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The Changing Water Paradigm
A Look at Twenty-first Century Water Resources Development

Peter H. Gleick, *IWRA Member, Pacific Institute for Studies in Development, Environment and Security, Oakland, California, USA*

Abstract: *Water resources management approaches around the world are changing dramatically. This "changing water paradigm" has many components, including a shift away from sole, or even primary, reliance on finding new sources of supply to address perceived new demands, a growing emphasis on incorporating ecological values into water policy, a re-emphasis on meeting basic human needs for water services, and a conscious breaking of the ties between economic growth and water use. A reliance on physical solutions continues to dominate traditional planning approaches, but these solutions are facing increasing opposition. At the same time, new methods are being developed to meet the demands of growing populations without requiring major new construction or new large-scale water transfers from one region to another. More and more water suppliers and planning agencies are beginning to explore efficiency improvements, implement options for managing demand, and reallocating water among users to reduce projected gaps and meet future needs. The connections between water and food are receiving increasing attention as the concerns of food experts begin to encompass the realities of water availability. These shifts have not come easily; they have met strong internal opposition. They are still not universally accepted, and they may not be permanent. Nevertheless, these changes represent a real shift in the way humans think about water use. This paper summarizes the components of this ongoing shift and looks at the new paths being explored. It evaluates the major reasons for the change in approach and discusses the applicability of these new concepts in different parts of the world.*

Keywords*: Water policy, demand management, water supply, efficiency, conservation, development.*

Introduction

Water resources development around the world has taken many different forms and directions since the dawn of civilization. Humans have long sought ways of capturing, storing, cleaning, and redirecting freshwater resources in efforts to reduce their vulnerability to irregular river flows and unpredictable rainfall. Early agricultural civilizations formed in regions where rainfall and runoff could be easily and reliably tapped. The first irrigation canals permitted farmers to grow crops in drier and drier regions and permitted longer growing seasons. The growth of cities required advances in the sciences of civil engineering and hydrology as water supplies had to be brought from increasingly distant sources. And our "modern" industrial societies routinely and dramatically modify the hydrologic cycle through unprecedented construction of massive engineering projects for flood control, water supply, hydropower, and irrigation.

As the new millennium dawns, the dynamic process of managing freshwater resources and human demands for water is changing again. I have previously described these shifts as "the changing water paradigm" (Gleick, 1998). There are many components to this change: a shift away from sole, or even primary, reliance on finding new sources of supply to address perceived new demands; a growing emphasis on incorporating ecological values into water policy; a re-emphasis on meeting basic human needs for water services; and a conscious breaking of the ties between economic growth and water use. The evidence of a true change in the way we think about water continues to accumulate.

A reliance on physical solutions continues to dominate traditional planning approaches, but these solutions are facing increasing opposition. At the same time, new methods are being developed to meet the demands of growing populations without requiring major new construction or new large-scale water transfers from one region to another. More and more water suppliers and planning agencies are beginning to shift their focus and explore efficiency improvements, implement options for managing demand, and reallocate water among users to reduce projected gaps and meet future needs. The connections between water and food are receiving increas-

ing attention as the concerns of food experts begin to encompass the realities of water availability. These shifts have not come easily, they have not come without strong internal opposition, they are still not universally accepted, and they may not be permanent. Nevertheless, these changes represent a real shift in the way humans think about water use (Gleick, 1998).

Any article trying to present the components of such a shift must necessarily only skim the surface. This piece discusses twentieth century water management approaches and looks at the new paths being explored for the coming decades. It evaluates the major reasons for the change in approach and discusses the applicability of these new concepts in different parts of the world.

Twentieth Century Water Planning and Management

There have been three major drivers to the enormous expansion of water resources infrastructure in the past century: (1) population growth; (2) changing standards of living; and (3) expansion of irrigated agriculture. All three factors have increased dramatically. Between 1900 and 2000, the population of the world has grown from 1,600 million to over 6,000 million people. Land under irrigation increased from around 50 million hectares at the turn of the century to over 267 million hectares today. These and other factors have led to a nearly seven-fold increase in freshwater withdrawals (Figure 1).

