Optimizing Water for Life

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Abstract

Water is essential for life. Food is also essential, as is a quality environment. All require water. And when water is scarce, just how do we decide how much water to allocate to all of these and other purposes that enhance a sustainable quality of life? This paper addresses some of the complexities of answering such a question, especially related to environmental flow allocations. Only relatively recently have we all begun to recognize the importance of not only keeping we humans from becoming too thirsty, but also of maintaining healthy functioning ecosystems as indeed these ecosystems what we depend on to sustain our own lives. We are indeed apart of our ecosystems. We depend upon our environment and ecosystems to sustain the quality of our lives, if not life itself.

Balancing water demand allocations, especially when the demands exceed supplies, is a complex, and largely political, problem. It is likely to become even more complex and political and contentious in the future as populations grow and as water quantities and their qualities become even more variable and uncertain. But at least the political process of making allocations should be informed by scientific studies of the likely impacts of alternative allocation decisions, especially with respect to environmental flow demands.

How do we allocate scarce water supplies optimally among all demands that impact on the quality of, or even on the existence of, life – both human and ecosystem life – in times of critical water scarcity? The temptation is to ignore environmental flow demands. Such decisions can be at the expense of maintaining a sustainable place to live and prosper.

Introduction

We all know water is essential for life. We also know that many people – too many - are not getting enough of it, or of the quality, that allows them to live healthy lives. And for many of the world's poor, access to clean water too costly. Numerous UN reports document the number of people in this world whose water and/or sanitation needs are not being met. For some countries, the percentage of people lacking adequate water supplies exceeds well over half of their total populations. As a result, many, especially the very young, die. Others are constantly sick, and hence cannot achieve their full productive potential. So, the question is just how can we "optimize water for life" especially in situations where there is not enough to satisfy even the basic needs for life? How do we make decisions on how much water to allocate to each of the many beneficial uses of water in times of water stress?

In addition to drinking water, people need food, and all of the world's food comes from water. There is nothing we eat that doesn't depend on water. People need energy, and in some parts of the world water is a major source of that energy. Water also serves as an inexpensive means of transporting cargo and wastes. And very importantly, we need water to maintain viable and diverse ecosystems. We depend upon our environment and ecosystems to sustain the quality of our lives, if not life itself (Postel, Daily and Ehrlich, 1996).

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In the past decade, progress has been made in providing more people with access to clean drinking water and basic sanitation. But a major effort is still required to extend these essential services to those still without, the vast majority of who are poor and cannot pay the costs of these basic services. In addition, we are increasingly recognizing that we humans will not easily survive in the long run unless we pay attention to maintaining a quality environment and life-supporting ecosystems. Again, water is needed to do this, and in times of drought determining the ‘optimal’ allocations of water to sustain our lives, our economic activities, and our ecosystems is indeed a challenging endeavor.

Balancing water demand allocations, especially when the demands exceed supplies, is a complex, and largely political, problem. It is likely to become even more complex and political and contentious in the future as populations grow and as water quantities and their qualities become even more variable and uncertain. But at least the political process of making allocations should be informed by the sciences of the likely impacts of alternative allocation decisions, especially with respect to environmental (ecosystem) flow demands. (Postel, 2000: King, J., and C. Brown. 2006)

How do we allocate scarce water supplies optimally among all demands that impact on the quality of, or even the existence of, life – both human and ecosystem life – in times of critical scarcity? This is the question I’ve been asked to address. A general precise answer that fits all circumstances is never clear, but what is certain is that both humans and ecosystems should be kept alive and healthy! If the latter is not, it is unlikely the former will either in the long run (Postel, and Richter. 2003).

How much water do we need?

Just how much water do we need, now and into the future, to be sustainable? By 2025, it is expected that 3.4 billion people will be living in countries defined as water-scarce. Many in those countries seem to be able to survive on as little as 3 liters per day. It takes about 3,000 liters of water to produce a daily ration of food, about 1,000 times what we minimally need for drinking purposes. Much of our food comes from irrigated lands. On average over 70% of total freshwater use in the world is devoted to irrigation. Over the next 30 years, about 70 % of gains used in cereal production are expected to come from irrigated land.

Water is needed for energy as well. Hydropower provides a substantial portion of the energy consumed by many countries, and this percent is increasing. Iran is a good example. Hydropower production there exceeds the current demand, so they are selling the excess to their neighbors. But the consumption of water in hydropower production is minimal compared to the production and processing of crops used for biofuels. The demand for water in the production of biofuels is a growing concern. For example, in the U.S., about 40% of all water withdrawals in the Midwest are for biofuel production. This demand is expected to increase by 80% in the next 30 years. In Europe, where the issue is only beginning to be recognized, water consumption for energy production is expected to be equivalent to the daily water needs of 90 million people by 2030. (DOE, 2006; EPRI, 2002)

Water also transports cargo and assimilates much of our domestic and industrial wastes. In developing countries, more than 90 per cent of sewage and 70 per cent of industrial wastewater is dumped untreated into surface water. (UN, 2006).

Freshwater is vital to human life and societal well-being, and thus water use for energy production, domestic and industrial consumption, crop irrigation, and ship transport has long been considered a key factor in economic development and consequently human welfare. These direct human and economic uses or purposes have traditionally taken precedence over other commodities and services provided by freshwater.

