removal of Pb from gasoline led to a great reduction in Pb releases to the environment along various pathways, including those represented by urban stormwater and highway runoff. While no 'before and after' Pb removal studies exist, it is possible to compare the general chemical composition of highway runoff from the periods before and after phasing out Pb. Such a comparison (Fig. 3) shows a large reduction

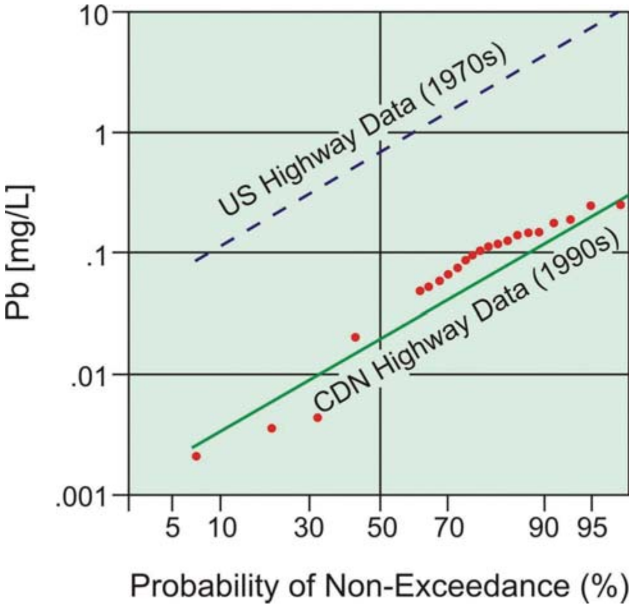

Figure 3. Pb concentrations in highway runoff: before (1970s) and after (1990s) phasing Pb out of gasoline (from extractable Pb data).
Source: Marsalek et al. (1997).

in Pb concentrations in highway runoff (about 35 times). This reduction is equivalent to removing about 97 per cent of Pb from highway runoff corresponding to the leaded-gasoline era, and is about equal to the relative reduction in the gasoline Pb content (i.e. reduction = 100 • (0.4-0.013)/0.4 = 96.8 per cent R = 0.4/0.013 = 31). Even though some other, much smaller traffic sources of Pb remain, the removal of Pb from gasoline by policy approaches has been highly successful and has been achieved by the close cooperation of industry and governments in solving this problem.

Removing Cu (and other toxic materials) from brake pads

Cu occurs in urban stormwater at levels (median values = 34 - 48 μg/L; (Fuchs et al., 2004; US EPA, 1983)) which, depending on speciation and bioavailability, may be toxic to aquatic organisms and particularly to juvenile fish. For example, Sandahl et al. (2007) showed that even at concentrations as low as 2 μg/L, predatory avoidance behaviour of juvenile coho salmon was significantly impaired. Typical sources of Cu in urban stormwater include architectural Cu, pool algaecides, pesticides, vehicles, soil erosion and vehicle brake pads, with the last source being one of the most important ones. During braking, friction pads rub against the brake rotors and fine particulate Cu is released, deposited on the highway surface and transported with surface runoff to the receiving waters. Hulskotte et al. (2006) estimated that brake wear contributed about one-half of atmospheric Cu emissions in Europe (i.e. 2400 t/y) and concluded that non-exhaust emissions from road traffic deserve more scientific research to support cost-effective programmes to reduce diffuse emissions of metals, including Cu, Zn, antimony and Pb into the environment.

Such control programmes have been initiated in some jurisdictions by introducing legislation limiting the use of Cu (and other toxicants) in brake pads. The State of California introduced such legislation in 2009, requesting reduction of Cu in brake pads sold in the State to no more than 5 per cent (by weight) by 2021, and no more than 0.5 per cent by 2032. This became law in September 2010, and similar legislation was introduced by Rhode Island and New York. In March 2010, the State of Washington became the first state to enact a law that brake pads should be Cu free. This regulation was driven by the need to protect salmon and other aquatic life important to the State, recognizing that Cu (discharged with stormwater) can interfere with the salmon's sense of smell, which is used when they return upstream to spawn and to avoid predators. To eliminate this source of Cu (and other toxicants), the State, with support from many stakeholders including the environmental community and brake pad manufacturers, adopted a law mandating the following schedule (Stormwater, 2010):

(a) Starting in 2014, the sale of pads containing more than trace amounts of asbestos, cadmium, chromium, Pb and mercury is banned. Inventories of pads manufactured prior to 2015 are exempt to permit clearing of inventory until 2025.

(b) Starting in 2021, the sale of pads containing > 5 per cent Cu is banned. Pads manufactured prior to 2021 are exempt to allow clearing of inventory until 2031.

(c) By December 1, 2015, the Department of Ecology must determine whether pads containing ≤ 0.5 per cent Cu may be available; if yes, and the assessment of their availability is favourable, the sale of pads containing > 0.5 per cent Cu will be banned eight years after the determination that alternatives are available. So the earliest that pads containing > 0.5 per cent of Cu could be banned is 2025 (Stormwater, 2010).

The potential effects of these policies on reducing Cu emissions are highly significant, considering that historically some brake pads contained as much as 20 per cent of Cu, while others contain as little as 0.1 per cent. Expedient implementation of the above policies or even their acceleration would greatly reduce the significance of brake pads as a source of Cu and reduce loadings of Cu to urban waters.

The two above examples demonstrate the effectiveness of source control policies in mitigating diffuse sources of pollution, and even though the data for comparing the costs of policy measures vs. those of structural measures (e.g. stormwater ponds, granular media filters or biofilters) are not available, it is obvious that structural measures, which immobilise, but do not remove, Cu from the environment would be very expensive.

Conclusions

Studies of sources of pollutants in urban stormwater continue to attract the attention of the environmental community because the knowledge of such sources can be used to develop control strategies for reducing the presence of harmful contaminants in urban stormwater. Experience in this field indicates that source controls have been successful in reducing the entry of pollutants into stormwater and their release into the receiving waters. Good examples of this approach are offered by phasing Pb out of gasoline, removal of Cu and other contaminants from vehicle brake pads, and substitution of traditional materials containing exposed heavy metals in the building industry. In spite of such successes, there is a significant time lag between completing the research indicating environmental risks, thereby assessing the need for regulatory action, and the actual implementation of supporting policies and regulations. Thus there is a strong need to continue this pollution source management process by involving both researchers and science policy communities, identifying sources of contaminants in urban stormwater, assessing the associated environmental risks, engaging in advocacy and argument in support of source controls, adopting source control decisions and actions and, finally, providing feedback and revision of environmental regulations. When dealing with low-level diffuse contaminants, source control policies are the most cost-effective management control tools and they deserve further promotion and development.

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WATER SECTOR RECOVERY AND RESOURCING IN LIBERIA

This article presents evidence of the challenges to, and opportunities for, the water sector in achieving the targets to which Liberia has committed itself in its Poverty Reduction Strategy (PRS) and in the Millennium Development Goals (MDGs). It assesses the current state of access to improved water and sanitation, identifies the financing and institutional challenges and, through consultations among sector actors, recommends actions to address the bottlenecks to progress. It is based upon the findings of a United Nations Development Programme (UNDP) country scoping mission which, after consulting most stakeholders, identified the critical interventions required in the sector.

Key words: water supply, sanitation, hygiene, Liberia, poverty reduction, water governance, water financing, Millennium Development Goals.

Introduction

The article presents the reality in the Liberian water sector in order to generate international interest for support in meeting MDG targets. The report has been prepared as a response to a presentation made at the 2010 World Water Week held in Stockholm, Sweden, from 5 to 11 September 2010, using secondary information and learning gathered through consultations with many sector actors in Liberia. It is also informed by the poverty reduction strategy (PRS), the UNDP Governance, Advocacy and Leadership for Water, Sanitation, and Hygiene (GoAL-WaSH) Programme internal assessment report and a paper prepared by the Liberia WaSH Consortium entitled 'Life and Dignity at Risk: Financing for Water, Sanitation and Hygiene in Liberia. The Liberia WaSH Consortium paper is an advocacy document which draws attention to the institutional, policy and financing and service delivery gaps in the sector and supports Liberia's participation in the Sanitation and Water for All: A Global Framework for Action. A substantial part of the discussion on the sector institutional framework is based on the National Water Supply and Sanitation Policy (NWSSP) document.

Country context

Liberia covers an area of 111,370 km2, of which 15,050 km^2 is water and the remaining 96,320 km2 is land. The territorial water is 159,000 km^2 in extent. It is bordered to the south by the North Atlantic Ocean, Côte d'Ivoire to the east, Sierra Leone to the northwest and Guinea to the northeast. The equatorial climate is hot and humid.

The country has abundant water, and the high rainfall and good soils combine to create an environment conducive to the cultivation of high value crops, such as rubber, oil palm, coffee and cocoa. Nevertheless the nationwide Comprehensive Food Security and Nutrition Survey (CFSNS) carried out in 2006 concluded that 68 per cent of Liberians rely on untreated wells, rivers, ponds, creeks and swamps for drinking water. Even in the capital, Monrovia, Liberian water authorities said conditions are hardly any better. Safe drinking water is available to 79 per cent of Liberia's urban dwellers and 13 per cent of its rural population. Thirty four per cent of households draw water from safe sources during the rainy season, and slightly less (32 per

Picture 1. Latrine perched over the Mensurrado river in Monrovia. Arwen Kidd/Liberia WASH Consortium.

cent) draw water from such sources during the dry season. However, according to official documents before the war, 45 per cent of the country's population had access to piped, clean water, and all 15 of Liberia's counties had water treatment facilities.

Rural water supply is usually limited to open sources, such as streams, swamps and shallow uncovered wells. The result, especially during the rainy season, is that insects and parasites thrive, creating a major health hazard. The rainy season lasts from April to November and the average annual rainfall is estimated at 2,391 mm, with a spatial variation of between 2,000 and 5,000 mm. Although this is much higher than the quantity of water required for crop growth, an acute water deficit is still experienced during the three to five month dry period, particularly in the uplands.

Liberia has two kinds of river systems – major basins that drain 97 per cent of the territory and originate in the Fouta Djallon highlands in Guinea, and short coastal watercourses, which drain about 3 per cent of the country. Of the major basins, the six major rivers are the Mano, Lofa, Saint Paul, Saint John, Cestos and Cavalla, and together they drain 65.5 per cent of the country. There are 1800 km of river, most of which are shallow, rocky and with cataracts and fallen logs that render them unnavigable. There are also large areas of inland valley swamps and numerous coastal lagoons, including Lake Piso, one of West Africa's largest lagoons. Liberia has among the highest amount of renewable water resources per inhabitant – more than 71,000 m3/y.

Rivers flowing through urban and other large settlements are seriously polluted. The Mesurado River is the most polluted body of water in Liberia. It is estimated that the city of Monrovia produces more than 500 t/d of waste and about 35 to 40 per cent is dumped in the Mesurado River and its tributaries, the Junk and Du Rivers. Toilets are common on the banks of the rivers and fish species, such as the tilapia, caught in the vicinity of these toilets are infested with human faeces. Petro-chemical and other industrial wastes are also discharged into the river (EPA/UNEP, 2007). The Mano and St. John Rivers in Grand Cape Mount and Nimba Counties, respectively, are increasingly polluted from the dumping of iron ore tailings, and the coastal waters from oil residue and the dumping of untreated sewage and waste water.

The country also has several large wetlands systems. Host to considerable biodiversity and providing vital ecosystem services, the wetlands are threatened with degradation as a result of pressures from fire wood and charcoal production to meet the energy needs of ballooning urban populations as well as the fishing industry, pollution from uncontrolled solid and liquid wastes, overfishing, unregulated settlements and construction, agriculture production and industrial expansion. Although plans are underway to conserve and protect the wetlands, implementation is proceeding slowly, with only Lake Piso having been formally gazetted as a protected wetland to date.

People and history

Liberia has a population of about 3,5 million people. The country is divided into 15 counties, which are subdivided into districts, and further subdivided into clans. This West African state is the oldest republic on the African continent. It was founded and colonized by freed American slaves, with the help of a private organization, called the American Colonization Society, in 1821-1822. The country gained its independence in 1847, establishing a government modelled on that of the United States.

A military-led coup in 1980 overthrew then-president William R. Tolbert, which marked the beginning of a period of instability that eventually led to a civil war that left an estimated 250,000 people dead and devastated the country's economy. Today, Liberia is recovering from the lingering effects of the civil war and the related economic dislocation. The country's infrastructure is still, for the most part, derelict; pipe-borne water and electricity are generally unavailable to most of the population, especially outside Monrovia, and schools, hospitals, roads and infrastructure remain derelict. Following 14 years of civil war (1989-2003), Liberia returned to democratic rule in 2005 with the election of Africa's first female president, Ellen Johnson Sirleaf.

Analysis (state of water, sanitation and hygiene)

Before 1990, approximately 45 per cent of the urban population had access to safe drinking water, managed water systems or improved hand-pump wells, compared with 23 per cent of the rural population. In 1991 the daily water production for Monrovia amounted to 61,000 m3/d. With the destruction of major water and sanitation infrastructures during the civil conflict, the situation drastically changed for the worse. All actors in the sector agreed that the state of the water, sanitation and hygiene services in Liberia is dire, and progress in increasing service delivery and improving the policy environment is slow. Only a minority of Liberians, whether in rural or urban areas, have access to safe water and sanitation facilities; three out of four people have no access to safe water, six out of seven are without access to safe sanitation facilities, such as toilets, and 19 out of 20 practice unsafe hygiene behaviour, such as not washing their hands with soap after using the toilet or not storing their water in clean environments.

The years of civil crisis in Liberia totally destroyed the infrastructure necessary for water testing, and prior to 2008 there were no government-managed water testing facilities in the country. Since 2008 a central laboratory for testing water has been established in Monrovia and portable water testing kits have been distributed to the 15 county health teams' environmental health divisions. Although this is a critical indication of progress, far more resources are required for water quality testing.

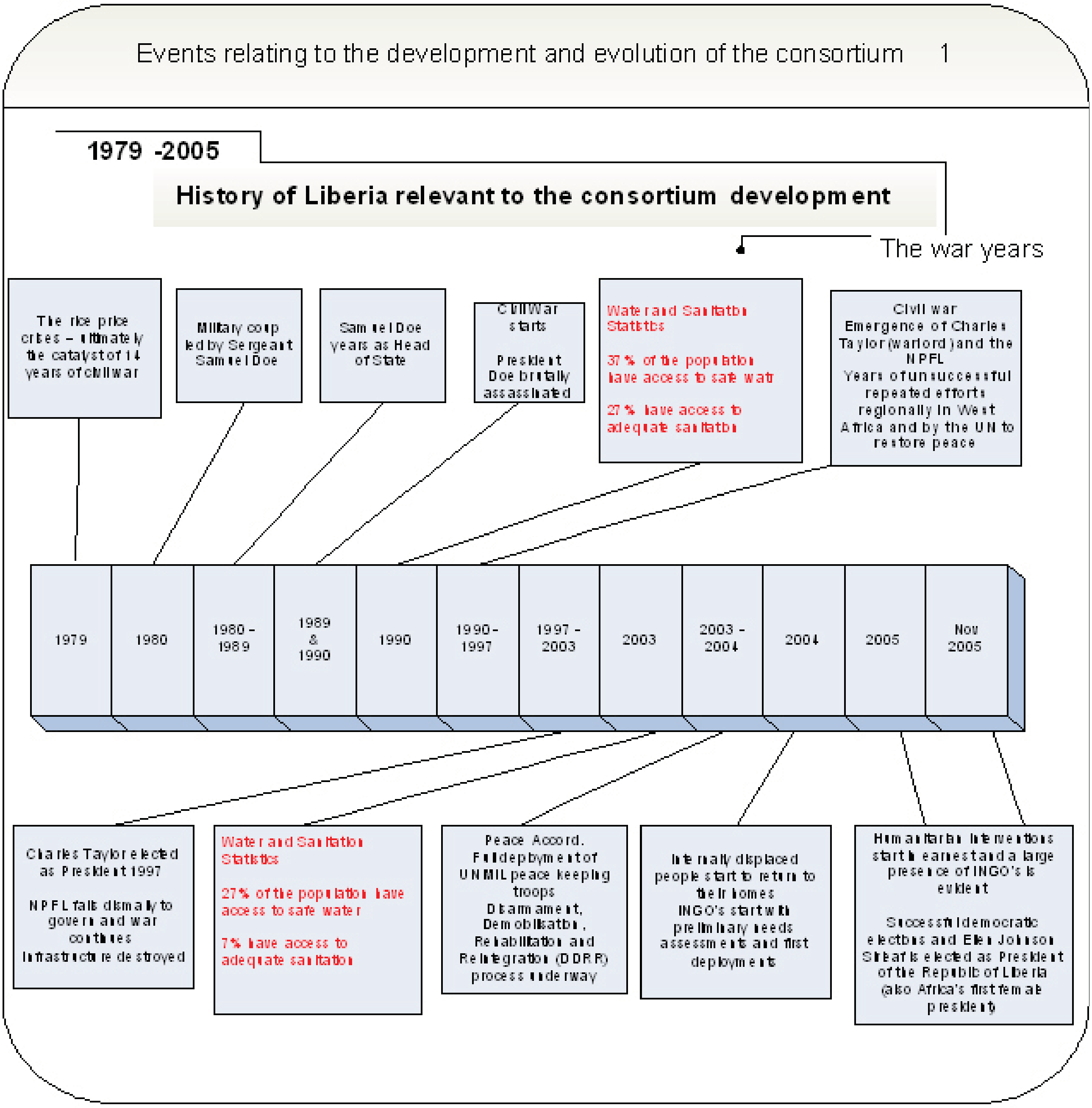

Figure 1 From a research study on how the Liberia WASH Consortium Emerged and Evolved in which the evolution of the water and sanitation is documented, depicts the chronological timeline of key events relating to the above text.