Twentieth century water resources planning and development relied on projecting future populations, per-capita water demand, agricultural production, and levels of economic productivity. Because each of these variables has always been projected to rise, water needs have also always been expected to rise. As a result, traditional water planning regularly concludes that future water demands will inexorably rise and will eventually exceed developed water supplies. The water management problem then becomes an exercise in coming up with ways of bridging the anticipated gap. Prior to the 1980s, these exercises led planners to focus on supply-side solutions: they assumed that projected shortfalls would be met by taming more of the natural hydrologic cycle through construction of more physical infrastructure, usually reservoirs for water storage and new aqueducts and pipelines for interbasin transfers.

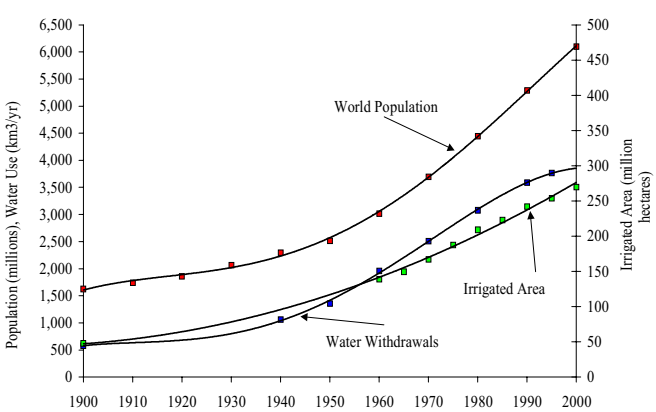

Figure 1. World Population, Water Use, and Irrigated Area.

The benefits of these past investments are undeniable. For example, food production has largely kept pace with population growth. Hydroelectricity generation reduces greenhouse gas emissions and has displaced air pollution associated with fossil fuel use. Water supplies in most developed countries are clean and reliable, eliminating many of the water-related diseases rampant in Europe and North America in the late 1800s. But these investments have also had costs. Providing this infrastructure has required an enormous economic investment. In the United States alone, total capital investment for water over the past century is estimated at $400 billion (unnormalized), mostly for large-scale engineering projects (Rogers, 1993). The numbers for worldwide investments are many times larger. And the costs have not been purely economic. The destruction of ecosystems, loss of fish species, dislocation of human populations, inundation of cultural sites, disruption of sedimentation processes, and contamination of water sources have been among the hidden costs of twentieth-century water development.

The End of Twentieth Century Planning Approaches

The twentieth century water development paradigm, driven by an ethic of growth, has now stalled as social values and political and economic conditions have changed. As the century and millennium change, major problems afflict current water planning and management approaches. The old paradigm of relying on ever-larger numbers of dams, reservoirs, and aqueducts to capture, store, and move ever-larger fractions of freshwater runoff is beginning to fail for environmental, economic, and social reasons. Basic human needs for water remain unmet. It is becoming harder and harder to find new, or even hold onto existing, water resources to supply croplands. And little attention has traditionally been paid to protecting natural ecosystems from which water supplies have been withdrawn.

Official water planning efforts usually make no attempt to analyze the details of what water is actually used for or how much water is required to meet different types of demands. Nor do they try to identify common goals for water development among conflicting stakeholders or to seek agreement on principles to resolve conflicts over water. The lack of consensus on a guiding ethic for water policy has led to fragmented policies and incremental changes that typically satisfy none of the many affected parties. Some suggest that the problem is primarily tech-

nical, and that we only need apply more efficient technology or better benefit-cost models to satisfy all interests involved. Others believe that only a reorganization of traditional planning agencies will rationalize water policy. Among the factors driving these changes are high costs of construction, tight budgets, deep environmental concerns, new technological advances, and the development of innovative alternative approaches to water management. The search for new solutions is also being pushed along in some places by the changing nature of demand for water.

The Changing Nature of Demand

Throughout the first three-quarters of this century, demand for water throughout the world increased, as shown in Figure 1. Freshwater withdrawals increased from an estimated 580 km^3/yr in 1,900 to around 3,700 km^3/yr in 2000 (Shiklomanov, 1998). In the U.S., the world's leading industrial power, these increases were even more dramatic. In 1900, estimated water withdrawals for all purposes were 56 cubic kilometers per year (km^3/yr). Water use in the U.S. peaked in 1980 at over 610 km^3/yr (Solley et al., 1998), a tenfold increase in water withdrawals during a period when population increased by a factor of four. Water withdrawals were not only growing in an absolute sense, they were growing in a per-capita sense. In 1900 in the U.S., annual average per-capita freshwater use was less than 700 cubic meters per person (m^3/p/yr). By the late 1970s and early 1980s, it had increased to nearly 2,300 m^3/p/yr (Solley et al., 1998; CEQ 1991; and Perlman, 1997). These increases in water demands in the U.S. and elsewhere, more than any other factor, drove the vast construction of water infrastructure.