Historically humans have withdrawn freshwater from rivers, lakes, groundwater, and wetlands for many different urban, agricultural, and industrial activities, but in doing so have often overlooked its value in supporting ecosystems. In more recent years there has been a growing recognition that aquatic ecosystems provide many economically valuable services and long-term benefits to society. The short-term benefits include ecosystem goods and services, such as food supply, flood control, purification of human and industrial wastes, and habitat for plant and animal life—and these are costly, if not impossible, to replace. Long-term benefits include the sustained provision of those goods and services, as well as a more resilient and adaptive capacity of aquatic ecosystems to respond to future environmental alterations, such as global warming and its impact on the hydrologic cycle. Clearly, the maintenance of the processes and properties that support freshwater ecosystem integrity should be included in debates over sustainable water resource allocations, especially in times of water shortages (Kates, 2001; Gleick, 1998).

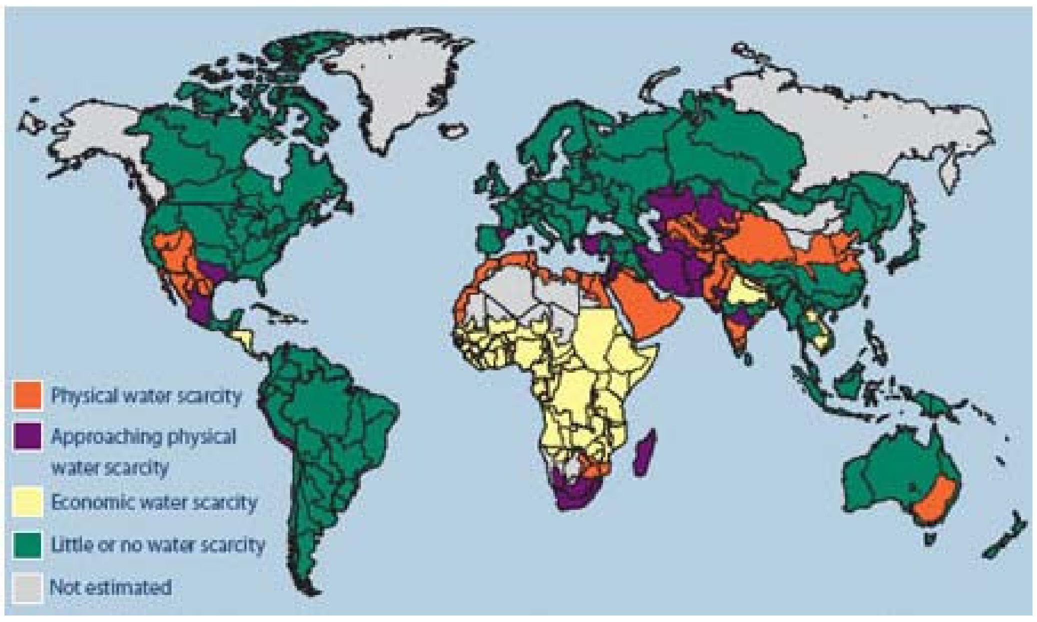

Figure 1. Water scarce regions of the world. Physically water scarce regions are not sustainable. The withdrawal and consumptive use of water exceeds 75% of the supply. Economically water scarce regions have sufficient supplies to meet demands, but potential users lack the means to access that water.

The physical evidence of water scarcity can be found in increasing magnitude around the world, affecting rich and poor countries alike. Nearly three billion people live in water scarce conditions (over 40 percent of the world's population), and this situation could worsen if current growth trends continue. The manifestations of pervasive water poverty include millions of deaths every year due to malnourishment and water-related disease, political conflict over scarce water resources, extinction of freshwater species, and degradation of aquatic ecosystems. Roughly half of all wetlands have already been lost and dams have seriously altered the flow of roughly 60 percent of the world's major river has. The situation only worsens with time. Figure 2 projects available water supplies per person per year by 2025 (earthtrends.wri.org/updates/node/179).

