Water for Food and Life: Preparing for Emerging Water Challenges

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ABSTRACT

Significant new water challenges are emerging as a result of increased climatic variability, land use intensification and energy supply concerns. The combination of these factors is resulting in more extreme events, greater hydrologic variability, and water shortages. There is a new interest in hydropower development, and this is occurring at a time when aquatic resources are under stress. Food production, which uses 70% of all freshwater resources, needs to be increased by 50% over the next 30 years and agriculture is now considered the largest contributor to non-point sources of pollution. To meet these food targets and at the same time maintain adequate water quality is a formidable challenge. Countries like Australia are looking at their water footprint and as water resources become scarce they are starting to reallocate water use. Water short countries will import water intensive food, so as to be able to use the remaining water for human consumption and for other strategic purposes. Countries like New Zealand, which is a large food exporting country, are exporting imbedded water. As the demand for water grows as a result of global warming it will likely be necessary to re-evaluate the crop water use efficiency and focus on how to reduce exporting water intensive food. With global warming we also anticipate new water-borne health concerns, more water demand from expanding cities and more problems to maintain critical environmental services and aquatic health. To overcome these problems requires a paradigm shift in the way we manage water. Source-water protection, water demand management, conservation and rehabilitation are the key initiatives that can only be achieved though major changes in human behavior, incentive programs and new legal initiatives that facilitate the use of innovative technologies.

INTRODUCTION

Increased climatic variability is creating a major challenge for water resource managers and all global climate models are projecting higher annual temperatures in most places. Where we have so far failed in our climate change predictions is how precipitation will change in the future. This is particularly critical in mountain regions which are the water towers of the world[1]. In the northern hemisphere it is in the Arctic and the mountain regions where temperatures are increasing the most and this is having major impacts on glaciers and snow cover. Most models predict more variable snowfall, earlier snow melt[2], advancement of spring peak stream runoff, and longer dry periods[3,4,5]. Glacial fed streams usually have two peakflow regimes, one in the spring as a result of snowmelt and one in late summer during the peak of the ice melt season. However, there is considerable evidence that almost half of the glacier fed steams in Western North America have lost the late summer streamflow peak because the glacial mass has declined to the extent that the glacial melt contribution can no longer be easily observed[6]. What this means is that stream flow regimes are becoming more variable with more intense storm events and more extensive low flow periods[7]. There is also new evidence from paleohydrological records that suggest that dramatic climate changes have occurred over very short time periods of 3-5 years[8].

What the global climate models do not address is the impact of land use changes on hydrology and water quality and there is sufficient evidence to suggest that land use changes can have a more pronounced effect on the hydrological cycle than climate change and the combination of these two factors could in some cases be additive or synergistic[9]. As a result we anticipate some dramatic challenges in the management of water resources for which we are ill prepared[10]. Figure 1 shows how the dynamics of the hydrological cycle changes as a result of different land use activities.

The main challenges that we are facing as a result of increased climatic variability and rapid changes in land use are in four areas: water and energy, water for food, water and health, and water for environmental services. Many of these challenges cannot easily be solved with technology and require a joint effort by government and society. The legal profession could play a major role in the sustainable use of water but this requires a shift from the traditional approach that relies on past precedence setting to one that facilitates the introduction of innovations for which there are few precedents.