Beginning in the mid-1980s and early 1990s, these trends ended in the United States (Figure 2). In a departure from the expectations and experience of water planners, water use started to drop, despite continued increases in population and economic wealth. Water withdrawals in the U.S. are now 10 percent below their peak, with declines in water use for both irrigation and power plant cooling. Industrial water use has dropped nearly 40 percent from its height in 1970 as industrial water-use efficiency has improved and as the mix of U.S. industries has changed. Yet industrial output and productivity have continued to rise dramatically, clearly demonstrating that it is possible to break the link between water use and industrial production. The decline in water use is even more dramatic when per-capita withdrawals are analyzed. Per-capita freshwater withdrawals peaked in 1980 and dropped more than 20 percent by 1995.

Though many regions continue to develop, and need more water, long-term projections of future global water needs have been steadily declining. Many conventional development water scenarios have been prepared over the past quarter century. Nearly twenty-five projections for the year 2000 are presented in Figure 3. This figure also shows actual water withdrawals over time. As these data show, the earlier projections (marked with asterisks) greatly overestimated future water demands by assuming that use would continue to grow at the historical rate. Even some recent projections for 2025, 2050, and 2075 project continued exponential growth. Yet actual global withdrawals for 1995 were only about half of what they were expected to be 30 years ago.

Without constantly increasing demand of three to four percent per year, the pressure to build new water infrastructure has diminished since existing supplies can be reallocated to other users. But the changing philosophy away from new development has also been driven by two other important factors: the increasing concern about the environmental impacts of water projects, and their increasing economic and costs.

The Role of the Environmental Movement: 1960 to the Present

Until the late 1970s and early 1980s, water planning and management rarely took into account the environmental consequences of major water projects or the wa-

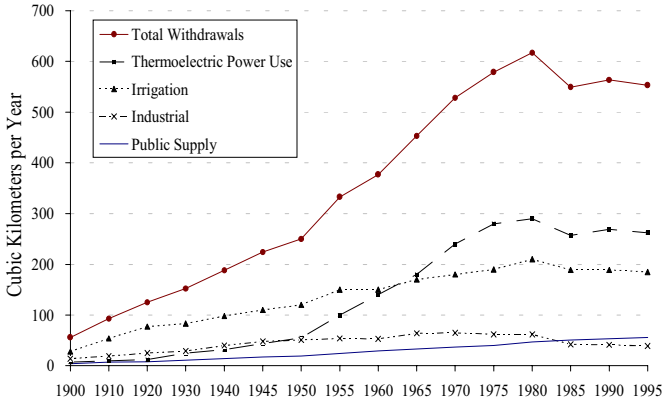

Figure 2. Water withdrawals in the United States: 1900 to 1995. Source: From Gleick, 1998.

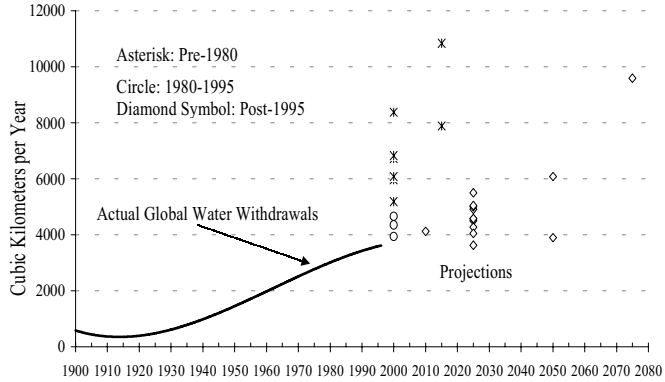

Figure 3. Water scenarios: projected and actual global water withdrawals. Source: Gleick, 2000.

ter required to maintain natural environmental resources and values. Recently, however, because of a wide range of well-publicized environmental problems and changing public opinions, even people who might previously have been willing to pay the economic costs of new structures are unwilling to accept their environmental costs.

In the industrialized nations, most of the good dam sites, as well as many of the bad ones, have already been developed, often with major environmental sacrifices. As a result, free-flowing rivers, natural riparian systems, and many aquatic species have become increasingly rare and valued. As overall environmental awareness has increased worldwide, the desire to protect some of these remaining natural resources has grown.