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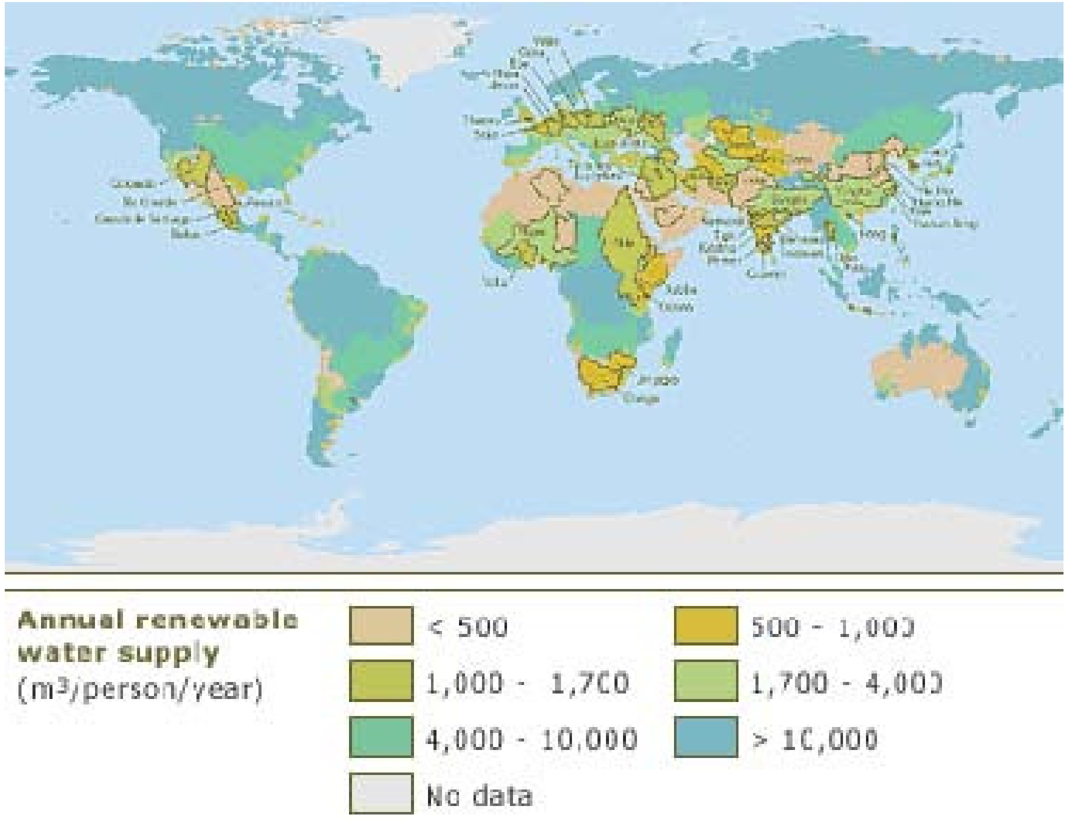

Figure 2. A Water Stress Map showing regions under stress whose available supplies in 2025 will be less than 1700 cubic meters per year per person.

The UN tells us that about 1.2 billion of today's world population have inadequate access to safe drinking water, and about 2.3 billion do not have adequate sanitation facilities. Over a third of the world's population is water stressed. If we assume "business-as-usual" forecasts, by 2050 about 40% of the projected global populations of 9.4 billion are expected to be facing water stress or scarcity, as shown in Figure 3 (Hinrichsen, Robey, and Upadhyay, 1997). With increasing variability being predicted by global climate models, we may have more people without adequate water more of the time, even in water richer regions.

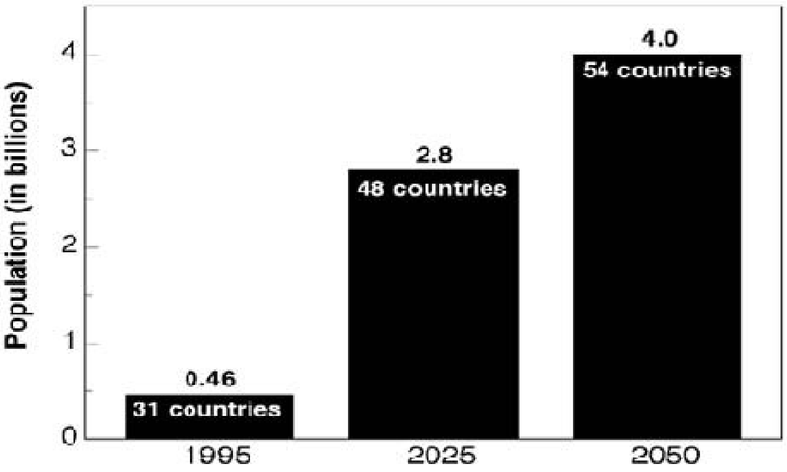

Figure 3. Populations in water stressed countries from 1995 to 2050. www.infoforhealth.org/pr/m14/m14print.

Where is the water will we need?

Most of that freshwater we now use comes from various river basins and aquifers. Figure 4 locates 26 of the world's major river basins, (http://maps.grida.no/go/graphic/major_river_basins_of_the_world), and Figure 5 shows the location of the world's major aquifers (www.bgr.bund.de/nn_335088/EN/Themen/Wasser). Rivers and aquifers will continue to be the major sources of our freshwater in the foreseeable future, in spite of a continual increase in the use of desalinated saltwater.

Source: United Nations Environment Programme (UNEP); World Conservation Monitoring Centre (WCMC); World Resources Institute (WRI); American Association for the Advancement of Science (AAAS); *Atlas of Population and Environment*, 2001.

Figure 4. Major river basins in the world.