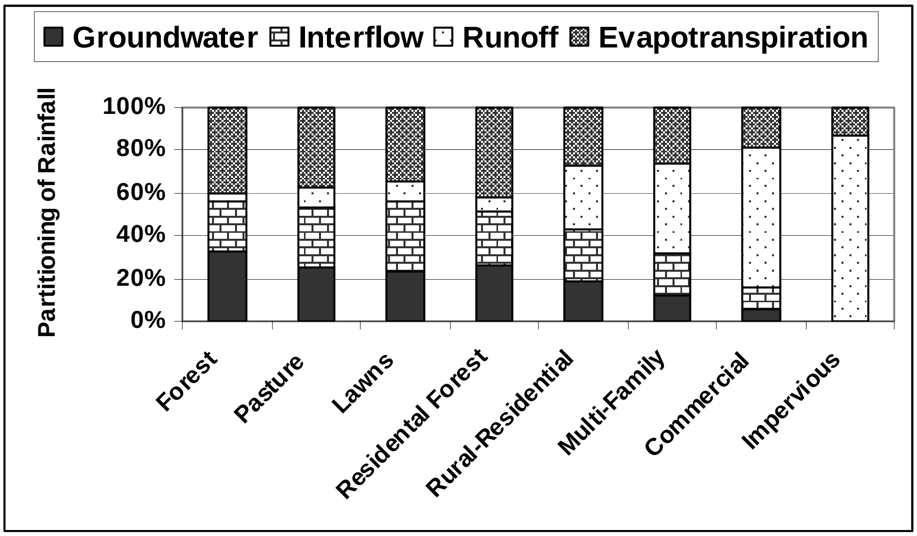

Figure 1. How rainfall is diverted into the different hydrological compartment by different land uses.

WATER AND ENERGY

Many countries and regions have relied on hydropower as a major source of energy, and during the 1960-1980 period we saw an enormous expansion of dams and reservoirs being constructed[11]. However, the love affair with dam construction has declined significantly because of the widespread negative impacts on the environment and the fact that most of the easily accessible sites are already developed in most countries. Because of the history of financial overruns and the many environmental impacts created by reservoirs it is currently difficult to construct new major hydropower reservoirs in most of the developed world[12]. However, this might change with the emergence of increased climatic variability, the concern about the decline of easily-recoverable petroleum resources, and the accelerated search for alternative renewable energy. Electricity demands are forecasted to increase dramatically with the need for more computerization, digital communication, electrical cars and industrialization. Also, in the past, power demands in the Northern hemisphere were greatest in the winter. However this is changing rapidly with global warming and the increasing demand for air-conditioning.

The push towards renewable energy puts hydropower generation once again in the forefront and this at a time when the public is unwilling to accept more modifications and obstructions to river systems. If we hope to develop more waterpower generating capacity we need to learn from all past experiences of the impacts of hydropower development on the environment. The main concerns resulting from hydropower development are summarized in Table 1. An alternative option that is emerging is “run of the river” systems. Such systems are deemed to be less intrusive and more environmentally benign. However, at present some 500 applications have been submitted to the government in Western Canada and only 20-30% of the rivers that have proposed projects actually have hydrometric monitoring stations. This creates new risk and uncertainty for the health of our river ecosystem and from a scientific point of view we are ill prepared to deal with this issue.

Table 1. Impacts of hydropower reservoirs on stream systems

Hydrological Effects	**Water Quality Effects**	**Geomorphological Effects**	**Aquatic and Human Health**	**Local Climatic Effects**
Stream Flow Control	**Changes Water Quality**	**Alters Sediment Regime**	**Reduces Habitat**	**Change in Micro-Climate (Temp. & Humidity**
Increased Evaporation	**Changes water Temperature**	**Reduces River Flushing**	**Inhibits Fish Migration**	**Exposes Shoreline to Wind Erosion**
Changes Groundwater Flow	**Reduces Nutrients Particularly Phosphorus**	**Changes Stream Morphology**	**Increases Insect Problems**	**Modifies stream Temperatures**
Creates Stagnant and Fluctuating Water Flow Downstream	**Changes mixing in Reservoir and below**	**Alters Streambanks, Shorelines and Deltas**	**Changes Macrophyte and Species Composition**	
Diverts Streams	**Decreases Oxygen Content**	**Down-cutting of Channel Downstream**	**Spreading of Waterborne Diseases**	
	Increases pollution below		**Reduces Biodiversity**	

	during summer			

With the decline of conventional petroleum reserves water is often used to maintain pressure in order to extract the resources in wells. An even more important water and energy link is in the oil-sand extraction of petroleum. Northern Alberta is the site of about 20-30 % of all new global oil reserves but because most of the resource is imbedded in a tar like form in deep sand formations, large quantities of water in the form of steam are required to liquefy and extract the oil. This type of extraction requires 16 times more energy than conventional oil extraction but more importantly water requirement for this type of oil extraction amounts to 3 liters of water for 1 liter of oil. The expansion of this resource is now so rapid that it is anticipated that water and not oil will be the limiting factor in the next 5 years[13].