Scientific and policy relevance

The most relevant scientific discussion in relation to the water sector recovery and resourcing in Liberia is one that assesses the disease burden in relation to water quality. As with many environmental exposures, the links between disease burden and specific water-related exposures have been difficult to identify. In recent years, with the development of more sophisticated epidemiological methods, there is increased awareness of the health impacts related to water. Diseases transmitted by water are mostly non-specific, such as the large cluster of 'diarrhoeal diseases'. In settings where the water-related disease burden is greatest (in certain developing country situations and in small community supplies), exposures to disease-causing organisms are frequent and occur often through various 'competing' pathways. These pathways can include exposure to drinking water and lack of hygiene (Pruss and Havelaar, 2006). Exposure often occurs at the household or small community level and drinking-water quality should be routinely assessed at the point of distribution, as well as at the point of consumption. Past epidemiologic studies have demonstrated the central role of water-borne and food-borne transmission, as well as hygiene, for the spread of cholera in the African setting. The potential for epidemic cholera is large where adequate water and sanitation infrastructure is lacking, as is the case in much of sub-Saharan Africa (Gaffga et al., 2007).

High incidences of water-borne diseases are evident in Liberia, such as cholera and acute watery diarrhoea, and water-related diseases, such as river blindness, onchasiasis exhibiting as filariasis and elephantiasis, shigellosis, malaria and, most devastating of all, the reports of high child mortality. In 2006 there were 4409 suspected cases, and 0.3 per cent of tested samples confirmed positive for vibrio cholera; in 2007, 3814 cases with 0.18 per cent confirmed cholera; in 2008, 1288 cases with 2.7 per cent confirmed cholera; and in 2009, 480 with 12 per cent confirmed cholera. Liberia has one of the world's highest rates of infant mortality – 157/1000 live births, which is well above the sub-Saharan Africa average of 102/1000 (National Health Policy, 2007). One out of nine Liberian children dies before their fifth birthday, or 110 out of every 1000 live births, according to the 2008 Liberia Demographic and Health Survey (LDHS). Of the surviving children, 39 per cent are stunted or short for their age. Malaria, diarrhoea and respiratory illnesses, like pneumonia, are the leading causes of death in Liberia. Many of the diseases and health problems are water and sanitation related (World Bank and the African Development Bank 2008).

In Liberia, diarrhoea remains a chronic problem in both towns and rural areas, accounting for 19 per cent of Liberia's high child mortality rates, and cholera is endemic, with annual epidemics, especially in major urban centres. Allowing preventable water-borne and vector-borne diseases to flourish is proving to be a deadly situation for huge numbers of Liberians. Together, lack of safe water for drinking and household use, poor sanitation and bad hygiene practices cause about 18 per cent of all deaths in Liberia (WHO, 2008). This represents a massive public health crisis. But these deaths can be prevented if investments for the sector are improved, if hygiene messages are targeted and if the sector leadership and policies are enhanced (Sitali, 2010).

The Government of Liberia Technical Guidelines for water and sanitation (2010) state that water quality testing (chemical and bacteriological) should be done on all wells during and after construction. Best practice should be that water monitoring is undertaken using WHO guidelines, and that indicators are monitored in stages through knowledge, attitudes and practices (KAP) surveys, clinic records, water-borne disease surveillance reports, well-log and yield test reports, water quality test reports, physical observation, training reports and records, and consultation with communities (Liberia WaSH Consortium, 2010).

Water governance

Alongside the destruction of basic infrastructure are the issues of governance, policy and institutional frameworks. The policy and institutional frameworks for managing and delivering water and sanitation are weak. There is a multiplicity of government ministries and agencies that play a significant role in the management and delivery of water and sanitation services. Responsibility for policy formulation, service delivery in urban areas and service delivery in rural areas lies with three different bodies.

The four line ministries/agencies responsible for water resources in Liberia are the Ministry of Lands, Mines and Energy (MLME), the Ministry of Public Works (MPW), the Ministry of Health and Social Welfare (MOH) and the Liberia Water and Sewage Corporation (LWSC). In 2006, these institutions, still recovering from years of war, had no sector-level policies for water and sanitation supply. From an operational perspective, because there were no overarching sector policies, an implementation strategy, containing information on county of operation, time-frame of intervention and budget, was not possible. None of the government agencies had the human and logistical resources required to effectively govern the sector. It was difficult to gather a collective civil society voice with regard to advocating for real policy change at the government level because the non-governmental organization (NGO) sector was uncoordinated (Richey, 2010). An effect of this fragmentation of responsibilities and lack of coordination is that planning and reporting of activities in the sector is ill-defined, monitoring and evaluation is weak, and government funding very low. Water and sanitation funding for the current PRS is underfunded by US$93.5 million. There are huge discrepancies on access and coverage data. Several instruments including the PRS, LDHS and MDG progress reports and the national census report (all of which were produced in 2008) are not coherent in their data.

Overall the challenges are numerous, but the major ones include:

- Ensuring that the government takes leadership in the sector through a sector-wide approach

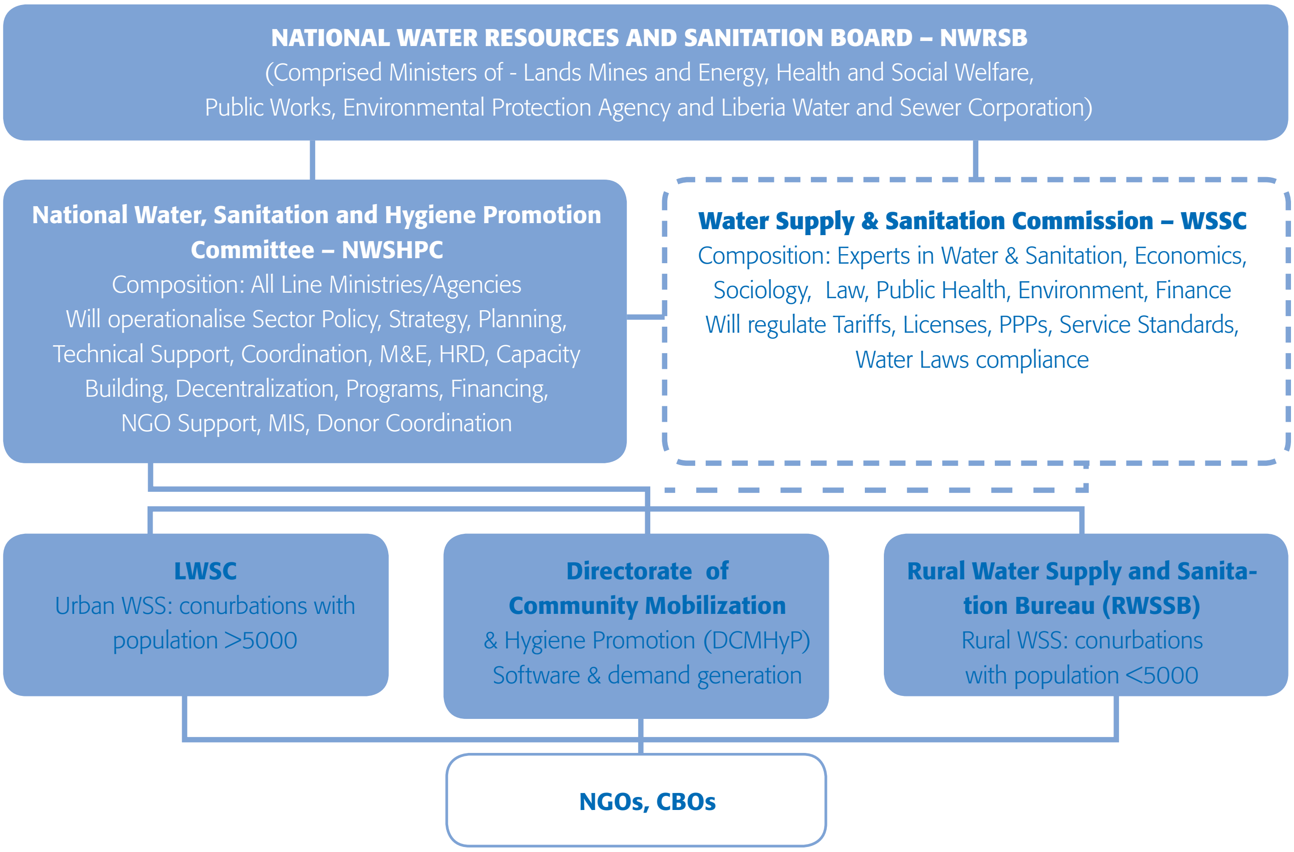

Figure 2. Presents the institutional framework structure for WASH governance in Liberia.

- Implementing policy (particularly establishing the National Water Resources and Sanitation Board (NWRSB) and establishing and supporting the Water Supply and Sanitation Commission (WSSC))
- Developing government capacity to plan, deliver and coordinate WaSH programmes
- Bridging the financing gaps. PRS WaSH costs are USD143.5 million, of which only one-third is committed from both government and donors and it is estimated that there is a USD93.5 million financing gap (Sitali, 2010).

Major obstacles still remain if the PRS is to be achieved and if progress towards the MDGs is not to be compromised. These range from weak governance structures, poor data management systems, inadequate government and donor financing, and inadequate human resources to deliver, manage and provide oversight for the sector.

Civil society engagement

Local civil society has also begun to develop skills in advocacy in addition to the service delivery elements that were being done by some local NGOs during the conflict. It is estimated that there are 128 Liberian NGOs with water and sanitation as a focus area. Most of these are engaged in direct service delivery and seldom engage with the government on policy matters, targeting of resources and financing for the sector. However, the Liberia Network of NGOs (LINNK) has a WaSH Sector team within its structures and this team engages with the government at various levels including policy discussions. Together with five other local NGO networks, LINNK is now a part of the local NGO WaSH Working Group which has been advocating for the operationalization of the water supply and sanitation policy and its implementation, particularly the creation of the NWRSB, with its operating arm of the National Water, Sanitation and Hygiene Promotion Committee (NSWHPC) and the WSSC, and lobbying for more and better financing and targeting of sector activities.

So far, the Working Group has conducted significant local and national awareness campaigns, particularly on World Water Day, Global Hand Washing Day and prior to the 2010 UN MDG Summit, when they held a poverty hearing for communities that are not served or underserved. This programme, like many others, was aired live on radio and it prompted the Minister of Labour to personally go and join the hearing as it captured the major gaps in the sector and presented real human stories from across the country.

It is expected that civil society will play a major role in ensuring that services are demand driven, respond to the core needs of poverty reduction and that the policies, institutions and financing are gathered for effective implementation of government plans. But this will not rest on civil society alone, as both government and donors are expected to reinforce their planning, coordination, mutual accountability and harmonization in line with the Paris Declaration aid effectiveness principles.

Picture 2. Billboard, Monrovia, advertising the Lifting Liberia campaign promoting the country's Poverty Reduction Strategy (Richey, 2010).

Recovery strategies

The challenges are not going unrecognised. The government, through the PRS 2008-2011, plans to increase access to safe water from 25 per cent to 50 per cent, and access to sanitation from 14 per cent to 33 per cent of the population. The initial strategy of the Government of Liberia (GoL) after the end of the civil war was articulated around a framework with four basic Pillars, upon which the PRS is also based:
Pillar I: Expanding peace and security
Pillar II: Revitalizing the economy
Pillar III: Strengthening governance and the rule of law
Pillar IV: Rehabilitating infrastructure and delivering.

Under Pillar IV, the basic goal of the GoL with respect to water and sanitation is to reduce the water and sanitation-related disease burden in Liberia. This is to be done through, among other actions:

- The rehabilitation of damaged water and waste collection/disposal facilities, and the construction of new facilities as needed
- Establishment of water-quality testing facilities nationwide with trained staff and the necessary equipment
- A scaling-up of hygiene promotion in schools and communities in all 15 counties, including establishing or supporting existing WaSH committees at the community level and engaging them in sensitization /training events
- Establishing theft control mechanisms for water and sanitation assets

A number of significant interventions are taking place in Liberia's Water Supply and Sanitation (WSS) sector to bring the country on track to achieving the targets set by the MDGs or by the country itself. To undertake these required a critical look at the policy, regulatory and service delivery environments. The sector performance management framework, which suffered through the years of civil war, is being overhauled with massive support from donors and NGOs as the country continues to enjoy external goodwill.

The GoL has only recently approved a WSSP. Prior to this, an Integrated Water Resource Management Policy (IWRM-P) had been approved by Cabinet in mid-2008. The IWRMP promotes a new integrated approach to manage the water resources in ways that are sustainable and most beneficial to the people. This new approach is based on the continued recognition of the social value of water, while at the same time giving due attention to its economic value. Thus, allocation in water resources development shall aim to achieve the maximum net benefit to Liberia.

Although the state is the ultimate custodian of the water resources, the objective of the policy is to achieve a public sense of ownership thus mobilizing the people's resources to assist in the management, protection and conservation of this natural resource. The policy is designed to be a broad-based charter, which must be recognised by all concerned sector institutions, and be taken into account by all projects and programmes, both public and private. All water-using sectors are required to develop their own policies in line with the IWRM-P.

As stipulated in the WSSP, its main objective is to "provide guidance and direction in institutional, economic and legal reforms that will lead to improved water governance at national, local and community levels, and improved access to safe water supply and adequate sanitation, in an affordable, sustainable and equitable manner, to all the peoples of Liberia". The policy is based on the principle of 'some for all' as opposed to 'all for some' and seeks to provide the impetus for better distribution mechanisms.

The policy also seeks to address the fragmentation of sector leadership and management. It provides for the re-introduction of the NWRSB which will have oversight over the sector agencies, including the LWSC, the Bureau of Rural Water Supply and Sanitation, which will be at the MPW, and the Directorate of Community Mobilisation and Hygiene Promotion, to be established at the MoH. The central uniting factor and principal institutions to facilitate these changes in the policy are identified as the National Water, Sanitation and Hygiene Promotion Committee (NWSHPC) and the WSSC, which will not only be responsible for regulation, but will also lead in planning, resourcing and fostering of better coordination in the sector, albeit under the auspices of the MLME. The UNDP GoAL-WaSH programme has positioned itself to support this framework as stipulated by the policy and contribute to its full realization by providing technical support to the MLME.

UNDP GoAL-WaSH Programme intervention

Influenced by the various GoL policies and initiatives, the UNDP GoAL-WaSH Programme developed two premier project options. The development of the project options followed extensive consultation with relevant GoL ministries and agencies, Liberian NGOs, United Nations agencies and other development partners.

The Water Supply and Sanitation Policy, adopted in 2009 calls for the establishment of a WSSC to address the main weaknesses identified by the GoL – the lack of coordination among government departments, NGOs and donors, coupled with the fragmentation of roles and responsibilities, need for better planning (data-based and demand driven) and effective approaches for poverty reduction. The absence of a national water supply and sanitation coordinating institution is one of the causes for the weakness. The UNDP GoAL-WaSH project option one is designed to strengthen the capacity of the government for coordination and resource mobilization.