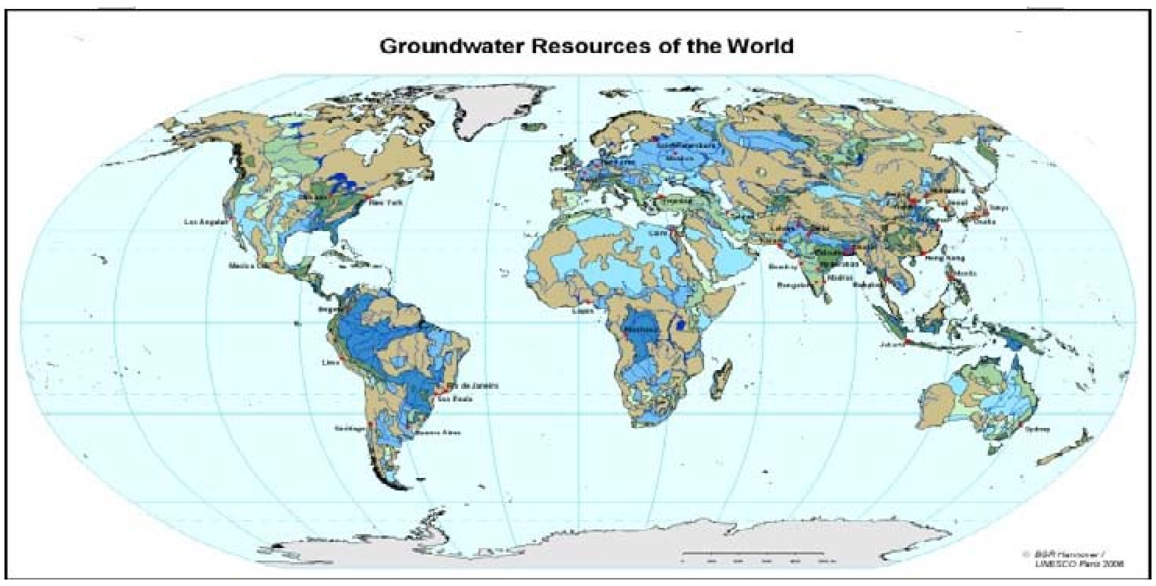

Figure 5. Major groundwater aquifers in the world.

As illustrated in Figure 5, about 30% of the area of the continents (excluding the Antarctic) is underlain by relatively homogeneous aquifers (blue) and 19% is endowed with groundwater in geologically complex regions (green). Most of the remaining continental area contains generally minor occurrences of groundwater that are restricted to the near-surface unconsolidated rocks (brown).

Where is there not enough water?

As Figures 1 through 3 suggest, over time an increasing number of places will not have adequate water supplies to meet all water demands, all of the time. Such regions are under water stress.

The countries of the Near East and North Africa face the greatest stress (see Figure 1). The Near East is the most water-short region in the world. The entire Near East uses more water from rivers and aquifers every year than is being replenished. Over the next two decades population increase alone—not to mention growing demands per capita—is projected to push all of the Near East into water scarcity. Many Near East countries are mining fossil groundwater to meet their water needs. Water is one of the major political issues confronting the region's leaders. Since virtually all rivers in the Near East are shared by several nations, current tensions over water rights could escalate into outright conflicts, driven by population growth and rising demand for an increasingly scarce resource (UNESCO, 2006).

Four Gulf states—Bahrain, Kuwait, Saudi Arabia, and the United Arab Emirates—have so little freshwater available that they resort to desalinization of sea water. Without desalinization, the Gulf States would be unable to support their current populations. Desalinization is too expensive and impractical for most water-short countries, not to mention land-locked countries, either today or in the foreseeable future.

Much of sub-Saharan Africa is facing serious water constraints Rapid population growth will make this problem worse. By 2025 some 230 million people will be living in African countries where water is scarce.

Parts of many large countries, such as India, China, and the United States, face water stress or water scarcity as well. India as a whole is expected to enter the water-stress category by 2025. Both India and China are considering substantial, and expensive, water transfers from water richer to water poorer regions to reduce some of that water stress.

China has 22% of the world's population but only 7% of all freshwater runoff. China's freshwater supplies have been estimated to be capable of sustainably supporting only half of the country's current population. Despite periodic flooding in the south, along the Yangtze River, China faces chronic freshwater shortages in the northern part of the country. Many of China's cities, including Beijing, face critical water shortages. The water table under Beijing has been dropping by roughly two meters per year.

In the US groundwater reserves are being depleted in many areas. Overall, groundwater is being used at a rate 25% greater than its replenishment rate. In some areas of the western part of the country, groundwater aquifers are being depleted at even faster rates. In particular, the huge Ogallala aquifer, which underlies parts of six states (shown in light blue in Figure 5) and irrigates 6 million hectares, has been overexploited. In some regions half of its available water has been withdrawn.

Competition for Scarce Water Supplies

Where water is scarce, competition among water users increases, and hence so does the potential for conflict. A number of developed water-short countries currently face tensions over water, including Belgium, the United Kingdom, Poland, Singapore, and the US. In southern Britain, for instance, urban demand for water is outpacing the capacity of rivers and aquifers to supply it during the drier summer months. In the western US, farmers who want more irrigation water for their crops are in conflict with growing urban areas that demand more water for households and other municipal uses.

India's states have disputes over water rights and over dams that might provide more water for one state but at the expense of another. Water disputes, if not attended to, could become a major cause of instability in Indian society.

China already is practicing what some call the "zero sum game of water management". The zero sum game—when authorities increase water supply to one user by taking it away from another—is played both between competing areas of the country and between competing types of use, as when cities compete with farmers. China's Yellow River is so oversubscribed that, for an average of 70 days a year for the past decade, its waters have dried up before reaching the coast. In 1995 the dry period lasted for 122 days. To meet urban needs, the government of China is planning an aqueduct that will carry water from the Danjiangkou Reservoir in Henan Province to Beijing, across 1,300 kilometers of heavily farmed land—land that also needs the water for food production.