The more we pollute our waterways the more we have to treat our wastewater. The cost of wastewater treatment and disposal is increasing dramatically because there is an increasing demand to remove not only nutrients and microorganisms but also pharmaceuticals and other organic and trace metal contaminants. All of these treatment processes are becoming more complex and require more energy. Pumping and moving water requires energy and it has been estimated that California uses between 4-6% of all electricity to pump water (irrigation water, drinking water and wastewater). Furthermore the demand to pump water is likely increasing since urban sprawl has resulted in large expansions of pipes that deliver dinking water and remove wastewater.

Similarly the water demand for irrigation is expanding. If we hope to meet the food demand for a population of 9 billion we need to allocate more water to irrigation. Since agriculture uses 70% of all freshwater resources there is room for more efficient water use but in all cases it will require more energy.

WATER FOR FOOD

Recent research[14,15] has shown that we need to increase food production by 50% over the next 35-40 years and this has to happen at a time when the land resources for arable agriculture are decreasing. Forty percent of all food production originates from 19% of agricultural land that is irrigated. Not only is agriculture using most of the freshwater resources but, as a result of intensification, agriculture is now considered the largest contributor to non-point sources of pollution of freshwater resources. There are a number of factors that play a major role in the need to increase food production. First we will have to feed another 2 billion people by 2050 and there are still some 800 million people that currently have insufficient food. However, a more significant trend is the change in diet as the developing world strives towards a more meat based diet[16]. Not only is it significantly less efficient to produce meat than crops but a meat based diet requires 2-15 times more water than a staple based diet. Basic staple crops usually require about 1000 L of water / kg of crop, while 1 kg of meat requires somewhere between 3500-25000 L of water. As developing countries advance, their meat consumption increases, and this requires significantly more water to produce (Figure 2).

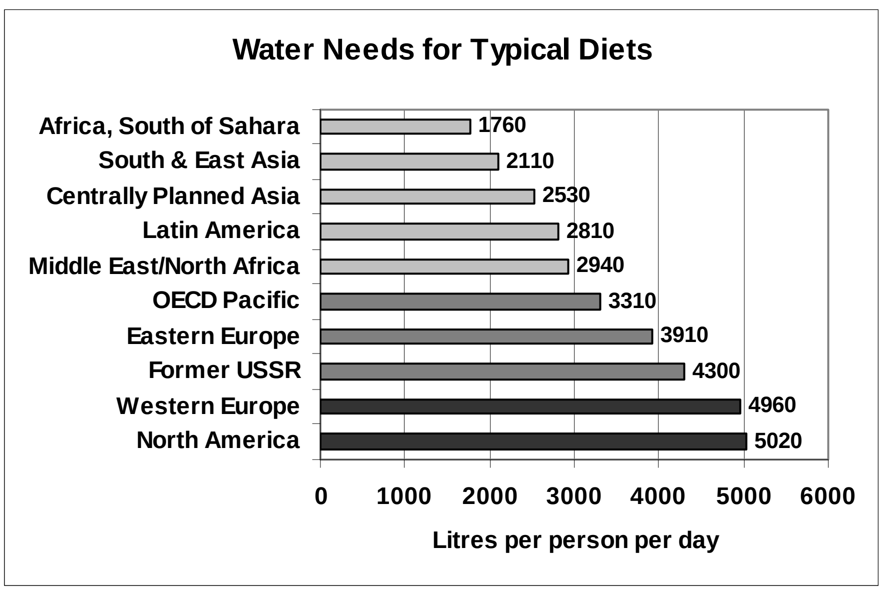

Figure 2. Water requirements for different daily diets (L/peron/day).

The change in moving from a staple based diet to a meat based diet is no more apparent that in China where the meat consumption/person has increased dramatically resulting in rapid imports of beef and chickens since 1999 (Figure 3). What is particularly important for New Zealand is the increasing consumption of dairy products in China, India and other Asian countries. To produce dairy products is highly water intensive and the intensification of dairy operations in New Zealand will likely be of concern to water managers in the near future.