By the late 1960s and early 1970s, environmental movements in many countries were growing in strength and they have gotten stronger in recent years. While there are some concerns in developing nations that "environmental" limits may simply mean constraints on their economic development for the benefit of industrialized nations, there is growing grassroots opposition to big projects because of their serious local costs, including population displacement, land inundation, and ecological disruption. In recent years, several major projects have been delayed or halted because of opposition from local groups (Cernea, 1988; World Bank, 1993; and McCully, 1996). A major re-evaluation of major dam projects is underway through the World Commission on Dams. This effort is an attempt to come to some consensus among dam proponents and opponents about how to evaluate dam projects and incorporate more accurate estimates of their true costs and benefits (see www.dams.org).

Economics of Major Water Projects

Economic factors are also playing a role in changing the way we think about water development. New water supply systems have increasingly become expensive compared to non-structural alternatives. When the first major dam projects were being built, it was relatively unimportant that they be economically justifiable and economic analyses were done with incomplete information and questionable assumptions. For example, all non-market environmental and social costs were simply excluded because they were unquantified or unquantifiable. Economic games were also played with stretched-out repayment periods, high discount rates, low-interest loans, and a transfer of costs to non-dam parts of water developments.

A second aspect of these new economic constraints is that almost all past water infrastructure development has been subsidized or fully paid for by governments and international financial organizations. Governmental budgets in Asia and many other regions are now under great pressure and there are serious constraints on new money for major water projects. While this pressure has been felt in every sector of society, it plays a particularly important and direct role in changing national water policies by limiting central governmental involvement in new capital-intensive projects and shifting more responsibility to regional and local governments.

Having seen large amounts of development in the past, and having borne many of the non-monetary impacts of that development, many people are no longer willing to pay for new structures to solve water problems.

A New Paradigm for Water Planning

Meaningful change towards a new approach and a new way of thinking has to begin with an open discussion of the ultimate ends of water resource policy. More people now place a high value on maintaining the integrity of water resources and the flora, fauna, and human societies that have developed around them. There are growing calls for the costs and benefits of water developments to be distributed in a more equitable manner and for unmet basic human needs to be addressed. And more and more, efforts are being made to understand and meet the diverse interests and needs of all affected stakeholders. If the next generation of water planners continues to try to integrate these principles, the present stalemate and paralysis on how to move forward will ease and a new era of innovative water management will ensue.

Traditional approaches to water planning, while still firmly entrenched in many water planning institutions, *are* beginning to change. Continued investments in huge systems that provide more water for some is being challenged by those who believe a higher priority should be assigned to projects that meet basic unmet human needs for water (Gleick, 1996). The question of whether we will be able to produce enough food to feed the world's burgeoning population, and get it to where it is needed, is now understood to be intricately connected to the question of where and when fresh water is available. Decisions made today about water policy will affect whether people continue to be undernourished in the coming decades. There is great potential for improving the "water efficiency" with which we produce food, by changing cropping patterns toward crops that require less water per calorie to produce, by reducing wasteful applications of water, by cutting losses between the field and the plate, and by altering diets and the functioning of international markets.

There is a new trend to take out or decommission dams that either no longer serve a useful purpose or have caused such egregious ecological impacts as to warrant removal. Nearly 500 dams in the U.S. and elsewhere have already been removed and the movement toward river restoration is accelerating (Gleick, 2000). Within a few months of the Edwards Dam being removed in Maine in mid-1999, salmon, striped bass, alewives, and other affected fish returned to waters above the old dam site from which they had been absent for 162 years (*New York Times*, 1999).

As traditional water-supply approaches of building

another dam or drilling another tubewell become less appropriate or more expensive, unconventional supply approaches are receiving more attention. More and more cities are discovering that wastewater can be a resource, not a liability, for purposes ranging from landscape irrigation to drinking water. Several other unusual approaches are receiving more attention, including large- and small-scale desalination technology, water reclamation and reuse, and techniques such as fog collection. Matching water demands with available waters of different quality can reduce water supply constraints, increase system reliability, and solve costly wastewater disposal problems. Even esoteric ideas are being explored, for example, the concept of transporting fresh water in large ocean-going plastic bags has moved from theory to reality, with small projects underway in the Mediterranean Sea (Gleick, 1998).