The GoL's GoAL-WaSH Programme proposes to support the appointment of a Senior Technical Advisor (STA) and a National Coordinator to the MLME, whose primary function will be to ensure that the WSSC comes into effective being. To this end, the STA and National Coordinator will:

- Interact with government and donors to secure budgetary and other financial support for the WSSC,
- Advise on and assist with the recruitment of appropriate personnel to staff the WSSC
- Assist in appointing external professionals in key areas to work with local counterparts, should local capacity be scarce or lacking
- Establish a work programme for the WSSC, including a schedule of key deliverables
- Support advocacy and awareness-raising of the importance of safe water and sanitation in a water-rich, but rapidly urbanizing country
- In conjunction with other actors in the sector, ensure that a rational system of reporting on the national state of WSS is in place. The project will also review the scope and mandate of the WSSC.

Through partnership with the Water and Sanitation Programme of the World Bank, project option two identified by the UNDP GoAL-WaSH will support one of the critical areas in the sector which is 'Building an Effective Database for Planning for Progress Towards the MDGs 2015'. The project intends to appoint a Technical Advisor (Water Sector Analyst) in the MLME who will:

- Support the nine to fifteen MLME WSS regional coordinators
- Support data collection and management purposes
- Facilitate capacity-building opportunities for the regional coordinators
- Improve the understanding and managing of WSS data collection
- Measure levels of and inequities in access to WSS according to geography, gender, disability and ethnicity
- Expand the survey nationwide in conjunction with civil society organizations
- Interact with the WSSC and policy development for achievement of MDGs.

Conclusions and recommendations

Liberia's WaSH sector is still facing the remnant challenges of the 14-year brutal civil crisis that claimed a quarter of a million lives, displaced hundreds of thousands more and destroyed key infrastructure necessary for basic service delivery. It will take a long time to fully recover, but progress so far has enabled Liberia to improve service delivery of WSS for over one-quarter of its population. It is yet to register the success of institutional reforms when the water and sanitation policy is fully implemented, partly by the creation of the WSSC.

The UNDP GoAL-WaSH Programme will intervene by providing support for the establishment of the WSSC, which, in part, is expected to provide coordination, demand and data-based planning, resource mobilization and leadership in the creation of sector strategies and plans. The Commission will serve as an implementation arm of the National Water Resources and Sanitation Board.

With proper institutional frameworks and arrangements, it is expected that Liberia will effectively respond to the challenge of water, sanitation and hygiene-related diseases that continue to face the country. With a high infant mortality rate and endemic cholera epidemics, Liberia's WaSH sector requires faster and better-coordinated institutional, policy and resource transfer approaches to overcome disease and its impact on both social and economic progress. The following recommendations are therefore put forward:

1. Develop a work plan for implementing the Water Supply and Sanitation Policy. A key operational requirement for realizing the policy is to have a clear timeframe for when and how each aspect of the policy will be achieved. This can be developed as a road map or Compact showing how the government will implement the key elements of the Water Supply and Sanitation Policy, such as when the institutions in the policy bureaux (at the MPW and the directorate at MoH) will be formed, and spelling out the resources that will be required. Without such a timeline, the process of implementing key aspects of the policy will remain elusive.

2. Nationwide assessment of the water and sanitation facilities is a necessity. A proper assessment of the current coverage and functionality of WaSH facilities is essential. Completion of this assessment is not only urgent, but important, as it is the starting point for creating the scenario and data-based planning that can help to determine what is needed to meet the MDG target on water and sanitation. This baseline can also resolve the credibility question hanging over the LDHS data, which has apparently been used for MDG reporting internationally. The assessment should also include the functionality of the existing infrastructure and the needs for maintenance and repairs.

3. There is a need to mobilise the support of NGOs in targeting mainly the urban poor, especially in densely populated slum and rural communities, with low-cost, effective water supply schemes. Together with the government, communities and NGO actors can explore different technologies in slum communities, such as ecological sanitation and community-led total sanitation in rural areas.

4. It is important for the government's budgeting process to adopt an activity-based budgeting system, which will clearly indicate the amount of resources targeting water and sanitation. As it is, the budgeting nomenclature does not clearly delineate resources meant for water and sanitation from the overall allocations to ministries with a responsibility to deliver water and sanitation targets. Doing this will also ensure that government will have a better tracking mechanism for its expenditures in the water and sanitation sector.

5. There is a need for increasing the budgetary allocation to the water and sanitation sector to close the financing gap of US$93.5 million for the PRS and to ensure that a costed plan for achieving both the sector strategic plan and the MDGs is put in place.

6. Local civil society organizations have an important role to play, and they need to be consulted and included in all processes, including strategic planning, annual budgeting, policy implementation and the targeting of services.

7. Demand-driven services. There is also a clear space that civil society organizations should continue to fill by systematically and consistently identifying areas of dire need and where social and economic indicators are very low.

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THE IMPOSSIBLE DREAM? THE UPPER GUADIANA SYSTEM: ALIGNING CHANGES IN ECOLOGICAL SYSTEMS WITH CHANGES IN SOCIAL SYSTEMS

The Upper Guadiana system (and Western Mancha aquifer) is a dramatic example of a deep (and reversible?) change in a socio-ecological system. Intensive groundwater use over 40 years, with 20,000 Mm3 abstracted from a 5500 km2 aquifer, has fuelled a spectacular socio-economic development of a poor and backward region at the expense of a Man and the Biosphere reserve, the Mancha Humeda, of which only 20 per cent of the original area remains. This analysis reviews these changes, with a new focus on the drivers of ecological and social conflict over water. The paper also analyzes the potential of the Special Upper Guadiana Plan, a large-scale effort aiming to restore a complete socio-ecological system.

Key words: socio-ecological systems, restoration, agricultural policy, Bayesian networks, extended water footprint

Introduction: starting at the end

The Upper Guadiana Basin in central Spain is a dramatic example of a deep but potentially reversible change in a socio-ecological system. It offers room for reflection on some of the main opportunities and obstacles to aligning social and environmental systems through choices made over the use of water in arid environments. Although this example reflects a specific case study in Spain, many of the issues raised have echoes in other parts of the world facing similar development dilemmas. The issues include the economic incentives that drive the use of natural resources and finding opportunities to change the behaviour of key 'water managers', such as farmers, who are responsible for more than two-thirds of global consumptive water use.

Our analysis refers to the so-called wicked policy problems (Smith, 2007), i.e. problems that are highly complex, with clusters of interrelated and dynamic interactions with high levels of uncertainty. The Upper Guadiana Basin is a case with many production and consumption externalities (in this case wetland destruction and aquifer drawdown), which need an inter-disciplinary approach to solve them. How do you make a decision when it seems that solutions for one group will generate problems for other groups? Are these problems solvable by any single organization? Or do they require a new, negotiated type of solution, based on a broad and agreed societal response by scientists, farmers, service agencies and civil society?

In the Upper Guadiana system and the Western Mancha aquifer, intensive groundwater use has meant that, over the last 40 years, about 20,000 Mm3 were abstracted from a 5500 km2 aquifer to fuel spectacular socio-economic development. Of those 20,000 Mm3, about 3000 came from storage; the average groundwater level depletion was about 30 m. The Mancha region had been a poor and backward region, experiencing strong outmigration from the area. Socio-economic development, however, has been at the expense of a Man and the Biosphere (MAB) reserve, the Mancha Humeda. It is a series of wetlands, the most iconic being the Tablas de Daimiel National Park

Photo Credit: E. Lopez-Gunn (2003)

Figure 1. The Tablas de Daimiel National Park.

Figure 2. Location of the Guadiana Basin and the Tablas de Daimiel National Park. Source: Zorrilla (2009).

(Fig. 1), where it is estimated that only 20 per cent of the original area remain and very few of the wetlands function naturally (de la Hera, 1998).

This paper offers two complementary perspectives on analyzing changes in socio-ecological systems. First, it undertakes a retrospective analysis of a dramatic regime shift over the last 40 years. This is achieved through a series of snapshots of changes in the Upper Guadiana Basin to understand and explain the drivers that led to the current impasse over the deterioration and ecological problems of the Tablas de Daimiel National Park. The impasse and conflict are between irrigated farming and wetlands, which are effectively competing for the same water resources. As seen by farmers, “It is a stark choice: the duck or the farmer”.

The paper then offers a prospective analysis of the Special Upper Guadiana Plan. The plan, with a budget of €5 billion, started in 2008 and will be operational until 2027. It is currently considered the main measure contemplated within the European Union (EU) Water Framework Directive for groundwater water bodies identified in the Western Mancha aquifer (Martinez Cortina et al., 2011). Compliance with the EU regulatory framework means achieving good quantitative and qualitative status by 2015 (or 2027 under justified derogations). The Special Upper Guadiana Plan (CHG, 2008) has now been operational for three years, and some preliminary analysis can be undertaken on the implementation of the plan from the perspective of the stakeholders and the re-allocation of water rights. It can offer some insights into the potential and the limitations for a regime shift towards restoring the whole socio-ecological system. The plan in many ways can be analyzed as a large-scale effort not only in ecological restoration, but also in incorporating its social aspects, i.e. aiming to restore a complete socio-ecological system.

The land of honey: a retrospective analysis

Tablas de Daimiel National Park (Fig. 2) has a strong symbolic value for a number of reasons. ‘Daimiel’ translates as the land that gives honey, a landmark in a largely arid and poor region which, thanks to natural springs and so-called tablas fluviales, provided sustenance for the local population from fisheries, crabbing and associated land uses like small orchards. Tablas de Daimiel is also a landmark in Spanish conservation history. The creation of the park in 1973 was largely driven by policies of the 1970s to drain wetlands because they were perceived as insalubrious wastelands, full of malaria and of little economic value. The Ley Cambó (Cambo Law), dating back to 1918, was re-vitalised with a new Act in 1956 to facilitate the reclamation of marshland as agricultural land. The rationale for incentivizing irrigated agriculture was the depopulation of the area, which in 1981 had regressed to numbers similar to the 1930s. The regional government gave soft loans to farmers to encourage the irrigation of a dryland farming system that consisted mainly of vines and rainfed cereals. The funding was based on the belief of many analysts (both academic and political leaders) that groundwater could be the engine driving regional development, encouraging farmers to tap ‘the sea beneath their feet’. This intensive groundwater use was part of the hydraulic paradigm dominant in Spain (Lopez-Gunn, 2009a), a semi-arid country that, because of its history, saw water and irrigation as the route to modernizing the country. In the context of rural and agricultural regions, this was a strategy to settle a rural population that would otherwise migrate to cities and other more industrialised regions.

In the same year the park was designated (1973), some existing watercourses were channelled and modified to increase the amount of agricultural land. The first wells were drilled to tap groundwater resources, which had been inaccessible due to lack of technology and knowledge. Wells were authorised to irrigate maize and barley, thus replacing a traditional, extensive dryland Mediterranean agriculture of olives, vines and wheat (Fig. 3).

This meant a silent revolution (Giordano and Villholth, 2007; Llamas, 2004; Llamas and Custodio, 2003) where, over a relatively short time, the area experienced a deep process of socio-ecological transformation. One of the main causes of the silent revolution is low abstraction costs (even without ‘perverse’ energy subsidies), usually within 0.02-0.20 €/m3. Intensive use of these previously untapped

Photo Credit: P. Zorrilla (2009)

Figure 3. Old and new agriculture.

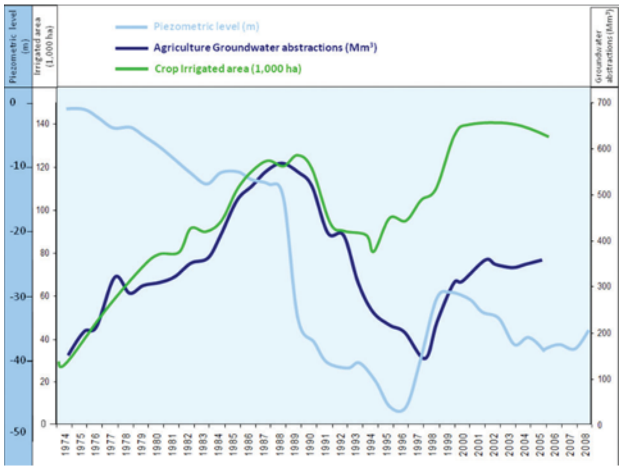


Figure 4. Aquifer levels, groundwater abstractions and irrigated area.
Source: Zorrilla (2009).

and extensive groundwater resources meant that, over a short period between 1974 and 1984, groundwater use grew from a mere 200 Mm3/y to 500 Mm3/y, when the estimated renewable resources were around 300-320 Mm3/y. The area under irrigation over the same period almost tripled, from 30,000 to 85,000 ha (Table 1 and Fig. 4). In the following years, groundwater abstraction increased substantially. Although the accuracy of the data on real abstractions is illusory, we have estimated an average of 500 Mm3/y during the last 40 years.

The consequence of intensive groundwater use was felt from the mid to late 1980s as a result of dry years coinciding with the expansion of irrigated land. The drop in aquifer levels reached 40 to 50 m in some areas. Many wells dried up and farmers deepened their wells (the so-called 'war of the well'). The push for modernization continued despite the fact that there was a growing awareness of the negative externalities associated with intensive groundwater use. A series of studies in the late 1970s and early 1980s had already predicted the impact of intensive groundwater use on dependent wetlands (IGME, 1980; IGME/IRYDA, 1979).

The Guadiana River Basin Authority declared the Western Mancha aquifer provisionally over-exploited on 4th February 1987 and made this definitive on 15th December 1994. The result of this declaration was a series of tough restrictions: (1) the drilling of new wells was forbidden, (2) the compulsory, top-down formation of Water User Associations, (3) the delimitation of the aquifer perimeter, (4) the ruling that existing wells could not be deepened, and (5) a strict reduction in water use allowed per hectare (water quotas) (Blanco Gutierrez et al., 2011). These restrictions under the Exploitation Regime (or Regimen de Explotación) applied to any farmer with a public or private well and established an annual abstraction regime. However, the Guadiana River Basin Authority did not follow through to ensure compliance, due to a lack of capacity and the large transaction costs associated with an estimated group of 16,000 beneficiaries.

Table 1. Evolution of irrigated area and aquifer abstractions

Year	Irrigated area (ha)	Volume abstracted (Mm3)
1974	31,166	205
1984	85,053	373
1990	123,321	576
2006	180,000-200,000	650-700

Source: Consorcio del Alto Guadiana (2009).

The regional government – responsible for agricultural policy, but with no regulatory powers over water use – had calculated that implementing the Regimen de Explotación would cost the region 7700 million pesetas (at 1990 prices, equivalent to €46 million). This was confirmed by an independent report for the European Commission:

> "… (the costs) were such that the authorities set up a scheme to provide compensation for having to reduce consumption of water for irrigation purposes. It should be remembered that, according to official data, there were around 8,400 irrigated farmers in the study area (7,900 in Western Mancha aquifer and 500 in Campo de Montiel), with an irrigated area of more than 135,000 ha. Assuming 100 per cent water availability (approximately 5,000 m3/ha/yr) and a cropping regime comparable to that which prevailed in the area in the 1980s, we estimate that irrigation was providing some 18,000 jobs per year. The reduction in water availability by half (to around 2,500 m3/ha/yr) implies a loss of around 25 per cent of these jobs, i.e. approximately 3,500 jobs. The regional authorities, for their part, estimated the loss of income as a result of the possible disappearance of irrigation at 7.7 billion pesetas per year (at 59,250 pesetas/ha x 130,000 irrigated ha)." (Viladomiu and Rosell, 1996; p. 12)

The loss of cultural and natural heritage: the status quo

The result was an economic model incentivised by the regional government that prioritised socio-economic development over the con-

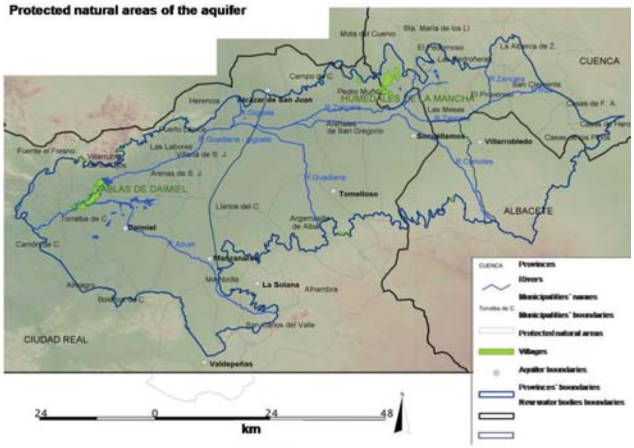


Figure 5. Main features of the Mancha Humeda Man and the Biosphere reserve. Source: Zorrilla (2009).

servation of natural resources , thus placing the emphasis on social and economic stability over ecological integrity and function. By 2010, 30 years after the start of the silent groundwater revolution in the 1980s, there was a dramatic transformation based on the linchpin of intensive groundwater use.