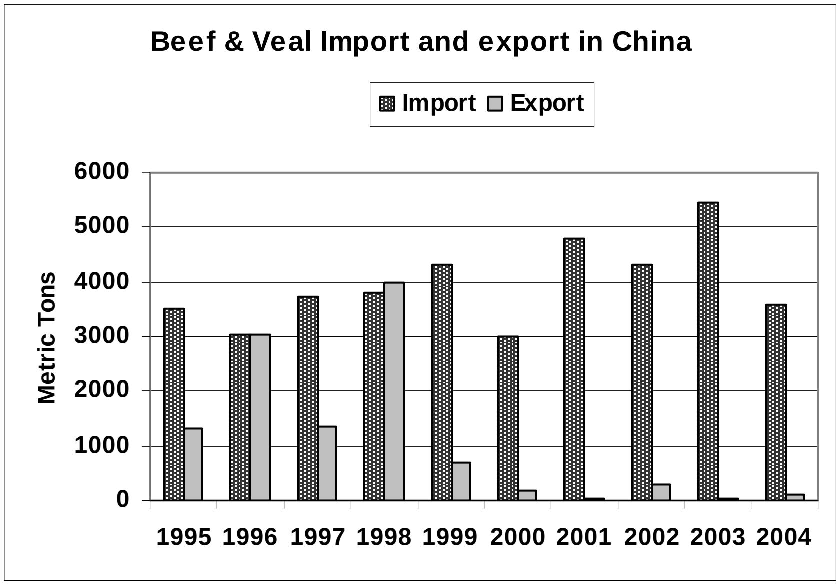

Figure 3. Change in Beef and Veal imports and exports in China, 1995-2004

A new challenge in meeting food production targets has come from the conversion of crops into biofuel. In the USA 19% of all arable land is now producing corn for biofuel. There is now sufficient evidence to suggest that using corn and wheat for ethanol production and canola and soybeans for biodiesel is a negative proposition, which in the worst case requires more energy than is produced[17]. In addition, these crops are not water efficient and restrictions are needed to assure competing demands for water are considered[18] (Figure 4). From an efficiency point of view it would be most appropriate to let the tropical countries produce ethanol from sugar cane and have the rest of the world focus on food production. This would be one of the most appropriate foreign aid policy propositions to be considered since transport of ethanol by ships is significantly easier than shipping liquid natural gas (LNG).

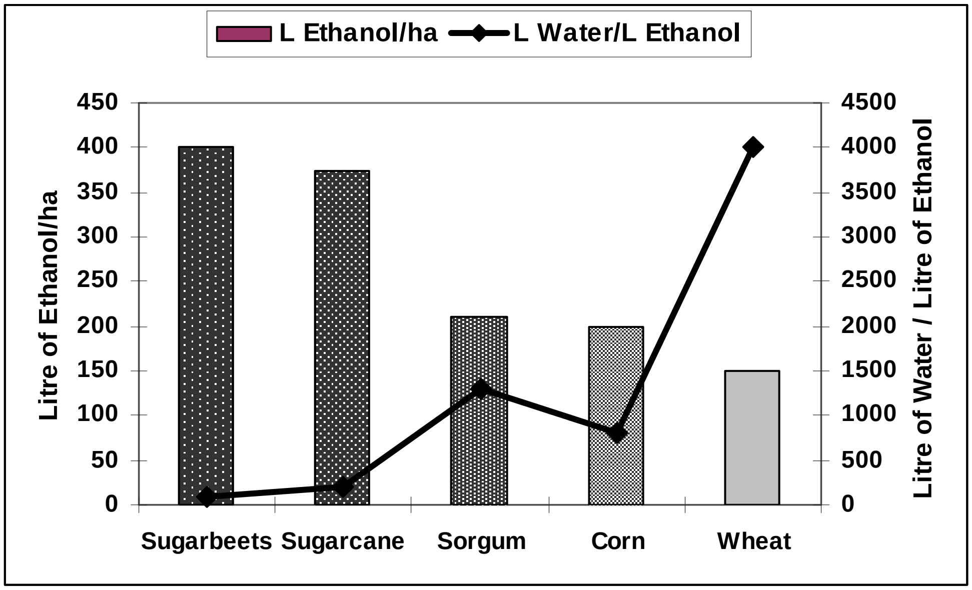

Figure 4. Efficiency to convert crops into ethanol (L/ha) and water needs to produce ethanol (L of water/L of ethanol).

All forecasts suggest that we have a formidable challenge to meet the food demands over the next 40 years because of a shrinking land base, higher costs for fertilizers and energy, increased climatic variability, more degraded land, and massive water challenges. It has been proposed that the yields in rainfed agriculture have to be increased by 50% and production from irrigated land by 40%. While there is sufficient room for improving the efficiency of irrigation[19] and to initiate multiple annual crop production cycles, increasing the rainfed production will be far more challenging[20]. The most effective way to produce meat is from rangeland but increased climatic variability and overgrazing are two key factors that are likely to limit the expansion of rangeland production.