As an alternative to new infrastructure, efforts are now underway to rethink water planning and management. Many individual nations as well as international aid organizations are rethinking water policy and putting greater emphasis on development principles that reflect environmental, social, and cultural values. Among the major principles that appear to be common to all these new approaches are:

- Basic human needs for drinking water and sanitation services must be met.
- Basic ecosystem needs for water must be met.
- The use of non-structural alternatives to meet demands must receive higher priority.
- Economic principles must be applied more frequently and reliably to water use and management.
- New supply systems, if needed, must be flexible and maximally efficient.
- Non-governmental organizations, individuals, independent research organizations, and other affected stakeholders must all be involved in water management decisions.

A working definition of sustainable water use applying these principles is that the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it.

Some new dams, aqueducts, and water infrastructure will certainly be built, particularly in developing countries where the basic water requirements for humans have still not been met. But even in these regions, new approaches are being developed, or old ones rediscovered, which permit water needs to be met with fewer resources, less ecological disruption, and less money. Successfully meeting human demands for water in the next century will increasingly depend upon non-structural solutions and a completely new approach to planning and management. The most important single goal of this new paradigm is to re-integrate water use with maintaining ecological health and environmental well-being. On the water use side, we must refocus our efforts with the objective of increasing the productive use of water. Two approaches are needed: (1) increasing the efficiency with which current needs are met; and (2) increasing the efficiency with which water is allocated among different uses. Where new supplies are still needed, major new projects must now compete with innovative small-scale approaches, including micro-dams, run-of-river hydro, land management and protection methods, and other locally-managed solutions. In addition to this, non-traditional sources of supply will play an increasing role, including reclaimed or recycled water and, in some limited circumstances, desalinated brackish water or seawater.

Meet Basic Human Needs for Water

Universal access to basic water services is one of the most fundamental conditions of human development. Yet as we enter the 21st century, billions of people lack such access. The numbers are stark as more than a billion people in the developing world do not have safe drinking water and nearly three billion people live without access to adequate sanitation systems necessary for reducing exposure to water-related diseases. The failure of the international aid community, nations, and local organizations to satisfy these basic human needs has led to substantial, unnecessary, and preventable human suffering. An estimated 14 to 30 thousand people, mostly young children and the elderly, die every day from water-related diseases. At any given moment, approximately one-half of the people in the developing world suffer from diseases caused by drinking contaminated water or eating contaminated food (United Nations, 1997). A formal review of international law, declarations, and State practice supports the conclusion that access to a basic water requirement can be considered a fundamental human right (McCaffrey, 1992; Gleick, 1999). This right to water could also be considered even more basic and vital than some of the more explicit human rights already acknowledged by the international community. And a transition is underway making a right to water explicit.

Certainly no rational water policy for the 21st century can continue to ignore this most fundamental need. Therefore, as a first step, governments, international aid agencies, water agencies, non-governmental organizations, and local communities must work to provide all humans with a basic water requirement and to guarantee that water as a human right. By acknowledging a human right to water and expressing the willingness to meet this right for those currently deprived of it, the water community would have a useful tool for addressing one of the most fundamental failures of 20th century development.

Restore and Maintain Ecological Health

Perhaps the next greatest failing of twentieth century water policy was the failure to understand the connections between water and ecological health, and the links between the health of natural ecosystems and human well-being. As a result, among the most important objectives for twenty-first century water managers are to understand those links and to integrate ecological and human water needs in a comprehensive way. For some ecosystems, it is too late. The destruction of the Aral Sea and the extinction of the endemic species of fish there are largely irreversible. Invasions of aquatic systems by exotic species, once established, can be difficult or impossible to stop. But we have also learned that ecosystems can be resilient and restored, if proper resources and knowledge are applied.

Minimum water requirements must be determined, provided, and protected for natural ecosystems. Determining the nature and characteristics of these requirements can be very difficult; sometimes they are related to minimum flow requirements, or temperature limits, or a need for peak flows during certain periods, or water of a certain quality. But these requirements must be met as a fundamental condition of water resources development or we risk impoverishing ourselves of our natural resources and undermining the natural support structures on which we depend.