In nearly all water-short areas the threat of regional conflicts over limited water supplies is emerging as a serious issue. In Africa, for example, about 50 rivers are each shared by two or more countries. In particular, access to water from the Nile, Zambezi, Niger, and Volta river basins has the potential to ignite conflicts.

In Central Asia the Aral Sea Basin is beset by international conflicts over water. Turkmenistan, Uzbekistan, Kazakhstan, Kyrgyzstan, and Tajikistan all depend for their survival on the waters of the Amu Darya and Syr Darya rivers. The flows of both rivers have been almost wholly diverted to feed water-intensive crops such as cotton and rice. Very little if any water reaches the Aral Sea. As demand for this water grows, the countries are increasingly at odds over its division, with all five Central Asian republics demanding a greater share. Disputes are growing between Kyrgyz and Uzbeks over water and land in the fertile Fergana Valley; between Kyrgyz and Tajiks over the allocation of irrigation water from the Syr Darya; and between Turkmens and Uzbeks over the distribution of irrigation water from the Amu Darya.

The Southeastern Anatolia Project in Turkey, known as GAP after its Turkish title (Guneydogu Anadolu Projesi) comprising a network of 22 dams and 19 power plants has significantly reduced the downstream flow of the river Euphrates (and to a lesser extent the Tigris), causing increased salinity and seriously affecting agriculture. The GAP project poses a real threat to future water supplies in Syria and Iraq and hence is a potential source of conflict in a region already embroiled in conflict. Cooperation among all riparian countries can reduce this conflict potential (Inan, 2004)

In the US, the Colorado River, which flows through the southwestern part of the country, has fed irrigated agriculture and enabled the explosive growth of desert cities. Now, however, demands on the river's water supply for irrigation and urban use have become so great that the river flow no longer reaches its mouth in Mexico's Gulf of California. Instead, it trickles out somewhere in the desert south of the US- Mexican border. The river's flow premature disappearance has been a source of irritation between the US and Mexico (Postel, 1998; Gleick, 1998; Hinrichsen, Robey, and Upadhyay, 1997).

In light of all these potential serious conflicts, and need for waters to drink and irrigate crops, just how easy is it going to be to allocate some of what is available to environmental flows?

Allocating water for life

Economics teaches us that to achieve maximum net benefits, the allocation of any scarce resource to multiple uses over space and time should be such that the present value of the marginal benefits derived from each use are all equal. (This applies of course to situations where there are no restrictions on any allocation except the total amount of water available.) Otherwise if one marginal benefit is greater than others, it pays to take a little water away from any use having a smaller marginal benefit and allocate it to the use having the higher marginal benefit, thereby increasing total net benefits derived from the allocated water. That advice is useful, perhaps, if net benefit functions can be defined for all uses and if everyone agrees that maximizing the present value of total net benefits is a reasonable criterion for optimality. Even if everyone agrees that this objective is worth pursuing, defining net benefit functions is very difficult when it comes to human drinking water needs to sustain life. It is even more difficult to define such functions for environmental flow regimes. And arguably, these two uses should have the highest priority for water. So, the question is what criteria should be used to determine just how much should be allocated to each of those uses (Postel, Daily, and Ehrlich, 1996).

To illustrate the difficulty of deciding just how much to allocate to support human as well as ecosystem health, consider the recent long-term drought in the south eastern states of the US. The drought resulted in a critical drawdown of Lake Lanier, the reservoir serving the metropolitan area of Atlanta, Georgia.

Figure 6. Lake Lanier and the Chattahoochee River basin, showing drought conditions throughout the basin.

This reservoir serves two main purposes, meeting Atlanta's water demands and providing environmental flows downstream. Reservoir releases are made into the Chattahoochee River to protect downstream mussels and sturgeon species and to enable a Florida power plant to operate. Downstream cities such as Columbus depend on the river flows for their water supply, and a certain level of flow has to be maintained to allow proper assimilation of treated wastewater back into the river. The reservoir is operated by the US Army Corps of Engineers, and as required by law, provided flows for both purposes. In a law suit, Atlanta asked the Corps to stop the release of downstream environmental flows. Atlanta lost the suit, but it case illustrates the political pressure that anyone making allocations to other than domestic water supplies will experience when there is a severe shortage of water.

Human life and well-being, especially in rural areas of the developing world, is closely linked to the health of aquatic ecosystems. Humans depend directly on the goods and services provided by these ecosystems, including food to meet nutritional requirements, clean fresh water to drink and wash, and the natural controls ecosystems provide on pathogens and other pests. These ecosystem services underpin most interventions promoted by health and hygiene programs, either supporting or counteracting them. They also strongly influence efforts to combat disease, prepare for climate change, and achieve Millennium Development Goals of reduced poverty and improved human health.

Estimating Ecosystem Requirements

Different ecosystems in different regions will be adapted to different flow regimes. But in any region, the fundamental requirement for maintaining aquatic ecosystem health is to maintain critical components of the natural flow regime.

Natural freshwater ecosystems have adapted to and depend on natural hydrologic variability. The structure and function of freshwater ecosystems are also linked to the watershed, or catchment, of which they are a part. Aquatic ecosystems are the recipients of materials generated from the land, and hence they are greatly influenced by terrestrial

processes, including human modifications of land use and cover. The environmental drivers that influence freshwater ecosystem structure and function include not only the flow regimes, but also the accompanying sediment, organic matter, nutrients and various pollutants, the thermal and light characteristics, and the interactions among the mix of species making up the ecosystem and in turn, their combined interactions with the water and land (Hughes, Colston, and Mountford, 2005).