By 2010, only 20 per cent of the original MAB Reserve remained, with very few of the wetlands functioning naturally, particularly those dependent on the aquifer (Fig. 5). Yet the region has experienced a change from a largely rural, autarchic economy to a mature water economy, dominated by the service sector.

It is undeniable that the region of Castilla-La Mancha has experienced dramatic socio-economic growth, driven by an irrigated agricultural model. What is also undeniable, however, is that this came at a cost in terms of the loss of both natural and cultural heritage and the deterioration in groundwater quality. The Ojos del Guadiana, or Eyes of the Guadiana, was a natural spring resulting from the aquifer overflow. The spring featured in history books and was used in schools to educate children about rivers, with the Guadiana as the river that played hide and seek. It featured in Don Quixote as an enchanted river that hid beneath the land. In Don Quixote, chapter XXIII, part II, Miguel de Cervantes wrote:

> "Guadiana your squire, the duenna Ruidera and her seven daughters and two nieces, and many more of your friends and acquaintances, the sage Merlin has been keeping enchanted here these many years; and although more than five hundred have gone by, not one of us has died. Ruidera and her daughters and nieces alone are missing, and these, because of the tears they shed, Merlin, out of the compassion he seems to have felt for them, changed into so many lakes, which to this day in the world of the living, and in the province of La Mancha, are called the Lakes of Ruidera. The seven daughters belong to the kings of Spain and the two nieces to the knights of a very holy order called the Order of St. John. Guadiana your squire, likewise bewailing your fate, was changed into a river of his own name, but when he came to the surface and beheld the sun of another heaven, so great was his grief at finding he was leaving you, that he plunged into the bowels of the earth; however, as he cannot help following his natural course, he from time to time comes forth and shows himself to the sun and the world. The lakes aforesaid send him their waters, and with these, and others that come to him, he makes a grand and imposing entrance into Portugal; but for all that, go where he may, he shows his melancholy and sadness, and takes no pride in breeding dainty choice fish, only coarse and tasteless sorts, very different from those of the golden Tagus. All this that I tell you now, O cousin mine, I have told you many times before, and as you make no answer, I fear that either you believe me not, or do not hear me, whereat I feel God knows what grief."

The Ojos del Guadiana is now an agricultural irrigated field of cereals (Fig. 6) and a series of bridges, part of the regional government´s heritage, are now redundant since the Guadiana river no longer flows due to aquifer depletion. As the current director of the Tablas de Daimiel National Park stated: "The drop in aquifer levels (>3.5 m in some areas) has meant there is no natural discharge (in the park). The disappearance of the Guadiana River is one of the biggest natural disasters in our country." (Ruiz de la Hermosa, Director, Tablas de Daimiel National Park, 2010).

Scientific and policy relevance: prospective analysis

In terms of the implications for the transfer of scientific knowledge to policy, this section will use a series of methodologies and tools to shed new light on 'old' problems. The objective is, on the one hand, to help explain existing inertias in the system and, on the other, to identify windows of opportunity for changing policy, i.e. the right policy lever for entry into what is currently a locked and rigid system.

Regulatory impact analysis

One of the tools applied to understanding the socio-ecological system is based on blending an institutional framework on rules in norm like laws and regulations and rules in use with a simplified regulatory impact analysis, looking at the design of the law and its implementation (e.g. in terms of effectiveness and evidence-based implementation). The Spanish water law is, on paper, a sophisticated law, but under the lens of regulatory impact analysis, it shows itself to be, in the specific case of groundwater, excessively complex for a number of reasons. It created a system under which both private and public rights to co-exist in the same aquifer, with very different implications in terms of flexibility granted to the water user and the regulator. The capacity to follow through by the authorities was limited because of the large number of users spread over a large area. In addition, given the declaration of aquifer over-exploitation, this meant that the aquifer was closed for new water allocations, and that no new rights could be issued to new users after 1991. The declaration of over-exploitation meant users who had private rights found them frozen in time, with no modifications allowed (Llamas and Custodio, 2003). Meanwhile, after 1994, new users were effectively illegal. Added to the mix were a

Photo credits: courtesy of the photo archive Centro del Agua de Daimiel

Figure 6. Changes experienced in the Upper Guadiana
Photos (top right and left) Ojos del Guadiana (1960 and 2009)
Photos (bottom right and left): Molimocho well (1960 and 2009).

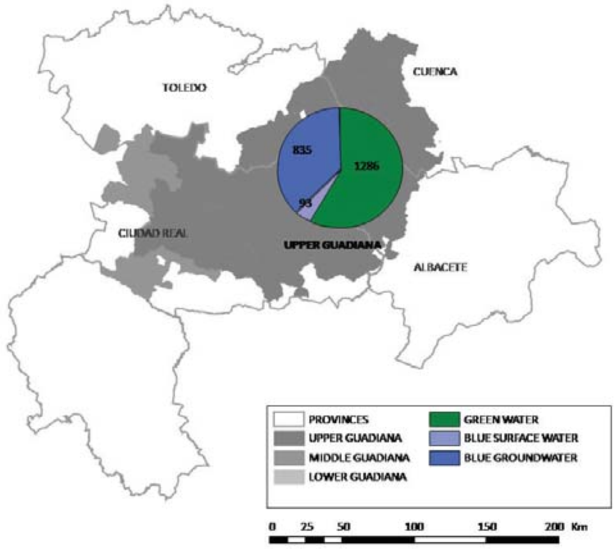


Figure 7. Agricultural water resources in the Upper Guadiana. Source: Aldaya and Llamas (2008). For the methodology used in the calculations, please refer to the original publication. Figures in the circle refer to Mm3. Blue water: water that is available in rivers, lakes and ground water aquifers. Green water: water in the root zone (Falkenmark, 1995).

strong underlying cultural element where 'norms are sometimes broken', which can be seen as a rational and logical response to a past history of autarchy, limited capacity and resources by the regulator, and the limited or eroded social capital in the past between the water authority (the regulator) and farmers. With a complex law, a difficult start and a weak regulator, the reality was that the aquifer had been over-allocated. It is estimated that around 590 Mm3/y been been allocated in water rights when the estimated average renewable groundwater resources are 320 Mm3/y. This means, in effect, almost a doubling in terms of paper rights of the actual amount of water that can be allocated per year. In 2010, under the new draft Hydrological Plan for the Guadiana, the 'renewable' resources have now been reduced further to 270 Mm3 of 'available' resources, including an environmental reserve for the gradual recovery of the aquifer by 2027.

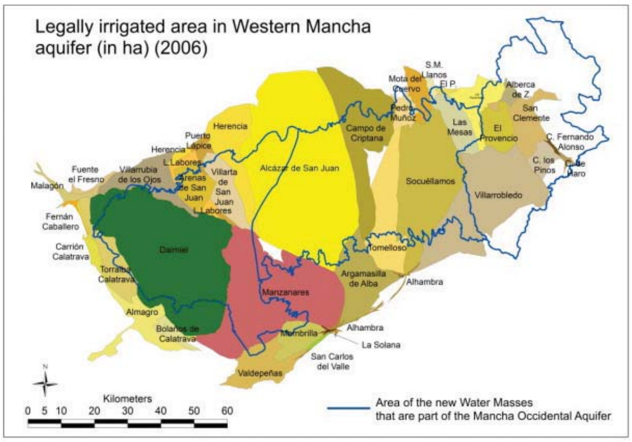
The extended groundwater footprint in the Upper Guadiana Basin and Bayesian networks

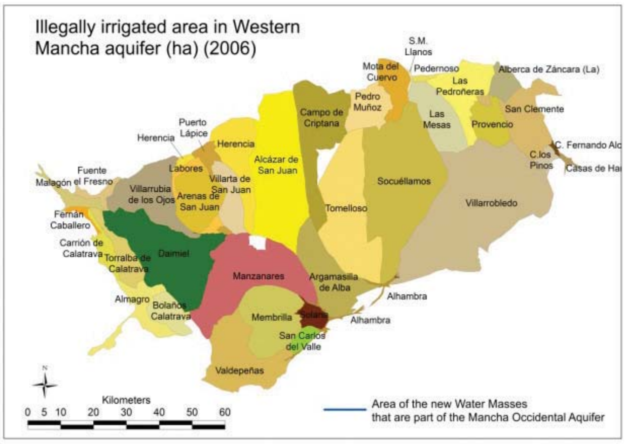
The traditional water footprint analysis is a metric, or tool, to assess consumptive water use that looks at both the direct and indirect water use of a consumer or producer (Hoekstra, 2003). The water footprint of an individual, community or business is defined as the total volume of freshwater that is used to produce the goods and services consumed. The innovation of the extended groundwater footprint is that it also considers the productivity of water (Garrido et al., 2010). The traditional water footprint analysis (Hoekstra et al., 2009) – when applied to the Upper Guadiana Basin – is in itself useful because the perception in the area is that groundwater is the main water resource available, given the stored groundwater resources in a relatively large aquifer. However, the study undertaken by Aldaya and Llamas (2008), as shown in Fig. 7 below, indicates that even in a semi-arid country like Spain, in an average climate year the main water resource is green water. It is important to remember though that soil moisture as well as surface water vary a lot over time compared to groundwater. This is very important in a context of wet and dry climatic periods. In terms of agricultural water resources, almost 1300 Mm3/y is green water in an average year, while 835 Mm3/y is groundwater and less than 100 Mm3/y is surface water from reservoirs (Fig. 7). This opens a number of opportunities for more nuanced management along the green-to-blue water spectrum, as highlighted by Vidal et al. (2009).

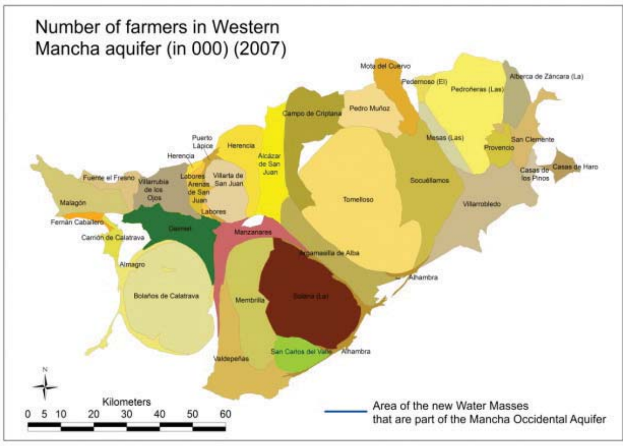
The added dimension provided by the extended groundwater footprint is more information on the economic drivers and on the incentives that influence the way farmers use groundwater, when framed in the context of water productivity (€/m3). In this context, it is highly relevant to note that it is products such as the region's traditional crops, where Spain has a comparative advantage due to its geographical location, that offer the greatest value per m3. This is the case when looking at cereals (0.1-0.2 €/m3) and vineyards (1.0-3.0 €/m3), or even new uses like thermo-solar power (10.0-20.0 €/m3). Economic water productivity in the Upper Guadiana varies, between e.g. 1.5-15.0 €/m3 for vegetables, 1.0-3.0 €/m3 for vineyards, 0.5-1.0 €/m3 for olive trees and 0.1-0.2 €/m3 for cereals (Aldaya and Llamas, 2008).

The most interesting analysis, however, comes from mixing the regulatory impact analysis and the extended water footprint, since it provides two things. First it provides a rational explanation for the current impasse in the Upper Guadiana Basin in terms of policy sclerosis or stasis (lack of action), and second, it provides new opportunities in helping to identify possible entry points for policy reform towards a process of socio-ecological restoration. The challenge is to identify opportunities where the sustainability of both systems (social-political and ecological) can co-exist in the long term without undermining the functional structure of the ecological system, and where the livelihoods of local people are guaranteed, rather than prioritizing one system (the social) at the expense of the other (the ecological) or vice versa.

When analyzing data on water rights in the aquifer area, it is important to note that three of the largest municipalities currently hold 44







Source: Lopez-Gunn and Zorrilla (2010)

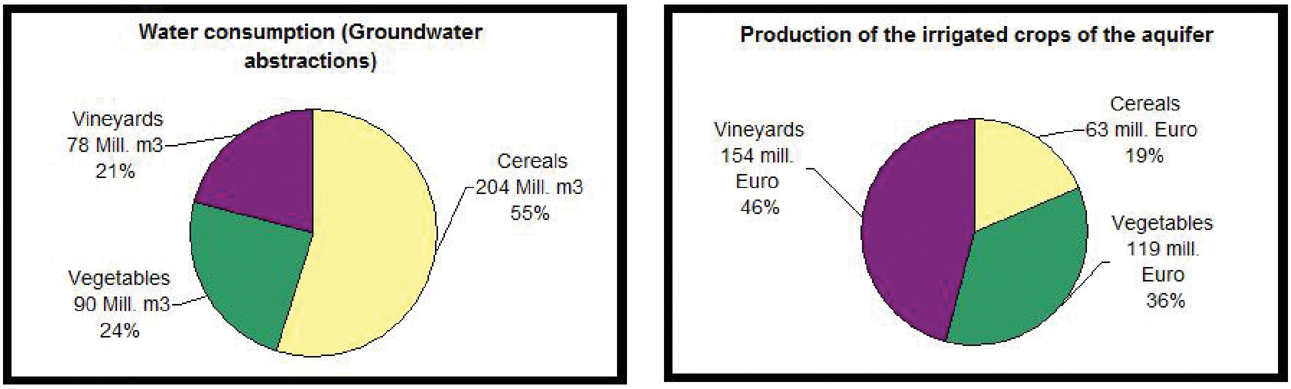
Figure 8. Cartograms of legal and illegal water use per village in the aquifer. (A cartogram is a map in which the geometry of the map is distorted so that the land area represents some thematic variable, in this case legal and illegal water use per village)

per cent of the legal water rights, for 7 per cent of the farmers (see yellow (center), green (left side) and red (left side) municipalities in Fig. 8). . Equally irrigated cereals consume 55 per cent of the water abstracted (also in these three villages), generating 19 per cent of the value. In contrast irrigated vineyards, which account for 21 per cent of the water abstracted, generate 46 per cent of the economic value (in 2006) (Fig. 9). What is more relevant, however, is that most of the irrigated vineyards had no allocated water rights, yet generate more jobs and income per drop as compared, for example, to irrigated cereals with water rights (Lopez-Gunn and Zorrilla, 2010; Dumont et al 2011).

What is most relevant in this context is that the combined use of the extended water footprint analysis and regulatory impact analysis highlights the dilemma posed by the lack of coordinated action between the regional government's department of agriculture and the central government's Guadiana water authority. The regional government successfully incentivised irrigation as a model for regional development and was very successful in achieving its aim. However, a failure to jointly implement the regulatory system and this, together with over-allocation by the water authority to highly consumptive users, resulted in the water authority having to declare the basin closed to new, more efficient water users, both in employment terms and also in terms of m3 per crop. The excessive rigidity of the regulatory system and the closure of the basin to new users, together with a lack of regulatory capacity to monitor and sanction thousands of legal and illegal users, led to an explosion of drilling. As highlighted by the extended water footprint analysis, 'illegal water use' is more efficient in terms of euros per drop (productivity of water), while it also generates more local jobs due to the types of crop (horticulture and vines), which are more labour intensive, compared to legal water use, mainly represented by cereals, which are traditionally cultivated in larger areas and with less of a need for labour (Dumont et al., 2011). One caveat is that vines grown in 'espaldera' (trellises) generate fewer jobs than traditional vines, since it is more mechanised. Also note that cereals are more dependent on rainfall (i.e. less irrigation in wet years like 2010) and are also more exposed to imports from countries with green water, e.g. France or Argentina (Garrido et al., 2010). The consequence of all the above has been the drawing up of an ambitious social-ecological restoration plan, the Special Upper Guadiana Plan, which is effectively a groundwater banking system on social and environmental grounds to address existing structural water rights towards a re-allocation on equity and efficiency grounds.

The crops with the highest economic productivity and the highest number of direct and indirect jobs associated with each drop of water used are horticultural crops, olives and vineyards. Cereals have lower economic productivity and generated employment. These differences in economic terms and jobs created suggest that a viable recovery of the aquifer from the socio-economic point of view could be achieved through a reduction in the area of irrigated cereals (Zorrilla et al., 2010). In fact, the results of an extreme socio-economic scenario show that a 'win-win' situation would imply substantially reducing irrigated cereals and maintaining – without any increase – the current vineyard, olive groves and horticultural crops (Zorrilla, 2009). This conclusion, however, has a caveat – the impact of extreme fluctuations in world cereal prices.