Non-Structural Water Development: Increase the Efficient Use and Allocation of Water

A key component of non-structural approaches to water resources management is a focus on using water more efficiently and then reallocating saved water. In the mid-1970s, arguments against developing new supplies of energy began to gain favor, driven in part by concerns over nuclear power's high costs and the potential for catastrophic accidents, and over the accumulating environmental consequences of fossil fuel combustion. During this period, some analysts argued that more efficient use of energy could significantly reduce future demand and delay or avoid the need for the construction of economically and environmentally costly new construction (e.g., Lovins, 1977). These arguments have turned out to be largely true, and the proper incentives have led to tremendous drops in energy demand, while economic well-being has continued to improve.

The same arguments are now beginning to be heard over water. New sources of water supply can largely be avoided in many regions by implementing intelligent water conservation and demand-management programs, installing new efficient equipment, and applying appropriate economic and institutional incentives to shift water among users. Improvements in water use efficiency will come about through changes in technology, economics, and institutions. Vast improvements in water use efficiency are possible in almost all sectors. In both developed and developing countries, large losses occur in distribution systems, faulty or old equipment, and poorly designed or maintained irrigation systems. In California, "unaccounted" for water in urban systems is estimated at 10 percent, but many individual water districts have much higher losses (CDWR, 1998). Many irrigation canals in the western U.S. are unlined, leading to significant seepage losses. In Jordan, one estimate is that at least 30 percent of all domestic water supply never reaches users because of flaws and inadequacies in the water-supply network, and the losses reach 50 percent in Jordan's capital, Amman (Salameh and Bannayan, 1993). It has been estimated that the amount of water lost in Mexico City's supply system is equal to the amount needed to supply a city the size of Rome (Falkenmark and Lindh, 1993). While such losses are difficult to estimate accurately, there is little disagreement that significant water savings improvements are possible.

Even where efforts to improve water use efficiency have begun, great potential still exists for reducing water use without sacrificing economic productivity or personal welfare. In a mundane but highly revealing example, the United States passed a law, effective in 1994, requiring that all new toilets use about one-third the amount of water traditionally used. Even today, however, this sector shows substantial untapped potential. In California, where major efforts have been made to retrofit old toilets with more efficient ones, more than half of the potential savings has yet to be achieved (Figure 4). Because of the growing difficulty of finding new sources of water to supply Mexico City, city officials launched a water conservation program. As part of this program, 350,000 toilet replacements have already saved enough water to meet the needs of 250,000 additional residents (Postel, 1997).

Technological innovation will play an important role in every water-using sector from producing goods and services to growing food. In all economic activities, water demands depend on two factors, what is being pro-

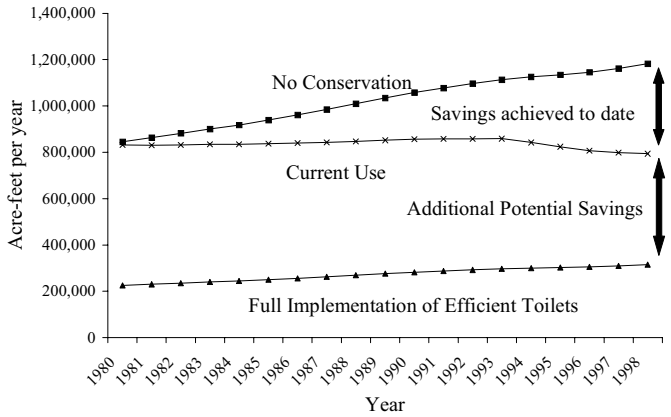

Figure 4. Water used for toilets in California, actual and potential savings to date.

duced, and the efficiency with which it is produced. Total industrial water use thus depends on the mix of goods and services demanded by society and on the processes chosen to generate those goods and services. Making a ton of steel in the 1930s typically consumed 60 to 100 tons of water. Today that same steel can be produced with less than six tons of water. Yet producing a ton of aluminum today only requires one and a half tons of water (Gleick, 1998). Replacing old steel-making technology with new can reduce water needs. Replacing steel with aluminum, as has been happening for many years in the automobile industry for other reasons, can also reduce water needs. Japan used nearly 48,000 cubic meters of water to produce a million dollars of industrial output in 1965; by 1989, this had dropped to 13,000 cubic meters of water per million dollars of output (in real terms) – a tripling of industrial water productivity (Postel, 1997). Similar changes have occurred in California, where total industrial water use dropped 30 percent between 1980 and 1990 without any formal or intentional efforts, because of natural economic and technological changes that occurred during the decade. Over the same period, total gross industrial production rose 30 percent in real terms (CDOF, 1994). The potential still exists to reduce industrial water use through cost-effective means by at least another 20 to 30 percent or more and similar savings are available in the commercial and institutional sectors in California (Gleick et al., 1995; Sweeten and Chaput, 1997).