Recent studies[21,22] have shown that food exports can have a significant impact on water availability in many countries. The largest share of freshwater consumption is for crop production and if a country is exporting a large amount of food, they are exporting imbedded water, water that is no longer available for other uses. The imbedded water is also referred to as virtual water[23]. The USA, Canada, Australia are among the greatest exporters of virtual water, while Japan, the Netherlands and South Korea are the greatest virtual water importers[21] (Figure 5). If a county is water short, then it has the option to import water intensive food and use the available water in the country for essential human uses. The best example is Jordan, which has the least amount of freshwater per capita of any nation. Jordan imports four times as much water imbedded in food as the freshwater it has available.

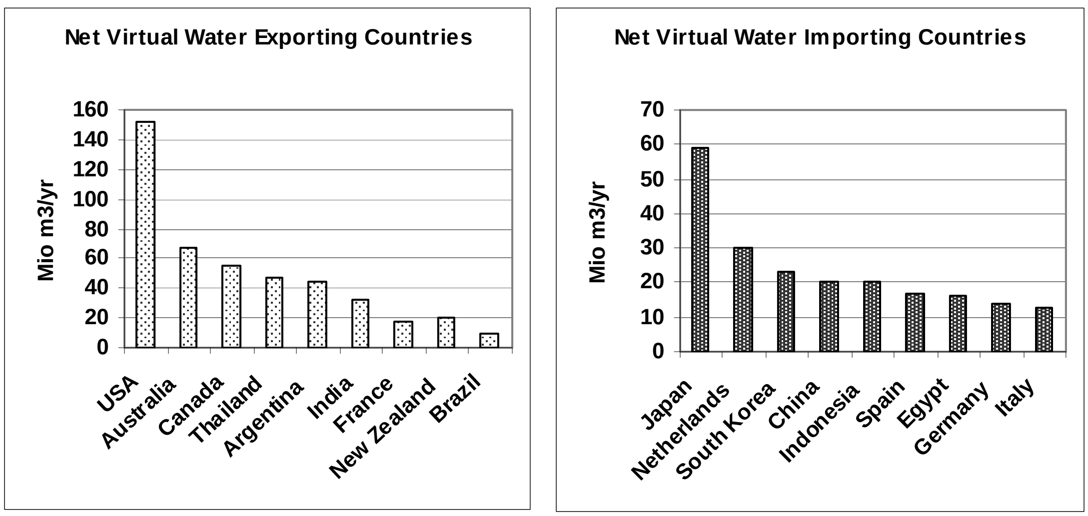

Figure 5. Virtual water importing and exporting countries (water imbedded in food that is imported and exported)[21,22].

What is particularly attractive when using the virtual water concept is that it allows us to compare the water efficiency between different crops. This is not only important for rainfed agriculture (green water) but more importantly for irrigated agriculture (blue water). During drought periods it might be wise to produce crops with low water requirements and in general the crop selection should be based on crop water requirement that are more closely matched to the prevailing climatic conditions[23]. Growing water intensive crops such as cotton and rice in the semi-arid climate of central California is clearly not an efficient use of scarce water resources.

Another important concept is not only the water needed for growing crops but for converting the crops into products. When examining the beverages we drink and then accounting for the water that is needed to produce each beverage we end up with enormous figures for water requirement. As is shown in Figure 4, a cup of coffee requires some 140 L of water to produce and a glass of milk requires more than 200L of water to produce.