Olive trees and vines, which are traditional Mediterranean crops, are better able to use green water and so consume less water per hectare, so they are the most efficient in terms of water use. From the point of view of 'ecohydrology' (Falkenmark and Rockström, 2004), the best choice in social and environmental terms for the Western Mancha would be Mediterranean crops like olive trees and vineyards.



Source: Lopez-Gunn and Zorrilla (2010)

Figure 9. Water consumption and production generated by all irrigated crops (legal and illegal) in the Western Mancha aquifer.

A process of socio-ecological restoration

The Special Upper Guadiana Plan aims to achieve ecological restoration in compliance with the EU Water Framework Directive. The aim is to reduce the estimated current abstraction to 200 Mm3/y to recover wetlands, and by 2027 to gradually raise groundwater levels to refill part of the 3000 Mm3 of groundwater storage abstracted from the aquifer. The Tablas de Daimiel would then once again become the natural discharge and overflow from the aquifer. At the same time, there is a parallel process of 'social restoration' in the purchase of groundwater rights to be re-allocated to illegal water users on social equity grounds. These were mainly small farmers irrigating vines and horticultural products that had no water rights, yet they were more efficient in terms of water use, generating higher added-value and more employment per drop.

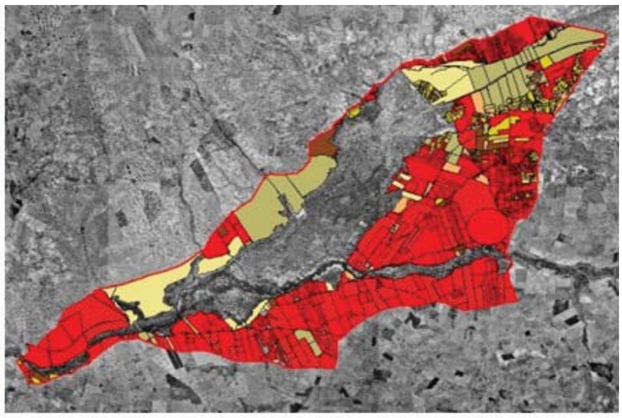
The plan however comes with a very expensive price tag but is motivated by a political desire to gain votes in the region. In the current economic crisis in Spain most of the money to purchase water rights has not materialised, and the only funding which is now likely to arrive refers to reforestation of land that has reverted to dryland farming after the purchase of water rights. The arrival of funding for forestation programmes occurs at a pre-electoral time linked to the generation of rural employment, as compared to the purchase of water rights, which has little political added-value. The target of the Special Upper Guadiana Plan was to purchase 130 Mm3 between 2008 and 2015, 70 per cent to be re-allocated for aquifer recovery and 30 per cent to be re-allocated to 'illegal' groundwater users, farmers who have agriculture as their main activity and source of income. The plan, although mainly focused on the purchase of water rights, has also established a parallel process of buying land (and water rights) in the park periphery (Figs. 10 and 11) with an estimated purchase of 2–3 Mm3 water rights by March 2011.

The total budget of the Special Upper Guadiana Plan is €5 billion for 2 per cent of Spanish territory, of which €810 million has been set aside for the purchase of water rights to be re-allocated on social and environmental grounds. An assessment of the early effectiveness of the Special Upper Guadiana Plan, the main measure in the draft Guadiana River Basin Plan, indicates that of the €340 million included in the plan for the period 2008–2010, only €104 million was actually budgeted for, and of this only €83 million was actually spent to purchase around 20–30 Mm3 (Barcos et al., 2010).

However, what is most problematic about the Special Upper Guadiana Plan is if it is seen as an end in itself, and the underlying incentive to irrigate is not addressed. As stated by WWF-Spain, the Special Upper Guadiana Plan should be seen as a catalyst for change, opening a window of opportunity for a long-term, robust and self-sustaining socio-ecological system.

Source: Consorcio del Alto Guadiana

Figure 10. Location of purchased water rights 2008–2010.



Source: Ruiz de la Hermosa (2009)

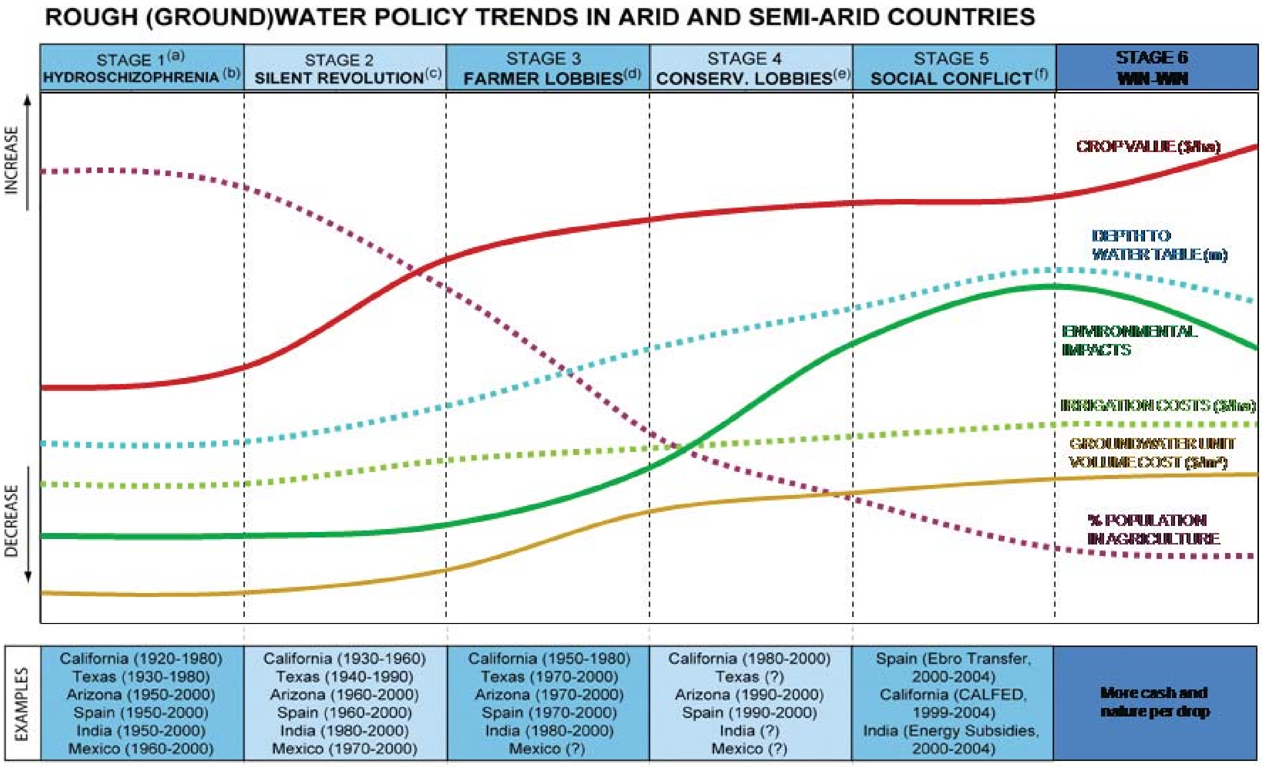
Figure 11. Land (and associated water rights) purchased in the periphery of the park.

The plan is an opportunity to re-direct agriculture towards a less water-intensive growth model, freeing up water for other users, or ecological functions. In fact, it could be argued that the National Park has acquired rights, (in line with first in time first in right). A key issue is the payments received from the Common Agricultural Policy (CAP), e.g. for cereals and also for alcohol production. The current process of CAP review and reform (CEC, 2010) for areas like the Upper Guadiana Basin is crucial because subsidies received by the CAP could be re-directed to other types of payment. Freeing up some of the water currently used for irrigation, could shift agriculture towards dryland farming and forestation with endemic (low water consumptive) species, which might have added value in terms of multifunctionality and carbon sequestration. Although this might not automatically mean less water consumption (Scanlon et al., 2007), it would result in a CAP focused on integrated rural development, eco-conditionality and environmental premiums (Table 2).

Table 2. Types of irrigated crops and prices (in red – the subsidies received in 2006 from the EU CAP)

needs irrig. crops	Total irrigation crops	(Euro/t)			Prod. (Euro/ha)	Econ. Prod. (GIS, CHG, 2008)	Farmers /ha (m3/ha)	Euro/L needs (Mm3)	UTAs*/ Mil (Euro/ha)	(Mill Euro)	(UTAs*)		L water
		Low	Aver.	High									
Cereal	Wheat	150	188	225	270.9	28,841	3,018	87	926	27	494	0.3	6
	Barley	130	163	195	270.9								
	Oats	140	175	210	270.9								
	Corn	143	147	215	346.5								
Veg.	Melon	122	196	270	0	16,422	5,027	83	6,666	109	6,425	1.3	77
	Tomato	-	367	-	0								
	Pepper	186	428	670	0								
	Garlic	934	977	1,020	0								
	Onion	57	98	140	0								
	Potato	-	177	-	0								
Others	Alfalfa	-	120	-	0	2,850	7,859	22	1,926	5	144	0.2	7
	Sugar-beet	53	51	50	0								
Vines	Vines	193	337	480	0	83,640	1,575	132	3,097	259	18,624	2.0	141
Total	**-**	**-**	**-**	**-**	**-**	**131,753**	**-**	**324**	**-**	**401**	**25,687**	**1.2**	**79**

*UTAs: Unit representative of the work of one farmer in one year all the day working in the farm.
(It is important to note that both vines and horticulture also receive CAP funding, but through indirect systems and also through Axis 1 Regional development funds.) (WWF-Spain, personal communication)



Source: Llamas and Lopez-Gunn (2010)

Figure 12. Evolution of conflict over groundwater resources towards 'win–win' solutions.

In this context, the Special Upper Guadiana Plan can be seen as a means to an end, a catalyst for change. It provides an opportunity for the gradual 'weaning' of the regional economy away from perverse external subsidies and also ensures that political rents are decoupled from water. At the moment, there is a clientelistic culture in the region, which is rent-seeking and has used the park as an excuse for subsidies. The shift increasingly is to ensure that public subsidies are ring-fenced as far as feasible for public goods (SEO/Birdlife and WWF-Spain, 2009). For example, shift the agricultural model towards reducing blue-water use with less irrigated cereals, and towards more high-quality vines, achieving true 'water savings', which are then kept in reserve for aquifer recovery. Also develop an agricultural model with a more sophisticated interplay between the conjunctive use of green and blue water (Vidal et al., 2009).

Results from the Bayesian network for the Western Mancha aquifer (2008–2027)

In a complex socio-ecological system, it is increasingly clear that the application of single measures from the Special Upper Guadiana Plan would not be effective. For example, key measures currently unfunded are those that focus on economic and social development and a programme for agricultural modernization and development. This is relevant because even if all groundwater rights were purchased as anticipated in the Special Upper Guadiana Plan, groundwater abstractions would not be reduced sufficiently if wells are not monitored, sanctions not executed, or the conditionality of CAP payments not overseen to ensure that groundwater abstractions stay within the given allocated quotas. The capacity of the organization created to manage the Special Upper Guadiana Plan and apply the measures (the Consorcio del Alto Guadiana) depends largely on available funding to execute the plan. Both funding and its use depend on political will, which thus becomes the main conditional factor for the future recovery of the aquifer. This was confirmed in a personal communication by the Director of the Consorcio del Alto Guadiana (November 2010).

In the context of the dramatic transformation of a socio-ecological groundwater-dependent system, and the six stages described in Fig. 12, the re-allocation of water towards more economically and water-efficient crops, which are also more socially equitable would represent the evolution from hydro schizophrenia to a win-win outcome for the environment and the socio-economic vitality of the region. An evolution from the formation of powerful farmers' lobbies asking for surface water transfers, to the consequent formation of powerful conservation lobbies, towards a final stage of reconciliation between social and environmental demands though 'win–win' solutions (Fig. 12).

Conclusion: from extrinsic motivation to intrinsic motivation: weaning the social system away from intensive groundwater use

The challenge is to change the current agricultural model where the social system in the short term is thriving at the expense of the ecological system towards a more balanced model, which aims to allocate

Table 3. Preliminary thoughts on a PES scheme bolted onto an alignment of 2013 CAP reform and river basin plans.

Crop	Current subsidy	Suggested PES
Cereal e.g. conversion to dryland wheat	180 euros/ha	Only available for dryland farming (green plusprima 50 e/ha carbon storage 50 euros desertification 50 euros for aquifer conservation
Vineyards	(through OCM)	Other (smaller) measures Green marketing (SEO)

water more equitably than at present between all users, including the biosphere reserve and the park itself. A process of socio-ecological restoration ultimately could have as its aim to develop a self-sustaining system (social, environmental and economic) through system re-design. In Europe the year 2013 – due to the CAP reform – presents a clear window of opportunity to create catalysts and tipping points in the re-design of the agricultural model. In the case of water in arid environments, facing strong competition between all users, moving away from the current trade-offs (and stand offs between sectors) requires identifying win–win solutions. In Spain the biggest challenge, therefore, will be to shift the paradigm, from 'more crops and jobs per drop' to 'more cash and nature per drop' (Llamas and Lopez-Gunn, 2010), and where the future reform of the CAP (and the wider context of World Trade Organization and increasingly regional or bilateral negotiations and agreements) will be pivotal. To put it simply, farmers and their behaviour whether to irrigate or not, is sometimes more heavily dictated or influenced by higher order systems and decisions like subsidies in Brussels (the EU) or protective fiscal barriers related to the World Trade Organization than by the rainfall regime.

The current Special Upper Guadiana Plan, which aims to re-allocate rights on the basis of environmental and social equity and justice, is an interesting experiment in the region. The downside is that the cost of the Plan is – in the current economic climate with an estimated budget of €5 billion over the period 2008 to 2027 for 2 per cent of the land in Spain –simply unaffordable by the national budget, even if the current economic crisis is overcome. But a parallel window of opportunity appears with the reform of the CAP. There is an opportunity under the concept of payment for environmental services (PES) and the rural development pillar of the CAP, to change the incentive structure away from irrigated agriculture by adding an environmental premium for dryland agriculture in the form of payments that include part of the payment for the services derived from soil conservation (Table 3).

A potpourri of visions is now available in the literature, with ideas and options under payment for environmental services and multi-functional agriculture (Wilson, 2010), with a more holistic vision on agriculture to produce not just food, but also 'clean water', the co-production of environmental and agricultural goods, and the re-direction towards a green economy model. As stated earlier, in the Upper Guadiana Basin this would be open to options like adding an environmental premium for dryland agriculture, e.g. green water credits, payments for soil conservation (although taking into account that the amount of rain-fed land doubles the irrigated area),

Photo credits: P. Zorrilla (2009); J.J. Rodríguez Barbero (2010)

Figure 13. Irrigated cereal farm and solar farm: growing cereals or Kwh.

for the training of rain-fed farmers on ecological rain-fed agriculture and green marketing, e.g. a label that certifies that the crop has been grown using only green water.

Other options are, for example, a 'climate adaptation fund' since Spain is a hot spot for climate change and the Upper Guadiana Basin has been identified as one of basins potentially most affected (Lopez-Gunn, 2009b). In preparation as a backstop adaptation measure even if predictions on climate change shift, would be a transfer of payments, that could be seen as part of a national adaptation and mitigation fund to pay farmers in rural areas to prevent desertification, and/or as investment in aquifers as green infrastructure (zero-cost storage for drought periods). Ultimately, it represents a growth model which inverts the existing incentive structure – paying for good behaviour instead of paying for not harming the environment – as well as the previous step of capacity building. This vision of a 'multifunctional' agriculture opens options. However, for this to be possible it has to go to the heart of the existing payment structure and deep inertias in the incentive structure for farmers to irrigate.

Buying water rights for both ecological and social equity reasons can be the key to opening the social consensus necessary for a change in the agricultural model towards a more diversified, self-sustaining 'green economy', which can in theory be bolstered by the reform of the CAP, with more emphasis on the rural development pillar. Equally, there would be a more diversified use of available blue and green water, e.g. re-allocating some existing water resources currently 'captured' by low-value irrigated cereals to free up water for the wetland itself (and associated tourism and the "experience economy" where consumers are ready to pay premium prices for various experience-aspects) and also for thermo-solar plants in the region. A new rural development model would aim to diversify the local economy, making it less dependent on large-scale irrigated farming. Instead, it would opt as a local farmer stated for 'growing kWh rather than maize', while also making more use of other economic sectors, like ecotourism, quality agricultural produce or payment for environmental services like carbon storage, exploring the water/energy nexus in its positive aspects.