Comparable industrial water savings are often possible in developing countries as well, though less detailed information is typically available. Gupta et al. (1989) describe how increased water prices and government restrictions on wastewater discharges encouraged the Zuari Agro-Chemical fertilizer plant in Goa, India to reduce total daily water use 50 percent between 1982 and 1988. Similar interventions in Tianjin, China reportedly reduced industrial water use per unit of industrial output there by about 60 percent, and economic incentives led to improvements in industrial water-use efficiency by between 42 and 62 percent in three industrial plants in Sao Paulo, Brazil in the early 1980s (Bhatia and Falkenmark, 1992).

Technological change is a dynamic and ongoing process, even for a technology as mundane as toilets. Concerns over the reliability of water supply in Singapore, and their vulnerability to water supply disruptions, led them to launch a campaign to improve water-use efficiency, which included replacing what the U.S. now considers "ultra-low flow toilets" with even higher efficiency models. These kinds of changes have already led to further water and economic savings in Singapore (Zachary, 1997). And there are no technological reasons why toilets have to use any water at all. Some experts argue that in regions of the world where water is scarce, it makes little sense to use water for disposing of human wastes when other satisfactory alternatives exist (Kalbermatten et al., 1982; Rogers, 1997).

Water productivity can also be improved in outdoor gardens, municipal lawns, golf courses, and other urban landscapes. In some parts of the United States as much as half of all residential or institutional water demand goes to water gardens and lawns. Improvements in watering efficiency could reduce that demand substantially, as could changes in the composition of these gardens. Innovative garden designs, combined with new computer controllers, moisture sensors, and water technology all can reduce outdoor water use in homes by 25 to 50 percent or more depending on homeowner's preferences, the price of water, and the cost of alternatives (Gleick et al., 1995). In some regions, outdoor municipal and institutional landscape irrigation is being done with reclaimed water, completely eliminating the use of potable water for this purpose.

The largest single use of water is in agriculture and a substantial amount of this water could be used more productively. Water is lost as it moves through leaky pipes and unlined aqueducts, as it is distributed to farmers, and as it is applied to grow crops. Some analysts estimate that the overall efficiency of agricultural water use worldwide is only 40 percent (Postel, 1997), meaning that more than half of all water diverted for agriculture never produces food. In most basins, overall irrigation efficiency may be higher than single farm efficiencies as downstream irrigators reuse water lost to seepage from inefficient irrigation. But even in these basins, efforts to reduce unproductive evaporative losses can produce new water for agricultural use.

In water-short areas, new techniques and new technologies are already changing the face of irrigation. New sprinkler designs, such as low-energy precision sprinklers and drip systems can increase irrigation efficiencies from 60 to 70 percent to as high as 95 percent (Postel, 1997). Not all crops are suitable for precision irrigation systems, although drip irrigation, formerly limited to orchards and vineyards, is increasingly being used for row crops. Even cotton is now being grown in parts of California with drip systems (Fidell et al., 1999). Identifying technical and institutional ways of improving the efficiency of agricultural water systems will go a long way toward increasing agricultural production without having to develop new supplies of water. Examples of successful implementation of these kinds of strategies have been described in Owens-Viani et al. (1999).

Economics and Water Pricing

Inappropriate pricing policies and economic subsidies encourage wasteful use of water and inhibit efficiency and conservation programs. There are growing efforts, however, to treat water as an economic good and this was one of the four principles adopted at the Dublin conference in 1992. While there is disagreement about how to define "economic good" or to apply the concept, a variety of new economic and pricing approaches are now con-

tributing to the shift in water resources development approaches.

In the past, widespread subsidies have encouraged rapid development of supply systems and hindered water efficiency efforts. These subsidies have been very effective at accomplishing their goals in both urban and agricultural settings. Urban centers in the western U.S., Mexico City, Singapore, Beijing, and many other cities now support very large urban populations where there would otherwise have been inadequate water supplies. Semi-arid deserts can now produce vast amounts of food where rainfall alone would be insufficient. But these subsidies have also been responsible for unplanned and undesired side effects. Subsidized cotton production in central Asia expanded so much that the inflows of water from the Amu and Syr Darya rivers to the Aral Sea were cut off, leading to a shrinking of the Sea, the extinction of endemic species, and adverse impacts on human health. Fossil groundwater in Saudi Arabia has been used unsustainably to grow subsidized wheat. Between 1980 and 1995, Saudi Arabia consumed more than 75 percent of the proven reserves of water in its major aquifers (FTGWR, 1997). This water can only be replenished over hundreds, or even thousands, of years. Groundwater overdraft in India, encouraged by subsidized energy costs for pumping and a lack of groundwater regulation, now threatens that country's agricultural self-sufficiency.