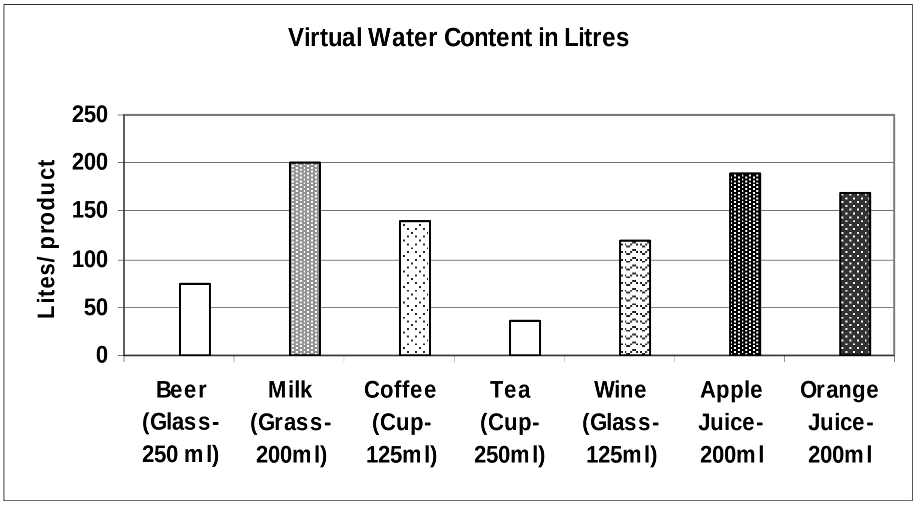

Figure 6. Water requirements to produce different beverages.

Flood irrigation is still the dominant method of irrigation around the world. It is also the most inefficient use of water. A major effort is needed in investments of efficient irrigation systems. Current sprinkler and drip irrigation systems can save up to 30-75% of irrigation water depending on crop type, soils and topographic conditions[19]. In all cases water storage will become critical because in most agricultural areas there is an uneven seasonal distribution of rainfall. If groundwater is not available then rainwater harvesting is a viable option. Since many groundwater resources are not managed in a sustainable manner[25] temporary storage of surface and rainwater combined with low cost drip irrigation will become a viable option for food production. Smart irrigation scheduling, advanced irrigation management and efficient use of irrigation technologies can go a long way to reduce the risk of future food shortages.

In the recent comprehensive assessment of Water for Food – Water for Life by the International Water Management Institute[16] it is clearly evident that the risk of not meeting the food production targets set by the United Nation is very high. The main question that needs to be answered is: is there enough freshwater available to meet the food demands? Growing food to drive your car is clearly not a viable option. A conscientious society should be concerned with growing and consuming food in a water conscious manner.

WATER AND HEALTH

This topic applies to both human and environmental health. As we expand populations and livestock production we generate more human and animal waste that enters our water resources and this create greater challenges for drinking water managers. The more antibiotics and pharmaceuticals we use for human and animal protection the more enters into our water systems[26]. Conventional wastewater treatment systems are not able to remove pharmaceuticals and some of these endocrine disrupting substances have a detrimental effect on the aquatic biota[27]. These substances also alter the resilience of the ecosystem.

As temperatures warm, pathogens and insects can flourish and expand into new areas, particularly when introduced by visitors, containers, and bulkwater release. One example is the West Nile Virus, which was introduced into North America some 8 years ago by visitors from Egypt. This virus, previously unknown in this area, has been able to survive and spread all the way to the West Coast of North America[28] because the winter temperatures have been relatively mild over the past 7 years. An even more dramatic impact associated with climate change is the Pine Beetle infestation in British Columbia[29]. This is an insect that has a long history in B.C. but outbreaks were relatively limited in the past because frequent periods of cold winters with 3-4 week periods of minus 30 degree temperatures have controlled the expansion of the organism. Unfortunately the mild winters that persisted over the past 6 years have resulted in a massive expansion of pine beetle infestation. Some 8 million hectares of forest are now completely devastated and this not only poses a widespread fire hazard but, if such fires occur, this could contribute large quantities of CO_2 to the atmosphere. This poses a dilemma. If the infected Pine trees are harvested within 1-2 years of infestation the wood can still be used for numerous purposes, if it is left standing it is a fire hazard. To reduce the fire and CO_2 emission risk it was decided to give the green light to widespread harvesting of infested trees. This is resulting in the greatest land use conversion in the history of the province and from a scientific point of view we do not know how this will change the hydrological cycle because we have never studied how such landscape size conversions affect the runoff and evaporation processes.

Warmer water temperatures will also stimulate algal growth that in combination with increased nutrients in drainage water result in widespread eutrophication. This is creating anoxic conditions in many estuaries and is becoming an annual problem in the Mississippi delta and other basin draining intensive agricultural areas.