The key is to be able to zoom in and shed light on options and finance schemes for self-sustaining green economic growth models. Most important is to make possible achieving the alignment of social and environmental systems, until now perceived in the local area as an impossible dream.

> Alice laughed: "There's no use trying", she said; "one can't believe impossible things"."I daresay you haven't had much practice", said the Queen. "When I was younger, I always did it for half an hour a day. Why, sometimes I've believed as many as six impossible things before breakfast".

By Lewis Carroll(1832-1898) – "Through the Looking Glass and what Alice Found There (1871) http://en.wikipedia.org/wiki/Through_the_Looking-Glass

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THE INDUS BASIN FLOODS OF 2010: THE COST OF AGRICULTURAL DEVELOPMENT?*

The great flood of 2010 in Pakistan was a bi-product of national decisions about water development and irrigation, integrally linked, to the social geography of the basin. In the short to medium term, the flood's acutest impacts are likely to be concentrated among households with fragile livelihoods. Post-flood focus should be on water drainage and targeting the most vulnerable. Resurrection of local government structures will help with future flood response. In Pakistan, the hydrological priorities have always been irrigation and power generation, but for future flood resilience, flood management needs to be an equal priority.

Key Words: flood management, hazards, hydrology, crisis, Pakistan, Vulnerability.

Introduction

The great Indus flood of 2010 and the unprecedented extent of the devastation resulting from it cannot be understood, or mitigated, in isolation from the 'routine' river management of the basin. The cultural, economic and social geographies of water use, distribution and regulation in the Indus basin are integral links in the causal chain of events that led to the disaster. The disaster is, therefore, deeply human in its genesis, even to the extent that the anomalous monsoonal pattern that triggered the floods may be linked to anthropogenically induced climate change – after all the weather anomaly observed in 2010 has recurred in a milder form about three times in the past decade, whereas it was seen only every few decades in the last century (NOAA, 2010a).

Our hope in writing this essay is that our brief work to examine the causes of the Indus flood will serve as an invitation to Pakistani water managers and their colleagues globally to critically re-evaluate their basic assumptions and procedures for river management, and perhaps lead to a greater integration of flood hazard and social vulnerability issues into water resources management. Here, 'vulnerability' is understood as a socially determined state of being where people are more likely to suffer damage from environmental extremes and are less able to recover from those extremes (Mustafa, 1998; Cutter, 1996).

The great floods of 2010 in the Indus basin of Pakistan have been declared the worst calamity to have hit the country in its history and to have hit the world in the 21st century. Although the death toll of more than 1700 (at the time of the writing of this manuscript) is relatively modest in comparison to other disasters such as the Asian Tsunami, the Kashmir earthquake or the Haiti earthquake, the scale of inundation and the material damage from the floods seem to be greater in scale than those three signature disasters of the 21st century combined (Giuliano, 2010). Furthermore with stagnant water in inundations zones becoming a major disease vector, the final indirect toll, especially of children and the elderly, is likely to be much higher.

* An earlier version of the paper was published in the journal 'Water Alternatives". The full citation for that paper is as follows: Mustafa, D. and D. Wrathall 2011. Indus basin floods of 2010: souring of a faustian bargain. Water Alternatives. 4(1): 72-85.

After a brief overview of the flood situation in Pakistan, we undertake a brief review of the literature on flood disasters to contextualise the Indus floods of 2010. In particular, we will be drawing upon the experience of flood hazards across the world to highlight the point that the Indus flood and the pattern of damage from it is an extreme example of something that happens with depressing regularity across the world. Following that, we outline our core argument that the Pakistani water managers have kept a sharp eye on the benefits that they could extract from the Indus basin rivers without regard for the hazards that are also integral to living in river basins. And the benefits from the Indus rivers have indeed been long term – from hydroelectricity from the two major dams in the basin (which provide 30 per cent of Pakistan's power needs), to the irrigation system sustaining agriculture (which accounts for 28 per cent of the country's gross domestic product [GDP]).

In between these benefits though, there are also the inevitable costs of manipulating the flow regimes of the Indus basin rivers. We argue that approaching the Indus rivers with a view to controlling and taming them is bound to fail. A better tactic would be to learn to adapt to the Indus basin's hydro-meteorological regime, particularly in view of the looming uncertainties from climate change. An adaptive flood strategy will not only involve different behaviour vis-à-vis the physical system, but also towards the social systems that depend on it. Greater attention to issues of differential vulnerability to floods and equity in the distribution of the irrigation system's benefits will be an integral part of a resilient, adaptive flood management strategy.

Overview of the flood situation

The 2010 flooding stems from a confluence of events associated with a warming planet. In July, when monsoon rain began in Pakistan, 2010 was already the hottest year on record, and high glacier runoff had already filled rivers to capacity (NOAA, 2010a). Evaporation rates over the hotter-than-average Indian Ocean soared, leading to especially active monsoon weather (PMD, 2010), and the oceanic phenomenon, la Niña, is thought to have exacerbated the severity of monsoon activity (NOAA, 2010b; Riebeek, 2010). As Michael Blackburn from University of Reading explains, both the fires in Russia and the precipitation activity in Pakistan were globally linked through an unusually strong polar jet stream, which stalled unprecedented levels of moisture over the Himalayas (Marshall, 2010; NOAA, 2010a), pouring into the Indus valley an unprecedented volume of precipitation (UN-OCHA, 2010).

Evidence of climatic changes cannot be deduced from a single meteorological event; nevertheless, the number of exceptionally heavy monsoons over India has doubled in the last 50 years, while at the same time moderate and weak precipitation has decreased (Pal and Al-Tabbaa, 2010; Goswami et al., 2006). South Asia is becoming more arid during dry seasons, and wetter during monsoons. In the Arabian Sea, data from the 1880s to the present indicate that in past decades severe cyclonic events have increased three-fold during intense cyclone months (Singh, 2010). In the past 15 years, Pakistan has directly received four considerable low pressure cyclonic systems, of similar orders of magnitude to this year's (in 1993, 1999, 2004 and 2007), as well as other lesser systems in 1998 and 2001 (Singh, 2010). Weather variability like we have witnessed this year may be part of long-term trends for the Arabian Sea.

By 22 July, 2010, record levels of rainfall had begun falling across Punjab, Khyber Pakhtunkhwa and Balochistan (PMD, 2010). Tens of thousands were immediately displaced, and up to a million more in the following week, as flash flooding surged through riverbeds and canals (UN-OCHA, 2010). Flooding started along major tributaries, overwhelmed flood barriers and spread through canals, and generally overwhelmed water management capacity, and eventually inundated large swaths of farmland (Ellick, 2010). By early August, flooding had reached the lower Indus valley, and red alerts were announced for the Sindh and Balochistan Provinces. According to Pakistan's National Disaster Management Authority, one-fifth of the entire area of Pakistan was submerged at the high water mark (Sayah and Desta, 2010), affecting 84 out of 121 districts (UN-OCHA, 2010). By August 31, Punjab, Sindh, Khyber Pakhtunkhwa and Balochistan Provinces along the Indus River valley were still flooded, and some 800,000 people were still physically cut off (UN-OCHA, 2010). Some levee surfaces, already saturated for nearly a month, began to deteriorate and burst, which exacerbated the crisis in several notable instances, as in the case of historic Thatta city where 95 per cent of the population, some 170,000 persons, were displaced (Tran, 2010).

By the first of September, though rain had largely ceased, contaminated flood waters continued to rise in the southern provinces (UN-OCHA, 2010), and roughly one million people in Sindh province alone were in the process of migrating away from submerged villages to higher ground, urban areas and camps for internally displaced persons (IDP) (UN-OCHA, 2010). Whilst some of the flooding was on account of the overwhelming of the levees and flood barriers, a considerable amount of inundation was also the result of the deliberate breaching of the embankments by irrigation authorities to keep regulatory infrastructure from suffering damage. This has been a cause of considerable controversy in the country and something we will discuss later on.

As of the last available figures, 1985 people had perished due to flooding; 18,074,850 persons were affected, 17 million of whom live in Sindh, Punjab and Khyber Pakhtunkhwa Provinces; and 1,744,471 homes were damaged and destroyed, displacing at least as many households (UN-OCHA, 2011; UN-HCR, 2010). At the national level, 5.3 per cent of health facilities were partially damaged, 11 per cent in Sindh and Khyber Pakhtunkhwa Provinces, seriously affecting health care capacity in those places (UN-WHO, 2011a, 2011b). Simultaneously, 10 million people were left with unsafe drinking water (MacFarquhar, 2010), expanding the epidemiological potential for the spread of water- and vector-borne epidemics. Cholera outbreaks were confirmed, as of mid-August, raising the alarm of a secondary health crisis (Al Jazeera, 2010), though rapid and costly interventions enabled health professionals to bring infection rates of measles, acute diarrhoea and acute respiratory illnesses to relatively normal levels by mid-December (UN-WHO, 2011b). Nevertheless, hundreds of deaths have been associated with infection spikes following floods (UN-WHO, 2011a).

The flooding affected 6.88 million ha of Pakistan's most fertile valleys, destroying 2.4 million ha of standing crops, 24 per cent of the 9.7 million ha sown in 49 of 81 flooded districts (UN-FAO, 2011; SUPARCO, 2011) with total damage estimated at US$2.9 billion to the agricultural sector alone (Hicks and Burton, 2010).

With agricultural production and food distribution systems disrupted, food prices spiking, and household economies ruined, the spectre of food insecurity has taken physical shape (UN-WHO, 2011c; MacFarquhar, 2010). Much of the country's power infrastructure was also severely affected, including some 10,000 transmission lines, hundreds of transformers, 7 major power stations, and 150 substations. By mid-September, the country had only regained 70 per cent of its capacity (Arsahd, 2010).

Future planting seasons seemed to have been placed in serious jeopardy due to poor drainage (WFP, 2010), and whilst at the time of writing costly interventions have partially mitigated the destabilizing effect of failed crops and food shortages (UN-WHO, 2011c; UN-FAO, 2011). There were considerable initial fears of the wheat crop failure, but as a result of the alluvium deposited by the floods, Pakistan has experienced unprecedented bumper wheat harvest in the spring of 2011, reminding us of the economic benefits that flood pulses can bring to society.

The brunt of the impacts have been borne by the most vulnerable and impoverished populations in low lying areas: the farming communities in the relatively remote districts of northern, central and southern Pakistan. With farmland trapped beneath water and silt, and at least 1.6 million head of livestock dead (WFP, 2010), small-scale and subsistence agriculturalists and cattle herders are especially sensitive to, and least able to cope with, impacts. According to earlier research on flood hazards in Pakistan, livestock is a key asset used for recovery in the aftermath of floods, and the loss of as much livestock is likely to stretch the Pakistani rural livelihood and recovery systems to the limits (Mustafa, 1998).

According to the International Monetary Fund (IMF), the total economic impact of flooding on rural livelihoods, agricultural output, industrial input and infrastructure, including lost economic productivity, are expected to total US$43 billion, raising the possibility of financial insolvency (AFP, 2010). Already deeply indebted, Pakistan will have to make tradeoffs in order to recover from the impacts and, inevitably, discussions will occur around scaling back essential social services, including education, rural healthcare and poverty reduction programmes. As government priorities drift toward flood response, rehabilitation and reconstruction, many expect elusive development goals to slip farther away still (WFP, 2010; Crilly, 2010; Conway, 2010).

Indus floods in a comparative context

Extensive river engineering on the Rhine River in Germany to improve navigation and for flood control, based upon the design and engineering insights of the German military engineer J.G. Tulla, provide one of the earlier examples of modern flood protection (de Bruin, 2006). Contemporary flood management, however, was largely influenced by the U.S. Army Corps of Engineers' attempts at river engineering in the Mississippi, Colorado and Tennessee River valleys for flood protection in the early 20th century (Platt, 2006). The river engineering paradigm for flood protection was built into the experiment in integrated water management for regional development in the form of the Tennessee Valley Authority (TVA) in the 1930s, which was actively marketed by the U.S. government overseas during the Cold War (Pelling, 2001; Schulman, 1994).

Modernist, engineering approaches have preferred technological, infrastructural adaptations to hazards – like flood barriers, reservoirs, canals and barrages – that could influence the risk equation by limiting exposure and serve as survival buffers between societies and the homeostatic limits of the natural environment (McLaughlin and Dietz, 2008; Mustafa, 2005). Like biological organisms, societies were thought to deterministically adjust to adverse environmental conditions through linear stages of technological interaction with the environment, whereby they developed the capacity to control nature (McLaughlin and Dietz, 2008). This deterministic view – that development ought to transform environmental threats into opportunities – proved to be highly exportable, and thus modern flood management was born (Pelling, 2003).

Armed with the modernist engineering techniques and the doctrine of economic growth and development, international financial institutions and donor countries – including the Tennessee Valley Authority administrators – began to promote and finance mega-projects, like the 1960 Indus Basin Development Project (IBDP) in Pakistan and the Helmand-Arghandab Valley Project in neighbouring Afghanistan. This international, one-size-fits-all engineering approach to hydrological mega-project spread to developing countries around the globe, in spite of important regional peculiarities (Jacobs and Wescoat, 1994). With plans drawn as early as the 1950s, similar agreements in other regions paved the way for similar projects. Corpus Itaipu River Agreement was signed among South American countries in the La Plata Basin; the Mekong Hydropower Development Strategy in South East Asia; and the Zambezi Southern African Development Community, among others (McDonald and Ruiters, 2005; Bakker, 1999; Lee, 1995).

These water projects, while credited with transforming developing countries into the world's producers and exporters of commodities like wheat and cotton, are also generally critiqued for their environmental impacts. Depending on the level of intervention, water engineering can transform water systems from flourishing ecosystems with an array of natural ecological functions that benefit human economic activities (including soil nutrient regeneration, groundwater regulation and natural flood resistance) into water resource conveyor belts. Species biodiversity plummets in the face of habitat destruction, and consequently the benefits of speciation on environmental quality are lost. Soil erosion increases, grazing land disappears and water-borne disease proliferates. In addition, the nature of riverine sediment aggradation and erosion processes changes in engineered systems, which can result in accentuated flood events. Some of these

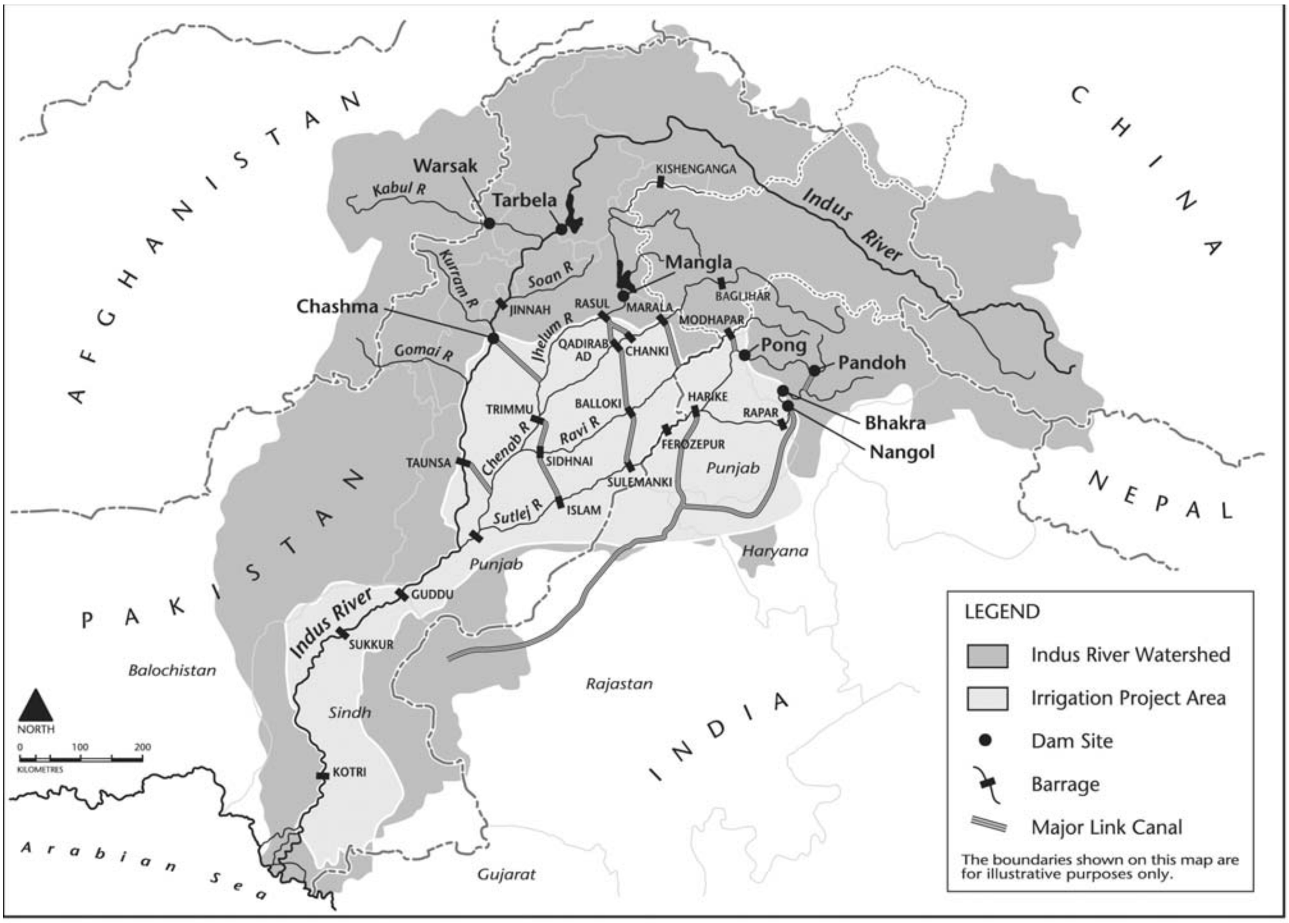

Figure 1

consequences in the case of the Indus were even recognised under the British colonial administration, but were generally deemed to be the price of development (Whitcombe, 1982, 1995; Michel, 1967)