Estimating just how much water should be allocated to instream environmental flows, particularly in data-poor arid areas, can be challenging. Those deciding on what water allocations to recommend or make can benefit from having models that can predict ecosystem and geomorphologic responses to flow changes, and the impacts of such changes on other users of the rivers. Generally these predictions depend on several characteristics associated with the flow regime.

The water stress indicator (WSI) map shown below as Figure 7 applies to environmental water needs – the amount of water needed to keep freshwater ecosystems in a fair condition. It was developed using global models of hydrology and water use. Red areas show where environmental water needs are not being satisfied because too much water is already being withdrawn for other uses.

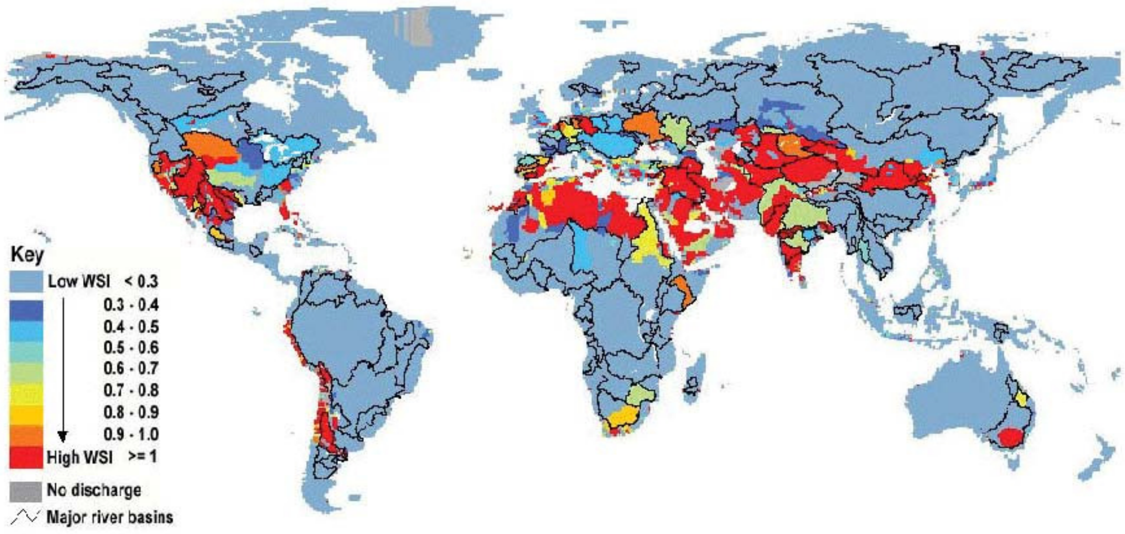

Figure 7. A current Water Stress Indicator Map that shows regions where environmental flow needs are not being met (http://www.cgiar.org/enews/june2007/story_12.html)

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Flow regimes can be defined by flow duration curves (flows vs. probability of exceedance). In addition, certain aspects of flow regimes are critical for regulating biotic production and diversity. These include base flow, annual or frequent floods, rare and extreme flood events, and annual variability. Flow regimes and hydroperiods also influence the circulation patterns, renewal rates, and types and abundances of aquatic vascular plants in lakes and wetlands.

The initial concept of water management was in part to tame nature, to eliminate if possible damaging floods and droughts. Engineers designed and built infrastructure to do this, and indeed this work continues throughout the world. But as a result, many rivers now resemble elaborate canals, with the timing and amount of flow completely controlled so as to maximize the traditional economic benefits derived from agricultural, domestic and industrial water supplies, protection from floods, navigation, recreation and the production of hydropower. While modern engineering has successfully delivered water to people and their farms and industries, mostly when and where they need it, it has often failed to protect the fundamental ecological function of rivers and aquatic systems.

Base flow conditions characterize periods of low flow between runoff events. They directly influence habitat suitability for aquatic organisms. The magnitude and duration of base flow varies space, reflecting differences in climate, geology, and land use.

Frequent small floods reset the system by flushing fine materials from the streambed, thus promoting higher production during base flow periods. High flows may also facilitate dispersal of organisms both up- and downstream. In many cases moderately high flows inundate adjacent floodplains and maintain riparian vegetation.

Occasional large floods can reform river systems. The flood waters transport large amounts of sediment, often transferring it from the main channel to floodplains. Habitat diversity within the river is increased as channel structure is formed, and succession regimes of riparian communities and floodplain wetlands are reset. Large flows can also remove exotic species that are poorly adapted to dynamic riverine environments, such as upland tree species, or non-native species whose success is often minimized by natural, high flows. The reduction of major floods due to reservoirs and their operating policies may also encourage the establishment and proliferation of exotic species in aquatic and riparian ecosystems.

Projected climate change is necessarily going to affect runoff patterns and hydrological dynamics. Most general circulation models (GCMs) of future climate change forecasting even greater flow variability with considerable variation in impacts between regions. Increased variability between seasons may well be one of many factors water allocation will have to consider in the future. Changes in climate will inevitably impact natural precipitation and runoff regimes which will impact many aquatic and terrestrial ecosystems.