WATER FOR ENVIRONMENTAL SERVICES

The topic of environmental services is emerging as one of the most challenging water issues for the scientific, economic and legal professions. The major dilemma is how to value environmental services that include such topics as a healthy aquatic biota, the purifying action of flowing water, the maintenance of biodiversity, and the minimum supply to assure survival and sustainability of the system. Until recently we allocated water primarily for human uses (hydropower production, drinking water allocation, irrigation and recreational use), but as the water resources become more stressed the issues of setting minimum flows regulations has become more complex[30]. The problem is how to maintaining flow variation that mimics nature under water stress[31,32]. The second problem is contaminant loading which we calculate for individual contaminants (nitrogen, phosphorus, sediments, etc) but not for cumulative effects. Cumulative effects and contaminant interactions are very difficult to examine scientifically and the lack of scientific understanding makes it difficult to come up with defensible regulations.

The more obstructions we put into river systems the more we moderate the streamflow dynamics and this is reducing the flushing capacity that the natural stream variability provides to maintain a divers habitat. In many cases hydropower companies are now required to release water during low flow conditions and at a time when they do not need the power. The reason is that contaminant concentrations increase during the dry season and water releases are necessary to flush out contaminants.

We go to great length to provide society with clean and safe drinking water. However, we do a very poor job in preventing wastewater generation and effective treatment of wastewater has a much lower priority. More than 2 million people have no access to sanitary services and even in the developed world wastewater treatment systems are doing a relatively poor job in reducing pollution.

INNOVATIVE APPROACHES TO ADDRESS THE GLOBAL WATER CHALLENGES

A major effort is needed to address these water issues and this can only be accomplished by an approach that deals with conservation, prevention and rehabilitation. Conservation and prevention can only succeed with behavioral changes which is often referred to as the "water soft path" approach, while rehabilitation requires a more "hard path" approach that involved engineering based options.

The two most important sources of pressure facing future water resources originate from agricultural intensification and from urban expansion, both of which use most of the water and are the major contributors of non-point sources of pollution. These are the two land use activities that need the greatest attention, since point sources of water pollution by industry can easily be identified and regulated. This is significantly more difficult for diffused non-point sources of pollution.

AGRICULTURAL OPTIONS

Many options exist in agriculture to use water more efficiently and to reduce the impacts on water quality[33]. More efficient nutrient management is one of the keys to prevention of eutrophication, which is considered the most widespread global problem resulting from agricultural activities. Using annual nutrient budget to prevent excess application of nutrients is the first step. However, this is becoming a major challenge in intensive livestock operations where manure production is excessive and is often disposed of as a waste product rather than a nutrient source. This means that other regulations need to be in place to reduce potential discharges of nutrient to the stream. Maintaining vegetated buffer strips, draining field runoff through wetland filter systems, regulating stocking densities, and fencing fields to prevent livestock access to streams are some of the so called “Beneficial Management Practices (BMP’s)” that are well established but are not easily regulated and enforced. Most of the agricultural BMP’s in North America are on a voluntary basis and are not working well. The problem with manure management is even more complex because of the pathogens that enter streams and groundwater during storm events after manure applications. In addition, more antibiotics are now used in intensive livestock operations than for human use and much of these chemicals end up in manure and eventually find their way into the water system. Similarly, trace metals (Zn, Cu) are regularly added to animal feed for growth promotion and health prevention. The widespread use of pesticide also continues to be a problematic scientific and legal challenge for water managers and health authorities.

Sediments are another major problem resulting from agricultural activities. Sediments can be abrasive to aquatic organisms and impare light penetration, which affect biological productivity. Sediments are also a perfect host for pathogens and trace metal pollutants. Pathogens can easily find protective hiding spaces in sediment particles where they are protected by biofilms. This is a particularly difficult problem in drinking water supplies because most disinfection chemicals are not effective in dealing with this issue. In fact 60-70% of all health issues associated with contaminated drinking water occurs after major storm events when pathogens transported with sediments enter drinking water systems.

The key to protect against land use intensification is to actively initiate source protection measures and to reduce the use of all chemicals at the source. There is no single measure that will suffice. A combination of source control, multi-barrier protective measures, and good land management practices is the only way to address these water issues.

URBAN OPTIONS

Considerable innovations are needed in water management in the urban environment. Urban stormwater runoff, wastewater discharge from sewage systems, and urban water use can readily be addressed with innovative source protection measures, improved treatment, and water demand management practices.