Questions also arise about the relevance of large-scale projects to goals of poverty reduction. In social–ecological coupled systems, upon which many of the world's poor depend for livelihoods, engineering projects can exclude and marginalise the vulnerable poor whose livelihoods are already sensitive to shocks. So much of rural, subsistence agriculture in developing countries is based on flood recession irrigation. Famous examples from Africa, both the Kainji Dam in Nigeria and the dams on the Lower Omo River in Ethiopia, have resulted in massive disruptions to flood recession agriculture livelihoods, on which hundreds of thousands of vulnerable poor depend (Drijver and Marchand, 1985). Other examples from Africa, for example the Manantali Dam in Mali, illustrate the disruptive nature of canals and reservoirs to rural pastoralists' grazing routes and the pastures, watering sites and other ecosystem services that they depend on (DeGeorges and Reilley, 2006). Not only are the poor excluded by technology, but their livelihood vulnerabilities are exacerbated. In addition, their governments' capacity for delivering upon the social goals of development (such as education, healthcare and basic services, to say nothing of social safety nets) are constrained due to the orientation of national budgets around paying the tremendous costs of such projects. Moreover, developing countries, like Pakistan, whose rural livelihood systems, infrastructure and economies are utterly transformed, become increasingly vulnerable not only to flooding events, but also to fluctuations and shocks in international commodity markets. Market-led growth in the absence of social programmes has another consequence; the climbing disparity of wealth between the haves and have-nots, who, incidentally, became the most vulnerable to riverine flooding. The point here is not that societies like Pakistan should revert to flood recession agriculture, but rather there should be greater attention to equitable distribution of the benefits of water development as well as protection from the hazards that are accentuated by virtue of these projects.

The relationship between anthropogenic environmental degradation and catastrophic flooding in Asia, Latin America, Europe and other regions is well documented (Gregory, 2006; Wisner et al., 2004; Smith, 2001; Alexander; 1992). Conversely, we know there is an established link between healthy watersheds with flow capacity – wetlands, marshes, estuaries and mangroves – and flood mitigation (DEFRA, 2002). Since disasters have been shown to be costly to long-term development goals, questions are raised about the need to invest in risk reduction and, with the rising challenges of climate change, we must ask ourselves, Can our engineered systems keep pace with climatic trends?

Flood policy and actuality

Pakistan benefits from an extraordinary water supply originating mainly with swift-flowing glacial melt from the Himalayas in late spring, and monsoon activity between June and October. To take advantage of this tremendous resource, the country has been highly engineered in hydrological terms (Fig. 1), with irrigated areas representing 82 per cent of all farmland, and 43 per cent of the population of 170 million directly dependent on farming activities (Wescoat et al., 2000; Mustafa and Wescoat, 1997). However, irrigated areas are exposed to flooding hazards, and consequently, the largest sector of the economy and the majority of Pakistanis are vulnerable (Mustafa and Wescoat, 1997). Additionally, many villages are situated on river terraces, or in low-lands, and urban migrants tend to informally settle in low-lying high risk areas (Mustafa, 1998, 2005). As the great flood of 2010 has illustrated in vivid detail, floods are typical in the five major rivers of the Indus River basin. Twenty major floods, and many more minor floods have occurred in the fifty years from independence in 1947 to 1997. The irrigation system in Pakistan has created a new geography of who is vulnerable to floods and to what extent. Its benefits are incontrovertible, but hazards that are accentuated by the system, somehow do not draw much attention.

The development of Pakistan's flood management system can be characterised by two dominating approaches and two corresponding periods – 1947 to 1973, a period of risk acceptance and limited risk management – and 1973 to the present, a period of comprehensive physical risk management (Mustafa and Wescoat, 1997). Although flood irrigation techniques had dominated farming along the Indus River since pre-historic times, the original canal network, upon which the current system is based, was conceived and executed under British colonial rule beginning with the Upper Bari Doab Canal in 1859. Throughout the colonial era, the system was maintained and expanded, such that on the eve of independence there were 150 major canals extending thousands of kilometres throughout the country. The colonial approach to flood management depended on a network of bunds (linear levees along rivers and ring levees around cities), which the army could strategically breach when waters approached flood stage. During periods of high water, barrages and cities with bunds were protected, but massive flooding would occur in breach areas and regions without protection from bunds. The general public had little influence on flood management, although public opinion in affected areas fell decidedly against risk acceptance. The bund system of flood management was carried forward after independence. In 1960, the IBDP, a colossal engineering project signed into existence with the Indus Waters Treaty between India and Pakistan, refashioned much of Pakistan's vast countryside into an extensive network of canals and reservoirs. The focus of flood planning was shaped, through the lens of the Indus Waters Treaty, on protection of the valuable diversion and storage infrastructure that had been constructed in the basin. Upon completion of IBDP in 1970, Pakistan's agricultural production expanded substantially. However, shortly thereafter, in 1973 when massive flooding generally overwhelmed the canal network, the risk management paradigm shifted. Vulnerability of the system was revealed, as well as the resource and experiential constraints of regional flood managers in dealing with newly engineered canals and reservoirs (Mustafa and Wescoat, 1997).

In 1978, the Federal Flood Commission was established to implement a comprehensive risk management strategy, the National Flood Protection Plan. The tool kit of the new strategy included greater resources for reservoir operations, including procedures, inspections and training, schedules for bund maintenance and reinforcement and bund breaching plans, expansion and modernization of data collection techniques, including satellite monitoring, and runoff modelling and flood forecasting, as well as the implementation of a flood warning system (Mustafa and Wescoat, 1997). In spite of these improvements to the flood management system, weaknesses remained evident, and flooding events disastrously re-occurred, most notably in 1988 and in 1992. Mustafa and Wescoat (1997) noted several institutional limitations to adequately addressing the fundamental issue of flooding. First, a failure to adapt the system to natural processes, like aggradation and erosion, was causing a mismatch between river flow measures and actual hazards. Of the 144 million acre feet (MAF) of water entering the system about 106 MAF is withdrawn for irrigation purposes, leaving little water in the system to flush the channels and carry the highest silt loads in the world to be flushed out to the sea. This long-term reduction in channel capacity to carry floods was one of the key reasons for exacerbating the effects of the exceptionally high floods in 2010. Moreover, monitoring stations were, in some instances, unable to take measurements and report them in a timely fashion due to their own physical location relative to flooding. Even when measurements were taken and alerts were issued, public warning, evacuation and safety measures, in some cases, were ineffective and haphazard. On the flood management side, canal and reservoir operators were not empowered to make important split-second decisions about flow adjustments that would attenuate flood hazards, and in some cases reservoir managers, for lack of system coordination, released waters exacerbating deadly downstream flows.

Besides the systemic weaknesses at the macro scale, the negative consequences of flood hazard at the local scale are often disproportionately experienced by the poor and most powerless segments of the population (Mustafa, 2002a, 2002b, 1998). Spatially, because of canal colonizing policies practiced by the British colonial administration and then the post-independence Pakistani government, which were often exercises in hierarchical social engineering, the small farmers were often disadvantaged by virtue of being at the low-lying tail end of canal commands (Gilmartin, 1994, 1995; Michel, 1967). Beyond the spatial disadvantage, the canal administration system has a strong colonial ethos in its enabling legislation and bureaucratic practices that discriminated against smaller farmers in terms of redress of complaints, water delivery and the all important levee breaching decisions (e.g. see Mustafa, 2001; Gilmartin, 1994; Ali, 1988). All the infrastructure on the Indus basin rivers has a safe design capacity, which has been exceeded quite often in the past (Mustafa and Wescoat, 1997). To protect the infrastructure the levees upstream are often breached to relieve pressure. The operation of the breaching section is a decision taken by the local canal officer, but that canal officer is often under the influence of local large farmers (Mustafa, 2002c). In such situations it becomes a question of which large farmer has the most influence to either prevent a levee breach or to affect the breaching of an alternative levee breaching section. There are accusations in the Pakistani press that in fact, some of the levees were breached to protect the lands of specific influential interests (e.g. see

Rodriguez, 2010). The veracity of the media claims is under judicial investigation, but suffice it to say here, that political influence in levee breaching decisions is a routine occurrence in Pakistan, and given the stakes involved it may be a perverse way of ensuring public oversight over technocrats in the absence of other mechanisms for ensuring public oversight.

Dispelling a few myths

So what can one expect to change in the aftermath of this mega-disaster in Pakistan? One may be tempted to say that nothing will change given the more than a century and a half of institutional inertia on part of the Pakistani water establishment. But changes in the aftermath of a disaster of this magnitude are not always planned and deliberate and not limited to formal governmental institutions (Wisner et al., 2004). One-fifth of Pakistan's population has been affected by this disaster and to pretend that somehow after a while they can go back to normal is unlikely. The new normal is likely to be very different from the old normal, and whether that normal will be for the better or worse is something that the Pakistani and international decision makers can affect and need to be attentive to. As documented before, in Pakistan the normal conditions for the rural poor are characterised by their virtual invisibility to the decision makers, limited access to water, subjugation to larger landowners and fragile livelihoods (Mustafa, 2002a, 2002b, 2002c; Dove, 1994). But those same normal conditions also have stories of adaptation to adversity, creative exercise of agency and of social mobility on part of some (Mustafa, 2004, 2002a). The point is to strengthen the latter to mitigate and undermine the former. Dispelling of some misconceptions and pointing out avenues for intervention might be in order to achieve that end.

In the post-flood period the greatest urgency is dedicated to the usual basic needs, such as food, shelter and clean drinking water. But two key issues have not yet received much attention – the first is drainage, and the other is targeted assistance to small farmers and the rural poor. First, the issue of drainage is going to be key – after all, according to Pakistan's National Disaster Management Authority (NDMA) as of December 2010, more than four months after the river floods subsided, up to 421,000 ha of land is still inundated in southern Sindh Province (Reliefweb, 2010). Most of the flooding in Pakistan is from breaching of embankments, which typically occurs on the right bank of the rivers, to allow water to drain right back into the river once the flood peak has subsided. In Pakistan the density of canal, road and levee development means that water that has entered the inundation zone has its drainage path back to the main-stem river interrupted by levees, roads, railways lines and canal embankments. The result is that the water does not drain back, becoming a cesspool of diseases and preventing return of those affected for long periods of time. Drainage or even pumping of water – if need be – from such inundation zones should be a high priority, but there is no evidence to suggest that that is being done or was even attempted. Water if drained before the winter sowing season, could give a sporting chance to displaced people to get back on their feet. Delay in water subsidence has consequences not just for livelihoods, but also for the proliferation of diseases and mortality levels. The drainage of flood water should not just be an episodic reactive measure, but should be a higher priority in infrastructure design or redesign and modification.

Second, the Pakistan Government, like most other governments inevitably deals with aggregate numbers when it comes to relief and rehabilitation aid. The need here is to specifically target small farmers who, with the loss of livestock and summer crops, are particularly vulnerable. There have not been any systematic vulnerability assessments in Pakistan, except some piecemeal ones undertaken by a few NGOs. The need is for there to be systematic vulnerability assessments using some of the insights from recent literature in vulnerability assessment (e.g. see Mustafa et al., 2010; Anderson and Woodrow, 1989). But in the interim, local level governance structures that used to exist, may be resurrected, even if briefly, in order to get the local level knowledge to national and international level agencies so that they can target the most vulnerable. There is a sufficiently robust moral economy in rural Pakistan to provide some level of support to the rural poor, but that moral economy has been strained to its limits and is in need of support.

On the institutional side, the Government of Pakistan (GoP) – as usual – has received considerable criticism for its slow response to the disaster. While the GoP merits criticism on many, many counts, in the context of flood response much of the domestic and international attention is unfair. First, the extent of the disaster is such that any government in the world could not have fulfilled the type of retrospective expectation that the press and the public seems to have attached to GoP's response. Second, all over the world the local level is the first and the most appropriate level for responding to environmental disasters, not the national government. The present 'democratic' government unfortunately and ironically has eviscerated local-level representative government. In 2001 General Pervez Musharraf's government introduced the most substantial devolution of powers to the local level with the formation of elected local government structure. The present elected civilian government has reversed those reforms and reverted to a more centralised bureaucratic mode of local governance. Third, disaster response in Pakistan is constitutionally a provincial subject, and not a federal subject. The federal government has no constitutional basis to intervene in disaster response unless requested by the provincial government; and, when it is requested the only institution it has to offer is the armed forces – which by all accounts is effectively delivering services (Haider, 2010). So the criticism that the military is doing everything and the federal government is doing nothing is incomprehensible. Fourth, even at the provincial government level, populations and geographical areas are so enormous that the functionality of a federalist structure to ensure more efficient devolved government would not hold. Consider that just the Punjab Province in Pakistan has a population of more than 90 million. If it were a country by itself, it would be one of the 15 most populous countries in the world. In the absence of local government structures, which the present provinces themselves have eliminated, their efforts for flood relief were also inevitably inadequate.

Conclusion: towards vulnerability mitigation

Flood policy in Pakistan has been somewhat of a peripheral area for Pakistani water managers, and their interest has been limited to concerns with physical risk and exposure reduction. On the physical risk management side, the priority for dam and barrage management has always been irrigation, power generation and then flood control as an afterthought. There is an urgent need for Pakistani water managers to be trained to undertake multi-criteria management of the system, where long-term flood management is a priority on a par with other priorities. The managers, if trained and given the autonomy, could operate infrastructure in such a way as to flush channels and reduce the need for costly levee breaching during flood events.

Secondly, Pakistani water managers need to be sensitised to the need for adapting to the rhythms of the Indus basin rivers, instead of maintaining the attitude of heroic engineering to control the rivers. Allowing some inundation zones and restoration of wetlands could go a long way towards moderating high flood peaks, in addition to providing important ecosystem services, such as groundwater recharge, carbon sequestration and biodiversity benefits, which the poor tend to benefit from the most. People living in such inundation zones could be relocated to newer canal colonies after fair and just compensation. A key issue in this regard is the disciplinary training of Pakistani water managers. Pakistani water bureaucracies are almost entirely staffed by trained civil engineers, with an odd hydrologist in the central offices. There is a need for a greater number of trained geomorphologists, hydrologists and even social scientists and public administrators in institutions such as the Water and Power Development Authority (WAPDA) and provincial irrigation departments (PIDs) to balance the overwhelmingly engineering ethos of these institutions.

Thirdly, exposure reduction and flood warning systems could also be improved. Pakistan has some of the highest cell phone penetrations in the world – 86 per cent of the men and 40 per cent of the women in Pakistan use one (Qamar, 2009). The cell phone penetration could be effectively used as a conduit for emergency information and warning.