Seasonal timing of flows (especially high flows) is important for the survival of many native species whose reproductive strategies are tied to such flows. For example, some fish use high flows to initiate spawning runs. Changing the seasonal timing of flows can degrade aquatic and riparian communities.

Annual variation in flow also impacts riverine systems. Interannual variation in runoff volume can improve species diversity. Ecosystem productivity and trophic structure can vary in response to interannual flow variation.

Quantifying Ecological Responses to Various Water Allocation Policies

One approach to quantifying the relationships between water regimes and ecosystem responses is to link hydrologic attributes (that can be managed) to the quality of the habitat of key species indicators. The use of these habitat index methods tends to be concentrated in the northern hemisphere and in developing countries aided by the United States and Europe. More holistic approaches are alternative methods. The use of these approaches seems to be more prevalent in the southern hemisphere, especially in South Africa and Australia (Tharme, 2003).

Environmental flow assessment methods are termed holistic if they address the management of all non-pristine river ecosystems, all major abiotic and biotic components of the ecosystem, and the full spectrum of flows and their temporal and spatial variability.

This may require the use of various models or modules of a larger ecosystem response model, such as:

a biophysical module designed to maximize understanding of an aquatic ecosystem and predict the effects of flow change on the stream, wetland, lake or river,

a social module designed to maximize understanding of how people use the water resources and to predict how they would be affected by changing flows and qualities, a module used to compile scenarios of hydrologic changes and the impact on people, and

an economic module in which the costs as well as the benefits of development scenarios can be identified and evaluated.

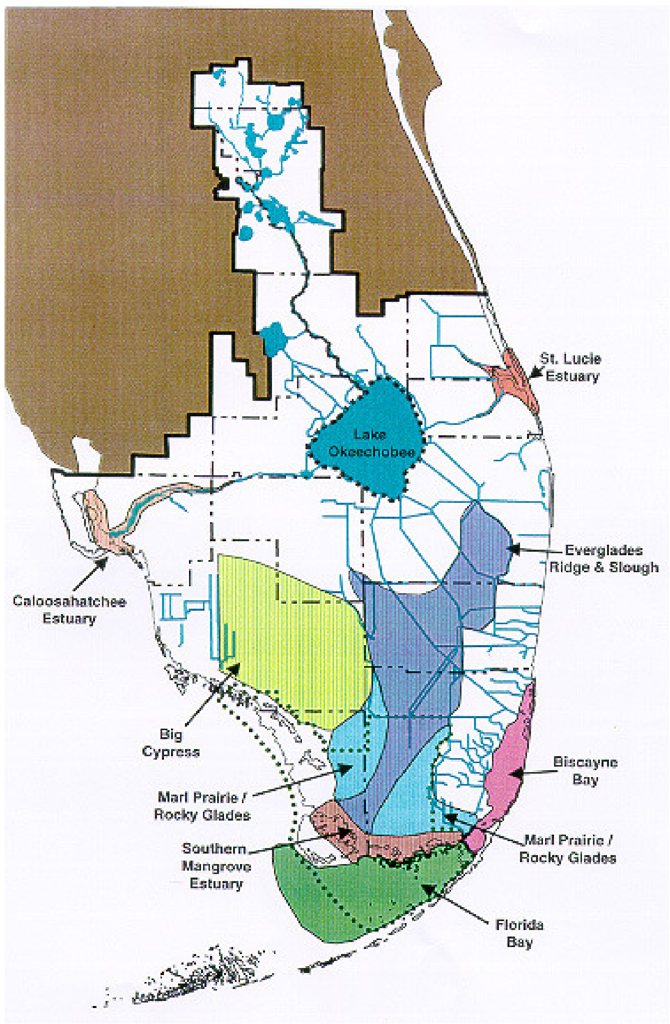
Such holistic environmental flow assessments (EFAs) are part of a new, comprehensive approach to water resource management that is to guide the sustainable use of water bodies and their ecosystems. The EFA approach makes the condition of the water body a priority management issue while still considering economic benefits. It is designed to identify the trade-off between development benefits and the maintenance of sustainable ecosystems. EFA implementation is not an issue for managers alone; scientists need to work side by side with managers to ensure its success and usefulness.

Case study of environmental flows – the Everglades

The south Florida ecosystem covers 47 000 km^2 (18 000 square miles) ranging from Orlando in the north to the Florida Keys at its southern extreme. It includes the Kissimmee River, Lake Okeechobee, Everglades National Park, and Florida Bay. The landscape is essentially flat; the elevation drop from Lake Okeechobee to Florida Bay, a distance of 161 km (100 miles), is 6.1 m (20 feet).

Figure 8. The Everglades region in Southern Florida, USA. The blue lines are the major canals used to transfer interior water to the coasts. The Everglades National Park is at the southern tip of the state. Lake Okeechobee is the second largest inland lake in the US.

South Florida (Figure 8) has undergone large changes in population, land use, and hydrology over the past 100 yr, resulting in substantial changes in ecosystem structure and function. The channelization of the Kissimmee River caused the loss of 11 000 ha (33 000 acres) of floodplain habitat. Accelerated eutrophication of Lake Okeechobee from runoff associated with dairy and beef cattle operations shifted algal, invertebrate, and macrophyte composition. Phosphorus enrichment of the northern Everglades from sugar cane farms has changed periphyton structure and biomass, while increasing cattail growth at the expense of sawgrass. Changes in the discharge of water to estuaries have resulted in large diebacks of seagrass, because of either too much or too little freshwater.