Conventional stormwater management focuses on draining and removing stormwater runoff. Innovative stormwater management focus on rainwater management[34] and aims at water retention, storage and infiltration. The new approaches are different depending on the three scales to be addressed: Individual properties, neighborhoods, and watersheds (Table 2).

Table 2. Innovative stormwater management practices

Scale	Priority	Innovations
Individual Property or Site	**Keep rain on site and detain, store and infiltrate rainfall (Focus is on low & moderate storm events)**	**Green roofs, Roofwater (rainwater) harvesting & Reuse, Minimize impervious surfaces, Use pervious pavement, Require 30 cm of topsoil, encourage urban trees, build rock pits and rain-gardens.**
Neighborhood	**Delay runoff, detention and filtration (Focus is on heavy storm events)**	**Smaller roads (with less pavement), No curbs and gutters, swales for road runoff, detention ponds and constructed wetlands, pervious pavement, innovative drainage of parking lots (infiltration)**
Watershed	**Minimize floods, detain, divert & store runoff, infiltrate runoff in buffer zones (Focus is on very large storms)**	**Large riparian buffer zones, diversify stream channels, land use zoning & enforcement, floodplain management, designate area to store floodwaters**

At the individual properties level we have sufficient tools to minimize stormwater runoff by infiltrating, storing and detaining rainwater. Collecting roofwater and using the stored water for gardening or indoor use such as toilet flushing is a common option. Significant topsoil addition requirements will assure that large quantities of rainfall are stored in the soil. For larger buildings green roofs are another efficient option. Minimizing the impervious surface on patios and driveways by using pervious pavement is another option. Maintaining large trees on individual properties also results in significant rainfall interception and delayed runoff. Much of the rainfall can be infiltrated on most properties and this not only results in minimum runoff but also assures that any contaminants are infiltrated into the soil where the soil organisms are able to break down many compounds. Underground rock pits can also be used to retain and infiltrate rainfall.

At the neighborhood scale road runoff can be directed into sand filters and wetlands before they are able to enter local stream systems. This can be enhanced by making the road surfaces smaller, using permeable pavement material, eliminating curbs and gutters, and directing runoff into sand filters and French drains.

At the watershed scale we need to assure that large vegetated buffer strips are maintained to absorb sediments and pollutants before they enter the streams. In addition wetlands should be maintained within the buffer zone so as to act as effective retention and filter systems. Flooding zones must be protected with protective structures but also by strict land use zoning regulations. Finally some areas need to be designated to store floodwaters on a temporary basis.

There are major innovations under way in wastewater treatment. It is apparent that the cost of treatment is increasing at an exponential rate as a result of having to remove ever increasing, potentially hazardous, new compounds. Source control and graywater reuse is being promoted because this reduces the amount of ”end of pipe treatment”. Urine separation and treatment for nutrient recovery is one of the new options in Europe that attempts to reduce the problem of pharmaceuticals impacts on the environment. Using a range of different treatment systems is possible but the more steps that are needed the more expensive the treatment becomes. Wastewater conversion into drinking water is becoming necessary in places where sufficient freshwater resources are scarce (Netherlands, Namibia, Brisbane, Australia etc.). However, aggressive source control and graywater reuse is a more cost effective option wherever possible.

Finally, water demand management is likely the most effective means of reducing the pressure on dinking water supply in cities. This can be accomplished by using water efficient utilities inside the house and restricting the outdoor water use by xeriscaping and roofwater use.

SOME LEGAL CHALLENGES

For many of these innovations to be successful we need flexibility in the existing laws because in many cases conventional laws inhibit innovations. Many of the innovative practices are experimental and need to be tested and improved over time. Unless we give innovators some leeway they are unlikely to take the risk of experimenting. What this means is we have to have incentives to bring about behavioral and structural changes to arrive at a more environmentally friendly way of managing water resources. In view of increased climatic variability there is an urgent need to develop adaptive measures and these require more flexible laws. Many water laws were developed at a time when water stress and water pollution were less critical. With climate change we are moving into a new water management future that requires wise and progressive actions in anticipation of coming problems. The time for progressive laws is emerging as the main challenge for the legal profession if we hope to adapt to the anticipated challenges facing water resources.

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