Fourthly, the Pakistani public needs to be educated about flood response strategies and what is expected of them. Greater communication and trust between the flood managers (e.g. WAPDA, PIDs and the military) and the people is the ultimate guarantee of safety.

It is appropriate that the federal government of Pakistan should limit itself to undertaking technical assistance to the provinces and then physical assistance if need be through the NDMA. But the NDMA has a very small budget during normal times and has dubious constitutional authority to intervene in disaster situations. Those constitutional and budgetary issues should be resolved.

However, for long-term flood hazard mitigation, there is no alternative to being attentive to issues of how to reduce vulnerability. At the national level, this flood could provide the impetus for the GoP to undertake some painful but necessary tax reforms to bring larger segments of privileged Pakistanis' income into the tax net. With a tax to GDP ratio of only 10.2 per cent, the long-term ability of the government to devote resources to vulnerability mitigation and development is likely to be very limited (Chaudhry, 2010).

Lastly, representative and accountable local-level governance structures are a must to tap information about vulnerable populations and then to target them. International donors and the Government of Pakistan could fruitfully engage the Pakistani provincial governments to restore local-level governance structures so as to facilitate local-level development, as well as vulnerability mitigation.

The 2010 floods have been a disaster, but the disaster can be used strategically to build better and to address the problematic social and physical factors that contributed to it in the first place. Climate change may not have been a top priority for the Pakistanis, but with anomalous meteorological events becoming alarmingly frequent, it is important that Pakistani managers start being attentive to a future world where their past experience of mean conditions is not going to hold. The water infrastructure in Pakistan has designed capacities based upon historical trends (Mustafa and Wescoat, 1997), which are unlikely to hold in the future. Consequently, it is unlikely that the infrastructure will be able to withstand the challenges that may be in store because of climate change. That means managers will have to rework operating procedures and their managerial outlook. Vulnerability reduction is the best defence they can have against future uncertainty and that is where they need to focus. Hopefully this intervention, coming fresh in the aftermath of a disaster, will serve as a reminder to focus on vulnerability, adaptation and even some humility in the face of river systems like the Indus.

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BIOGRAPHIES

Dr. Rita Colwell

Dr. Rita Colwell is Distinguished University Professor both at the University of Maryland at College Park and at Johns Hopkins University Bloomberg School of Public Health, Senior Advisor and Chairman Emeritus, Canon US Life Sciences, Inc., and President and CEO of CosmosID, Inc. Her interests are focused on global infectious diseases, water, and health, and she is currently developing an international network to address emerging infectious diseases and water issues, including safe drinking water for both the developed and developing world. In 2010, she received the Stockholm Water Prize for her pioneering research on the prevention of waterborne infectious diseases, which has helped protect the health and lives of millions of people worldwide.

Dr. Michelle Perez

Michelle Perez is a Senior Associate for the World Resources Institute's Water Quality Team. She leads a nutrient trading feasibility study in the Mississippi River Basin and a national Farm Bill environmental performance improvement project. Michelle received a doctorate in environmental policy from the University of Maryland School of Public Policy. Her dissertation is a three-state comparative case study of agricultural regulations in Delaware, Maryland, and Virginia. She has a Masters degree in environmental policy from Maryland and a degree in biology from Occidental College. Michelle also serves as President-Elect of the Soil Water Conservation Society's National Capital Chapter.

Mr. Allestair Wensley

Allestair Wensley has a degree in Civil Engineering from the University of the Witwatersrand (Johannesburg). He is a registered Professional Engineer in South Africa and a Chartered Civil Engineer with the Institute of Civil Engineers in the UK.

Allestair is a Chief Engineer within the Water Services Branch (community water supply) in the Department of Water Affairs, South Africa. He has extensive knowledge in the planning and development of sustainable rural water supply projects and specialist knowledge in the planning, development and deployment of engineering related information systems. He initiated the establishment of the Water Services National Information System (www.dwaf.gov.za/dir_ws/WSNIS).

Mr. Eddie Delport

Eddie Delport is a qualified Civil Engineer with an MBA. Early in his career he moved to municipal engineering and at Stellenbosch Municipal Council he distinguished himself as an innovator and a leader in the water and sanitation field and township development, presenting papers at several international conferences. He led the SALGA Technical Team in formulating the Strategic Framework for Water Services and represented the Institute of Municipal Engineering in Southern Africa at various forums and projects.

He currently teaches Project Management and Engineering Economy at the University of Stellenbosch and is a specialised consultant in water management services.

Mr. Grant Mackintosh

Grant Mackintosh is an experienced water utilization engineer in non-metro water services, water quality management, water treatment, capacity development, regulatory and cooperative governance. Grant has played a leading role in the research, development and implementation of municipal water quality management systems in South Africa. His company, Emanti Management, developed an electronic Water Quality Management System, eWQMS, which has received both national and international recognition. This system has added value to the South African community via the significant enhancement in efficiency of water quality management by local government, provision of information to water services sector partners, and raised awareness of the public.

Dr. Monique Dube

Dr. Monique Dubé is a Canada Research Chair in Aquatic Ecosystem Health Diagnosis at the University of Saskatchewan, Canada. Her area of expertise is integrated water resource management and watershed-scale cumulative effects assessment. She has published over 180 contributions, is the recipient of numerous awards, and her research has influenced policy, regulation, environmental impact assessment practices, and cumulative effects assessments for freshwaters. She serves on Scientific Advisory Panels for national and international (including UN) agencies. Her THREATS software is an exceptional contribution for defining a diagnostic process for assessing and managing watersheds towards sustainability.

Dr. Nicole Nadorozny

Dr. Nadorozny is a Landscape Ecologist whose research focuses on understanding landscape level influences on ecosystem processes. Her multidisciplinary approach branches fields of ecosystem science, spatial ecology and environmental geochemistry. Her work is focused on understanding how space and time influence patterns and trends in ecosystem structure, with specific applications to river water quality and quantity. Dr. Nadorozny provides the fundamental scientific leadership for Dr. Dubé's river research programs across Canada. Her current work is focused on the development of frameworks for effects based assessments within a Cumulative Effects Assessment (CEA) context across watersheds and for effects-stressor linkages within landscape-watersheds.

Ms. Allison Squires

Allison Squires is a PhD Candidate at the Toxicology Centre, University of Saskatchewan, Canada under the supervision of Dr. Monique Dubé. Her PhD research focuses on developing and implementing a watershed-scale framework for cumulative effects assessment using the Athabasca River in Alberta, Canada as a model river. She completed her MSc in Aquatic Toxicology at the University of Saskatchewan, and her BSc in Environmental Toxicology at the University of Guelph. She has presented her research at both national and international conferences and has received several awards for her presentations and research.

Dr. Peter Gleick

Dr. Peter H. Gleick is president of the Pacific Institute in Oakland, California. His work addresses the critical connections between water and human health, the hydrologic impacts of climate change, sustainable water use, privatization and globalization, and international conflicts over water resources. Dr. Gleick was named a MacArthur Fellow in October 2003 for his work, dubbed a "visionary on the environment" by the British Broadcasting Corporation in 2001, and in 2006 elected to the U.S. National Academy of Sciences. D.C. Gleick received a B.S. from Yale University and an M.S. and Ph.D. from the University of California, Berkeley and is the author of 8 books and many scientific papers.

Ms. Meena Palaniappan

Meena Palaniappan directs the International Water and Communities Initiative at the Pacific Institute. An engineer with more than 15 years experience in community-based environmental planning, Ms. Palaniappan has worked extensively on water, sanitation, and hygiene issues internationally including in Mexico, East and West Africa, and India. Previous projects include documenting successful water management worldwide, planning for future water infrastructure needs, and Peak Water. She is currently leading projects on a Community Choices decision-support tool (www.washchoices.org), and improving the resilience of communities to climate change induced water insecurity. She has degrees from UC Berkeley and from Northwestern University.

Prof. Patricia Burkhardt-Holm

Since 2003, Patricia Burkhardt-Holm is a professor of Ecology and heads the Institute Man-Society-Environment at the University of Basel (Switzerland). Before, she was director of a nation-wide project on fish catch decline (Fischnetz). Her research focuses on aquatic ecosystems, particularly on fish and the impact of natural and anthropogenic factors (e.g. endocrine disruptors, climate change). She is member of several national and international commissions and scientific boards and is Swiss delegate in the Scientific Committee of the International Whaling Commission. She initiated and co-chairs the curriculum commission of the interdisciplinary Master course in Sustainable Development at the University of Basel.

Prof. Takashi Asano

Takashi Asano is a Professor Emeritus at the University of California at Davis. Dr. Asano has more than 40 years of academic and professional experience in environmental and water resources engineering. He has conducted water reclamation and reuse studies at the California Water Resources Control Board in Sacramento and the University of California at Davis.

Professor Asano served as a member of the steering committee for the World Health Organization's Guidelines for the Safe Use of Wastewater, Excreta and Greywater. Professor Asano is the 2001 Stockholm Water Prize Laureate, the members of the European Academy of Sciences and Arts, and the IWA Council of Distinguished Water Professionals.

Ms. Akiça Bahri

Akiça Bahri is the Coordinator of the African Water Facility, African Development Bank, Tunis, Tunisia. Dr. Bahri has academic and professional experience in water resources management. Her specialization is in the area of agricultural use of marginal waters (brackish and wastewater), sewage sludge and their impacts on the environment. She has been working for the National Research Institute for Agricultural Engineering, Water and Forestry in her home country Tunisia. She had been a member of IWMI's Board of Governors before becoming the IWMI Director for Africa. She is a member of different international scientific committees and has received international honors.

Dr. Arno Rosemarin

Arno Rosemarin PhD is Senior Research Fellow and currently Research and Communications Manager within the EcoSanRes Programme at Stockholm Environment Institute. Arno is an aquatic biologist with a research background in limnology, eutrophication, ecotoxicology and ecological sanitation. Since 2003 he has been working on the introduction of dry sanitation systems in urban communities and also the topic of global phosphorus reserves and methods to close the phosphorus nutrient loop in sanitation systems with agriculture. In 2009 he was selected to be a member of the World Academy of Art and Science.

Mr. David Osborn

David Osborn was recently appointed as the Coordinator of UNEP's Ecosystem Management Programme. Prior to this he was the Coordinator of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities. A formal Officer of the Royal Australian Navy, David has also worked with the Australian Government's Department of the Environment and Water Resoruces as the Director, Water Quality, and Director, Coastal Policy, and the Great Barrier Reef Marine Park Authority. He has served as an Adviser to the Australian Government's Minister for the Environment and holds degrees in Environmental Science and Environmental Law.

Mr. Björn Stigson

Bjorn Stigson had a long career in international companies, among others as CEO of the Fläkt Group and Executive Vice President of ABB. He is a member of a number of boards/advisory councils, among others, Prince Albert II of Monaco Foundation; China Council for International Cooperation on Environment and Development; Energy Business Council of the International Energy Agency (IEA); America's Climate Choices Initiative of the US Congress, the Veolia Sustainable Development Advisory Committee and the Siemens Sustainability Advisory Board.

Mr. Joppe Cramwinckel

As Director for the Water Project at the World Business Council for Sustainable Development (WBCSD), Joppe Cramwinckel coordinates the implementation of an enhanced water programme in support of responsible water management. Before joining the WBCSD in 2010 he worked as Issue Manager for Water at Shell, which he joined in 1985, where he was, among others, the driving force behind the development of the WBCSD Business in the World of Water scenarios. Joppe is a member of a number of Advisory Boards and Advisory Councils including the European Water Partnership and the World Water Week in Stockholm, and is a member of the Supervisory Council of the Water Footprint Network.

Dr. Jiri Marsalek

Dr. Jiri Marsalek is research scientist and Head of the Urban Water Management Section at the National Water Research Institute, Environment Canada, in Burlington, Ontario. His research interests focus on the sustainable management of the urban water cyle. He serves as secretary of the International Association for Hydro-Environment Engineering and Research (IAHR) & International Water Association (IWA) Joint Committee on Urban Drainage and has worked extensively with UNESCO and NATO on urban water management. His recent awards include Environment Canada's Citation for Excellence (2005), two honorary doctorates from Sweden (2006) and Denmark (2008), and the IWA Honorary Membership Award (2010).

Prof. Maria Viklander

Prof. Maria Viklander, is Professor in Urban Water at Luleå University of Technology. She has a Ph.D. in urban water engineering (1997) and thesis focused on snow quality in urban areas and the paths of pollutants in urban snow deposit. Her research interests encompass broad aspects of urban water, ranging from water quality and quantity to management and strategies. She has served as a co-ordinator for a number of research projects, and organised many workshops and seminars. She chairs the Working Group on Urban Drainage in Cold Climate, under the IWA/IAHR Joint Committee on Urban Drainage.

Mr. Moses Masah

Moses Massah was born on 05 November 1959 in Liberia. He obtained a B. Sc. in forestry in 1985 and M.Sc. in regional planning with emphasis on environment/natural resources management in 2003 from the University of Liberia. Since 1985 Moses Massah has worked in many capacities including Lecturer of forestry and environmental planning and management, University of Liberia, Project Coordinator, Environmental Foundation for Africa, Program Officer/Natural Resource Management, Catholic Relief Services Liberia, Moses Massah joined the UNDP in Liberia in 2007 as Program Manager for Energy and Environment and was appointed as Programme Specialist in October 2010.

Ms. Chantal Richey

After 15 years working for a multinational corporate in the support services sector Chantal Richey changed gear to embark on a different career path and joined charitable sector. She is a leader with 20 years experience in post conflict, developing and developed nations in Africa in the private, humanitarian and development sectors. She has served in Liberia with Tearfund and Oxfam Great Britain in programme leadership. She is an expert in establishing and managing consortia and coordination in both the emergency stage and the post conflict transition and holds a Master of Science degree from Cranfield University, School of Applied Sciences.

Dr. Elena Lopez-Gunn

Dr Elena Lopez-Gunn is a Senior Research fellow at the Botin Foundation Water Observatory at the Universidad Complutense Madrid, where is currently leading a project studying collective action on groundwater. She is also a Visiting Senior Fellow at the London School of Economics and Political science and Associate Professor at Instituto Empresa. She was an Alcoa Research Fellow at the LSE Grantham Research Institute, where she was engaged on applying a rights based approach to Water in Bolivia. Her interests focus on governance aspects of water management, particularly the institutional analysis of different aspects related to collective action dilemmas at different scales.

Dr. Pedro Zorrilla Miras

Dr. Pedro Zorrilla Miras, PhD in ecology and environmental sciences, holds a Dipl.-Eng. degree in landscape and spatial planning. His current research fields are biophysical quantification of ecosystem services, ecosystem services and natural capital mapping, adaptive water management and public participation in natural resources management. His PhD research focused on the development of an participation tool for the analysis of groundwater management in the Upper Guadiana Basin (Spain) (as part of the EU-funded NeWater project).

Prof Ramon Llamas

Prof Ramon Llamas Director of the Botin Foundation Water Observatory, Prof. M. Ramon Llamas is currently emeritus professor of Hydrogeology at the Complutense University of Madrid. Since 1986 he is a Fellow of Spain's Royal Academy of Sciences. He chairs the Section of Natural Sciences (2000- present) and the International Relations Committee (2003-present) in this Academy. He is also a fellow of the Spanish Royal Academy of Doctors (2001) and of the European Academy of Science and Arts (2005).

Mr. Daanish Mustafa

Daanish Mustafa is a Reader in Politics and Environment at King's College, London. He received his Ph.D. from the University of Colorado, Boulder and his MA and BA degrees in geography from the University of Hawaii-Manoa and Middlebury College, respectively. His research interests lie at the intersection of development, water resources and hazards geography. He has been particularly interested in the role of social power relations at multiple geographical scales in influencing geographies of access to water and vulnerability to hazards. He has also maintained a parallel research interest in the spatiality of terror and violence.

Mr. David Wrathall

David Wrathall is a Ph.D. researcher at King's College London, studying environmental migration from coastal villages in Northern Honduras that have been irreversibly affected by tropical flooding. His research interests involve the development challenges of climate related hazards, social-ecological regime shifts and migration. From 2005 to 2007, he worked for Peace Corps/ Habitat for Humanity in La Ceiba, Honduras to mitigate tropical cyclone risk in marginalised neighbourhoods along the ferocious Cangrejal River. Previously he earned a MPA from the University of Georgia, and a BA from Brigham Young University, where he studied public policy and international development, respectively.

WORLD WATER WEEK IN STOCKHOLM

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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.

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