St. Lucie Estuary
Lake Okeechobee
Everglades Ridge & Slough
Caloosahatchee Estuary
Big Cypress
Biscayne Bay
Marl Prairie / Rocky Glades
Southern Mangrove Estuary
Marl Prairie / Rocky Glades
Florida Bay

Efforts began in the early 1900s to drain the Everglades wetlands, which were viewed as wastelands and a useless swamp. Hurricanes and floods prompted massive water management projects. This involved the construction of over .2600 km (1600 miles) of levees and canals, 150 gates and other water-control structures, and 16 major pump stations. This engineered system has worked remarkably well at what it was designed to do, i.e., making the region less vulnerable to the extremes of flooding and drought by storing water for supply and moving it for flood control. Environmental protection and ecosystem enhancement was not project objectives.

Management projects were designed in the 1950s when it was anticipated the population in the region would be two million by the year 2000. Today, the region is home to over ten times that, especially in the winter. One of the reasons people come to southern Florida is to enjoy the unique ecosystem – an ecosystem that has slowly been reduced and degraded by economic development and by the altered hydrologic flow regimes. Although it is not possible to restore this region to its pristine condition, efforts are underway today to redesign the south Florida environment to make it more compatible with the way the system used to function.

The Comprehensive Everglades Restoration Plan (Water Resources Development Act of 2000), is an ambitious, innovative partnership that includes the goals of enhancing the region's ecological and economic values, as well as its social well-being. The objectives of restoration activities are to increase the amount of water available by storing it instead of sending it out to sea, ensure adequate water quality, and reconnect the parts of this ecosystem that have been disconnected and fractured. This multi-faceted effort is expected to take 25 years or more to implement. And by that time the region will have experienced even more development, and possibly flooding from sea level rise.

The ecological goals of the plan are to increase the total spatial extent of natural areas, improve habitat and functional quality, and improve native species richness and biodiversity. Success will be evaluated with quantitative criteria, such as a goal for Lake Okeechobee of reducing the water column concentration of total phosphorus from a current concentration of 110 to 40 mg/L. Rigorous programs of scientific research will continue throughout project implementation, so that major uncertainties can be addressed.

This information, combined with results from the monitoring networks, will be evaluated so that the plan can be adaptively managed.

Management Actions and Challenges

Human society is served in the long term by ecosystem sustainability. We humans must

develop coherent policies that more equitably allocates water resources between natural ecosystem function and societal needs. Our welfare depends on it.

How can society extract the water resources it needs while not diminishing the important natural complexity and adaptive capacity of freshwater ecosystems? The requirements of freshwater ecosystems are often at odds with human activity, although this need not always be the case. Our present state of ecological understanding of how freshwater ecosystems function allows us to elaborate the requirements of freshwater ecosystems regarding adequate quantity, quality, and timing of water flow. Effective and timely communication of these requirements to a broad community is a critical step for including freshwater ecosystem needs in future water allocation decisions.

For scientific knowledge to be implemented science must be connected to the political decision making process. We scientists must explicitly identify and incorporate aquatic ecosystem needs in national and regional water management plans and policies. We must include watersheds as well as water in those plans and policies so that water resource allocation decisions are viewed within a landscape, or systems context. We must educate and communicate across disciplines, especially among engineers, hydrologists, economists, and ecologists to facilitate an integrated view of water resource management. We must include restoration efforts and protect the remaining freshwater ecosystems using well-grounded ecological principles as guidelines. We must recognize and acknowledge the dependence of human welfare on naturally functioning ecosystems. We must assist in the development of coherent policies that equitably allocates water to maintain functioning natural ecosystems as well as meeting other societal needs (Hinrichsen, Robey and Upadhyay, 1997).

Conclusion:

Society has been taught to think about the environment as something somewhere else. Ecological processes are often viewed as occurring in remote and exotic places, not as essential to our daily lives, or strongly influenced by our actions. Ecosystem sustainability requires that human society recognize, internalize, and act upon the interdependence of people and the environment in which they live and are a part. This will require broad recognition of the sources and uses of water for human health, societal and ecological needs. It will also require taking a much longer term view of water resource management and its associated infrastructure.

Water delivery systems, and even dams, are developed with lifespans and management policies of decades to at most a century. Aquatic ecosystems have evolved over much longer periods of time, and their sustainability must be considered for a long period to come. Governmental policies, mass media, and a market-driven economy all focus more on perceived short-term benefits. Local watershed groups interested in protecting their natural resources provide a good first step toward long-term stewardship. They need to be matched by state and national policies that recognize that fundamental human needs for water can only be sustained through decisions that preserve the life-support systems of aquatic ecosystems.

By satisfying the need for naturally varying flow regimes, and reduced pollutant

and nutrient inputs, natural aquatic ecosystems can be maintained or restored to a sustainable state that will continue to provide the amenities and services society has come to expect, as well as helping native species flourish. Especially in times of water scarcity, both humans and their ecosystems should have the highest priority for the water that is available. It is indeed water allocated to preserve and enhance life.

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