The agricultural sector has particularly benefited from water subsidies. In much of the world, around 75 percent of all water consumed goes to agriculture. The extremely low cost of water encourages the production of crops that are both low-valued and highly water intensive and it provides no incentive to use water efficiently. Even modest changes in agricultural practices would free up substantial amounts of water for other agricultural uses, urban needs, and environmental restoration.

Some changes are already beginning to occur. The growth of cities and their far greater economic productivity are now beginning to demand more water. In places like Israel and California, urban development combined with constraints on new supply options, have led to increasing reliance on water use efficiency programs and innovative management, and use of reclaimed water for irrigation and other uses (Owens-Viani et al., 1999).

Economic factors and pricing decisions also lead to inefficient water use in the urban sector. In many cities, water use is not measured or "metered," which leads to overuse of water and provides no incentives for efficient use. Even in regions with water metering, the inappropriate design of rate structures can lead to misuse of water. As a result, there is growing interest in the use of so-called "conservation" rates, such as increasing block rates, where increasing amounts of water are charged higher and higher rates. More and more water utilities are implementing such rate structures. In Beijing, China, a new pricing system links the cost of water to the amount of water used, thus encouraging conservation. A similar pricing system decreased average monthly residential water use by nearly 30 percent in Bogor, Indonesia (Postel, 1997). Regional water providers in South Africa have been able to delay the construction of new regional water-supply systems by imposing higher rates, distributing water-conservation equipment, and educating the public (Rand Water, 1996). In Hermanus, South Africa, a major conservation program included an 11-step rate structure that encouraged technological improvements and careful attention to wasteful practices. In just the first year of operation of the program, water use in the city dropped more than 30 percent (Gleick, 1998).

While the new emphasis on treating water as an economic good can eliminate wasteful practices and encourage increased efficiency and conservation, a purely market approach cannot adequately protect the natural ecosystems that also depend upon water. Nature provides services that help keep humans alive, but these services are not "purchased," rarely quantified, and routinely excluded from official economic accounts (Daily, 1997). In the drive toward economic rationality, care must be taken to preserve and protect those services that may fall outside of traditional economic measures.

Alternative Supplies

Efficiency improvements will go a long way toward reducing future demands. In some regions, these may be sufficient to completely eliminate the need to find and develop new supplies. In other regions, however, new supplies will continue to be required. Rather than seeking new pristine sources from far away, however, a wide range of alternative water supplies will increasingly be used to meet certain demands. Meeting different needs with the appropriate quality of water may prove to be economically beneficial and at the same time reduce the need for new supplies at a higher and higher marginal cost. "Reclaimed" water, graywater, fog collection, recycled water, brackish water, salt water, or desalinated water may all be considered usable for some needs, and in fact, may have environmental, economic, or political advantages. Reclaimed water, in particular, has some remarkable advantages, including a high reliability of supply, a known quality, and often, a centralized source near urban demand centers. Providing high-quality potable drinking water is expensive, and using that water to meet all needs is unnecessary where water is scarce.

Reclaimed Wastewater

Societies spends billions of dollars finding water, treating it to high standards, and then moving it to where it is needed. We then spend billions more to collect wastewater, treat it to reduce human and environmental health problems associated with sewage and industrial waste, and then dump it into the oceans or other sinks. The majority of urban water ends up being thrown away after

being used once. More recently, attention has focused on treating this water and using it as a resource rather than considering it extraneous waste (Asano and Levine, 1998). Drought conditions limiting supply, environmental problems with sewage disposal, and growing demands have all made water reclamation more appealing.

Reclaimed water can be used to recharge groundwater aquifers, supply industrial processes, irrigate certain crops, or augment potable supplies. In the Middle East, parts of Africa, and the western U.S. there has been a significant increase in the availability and use of treated wastewater for a wide range of industrial, commercial, and institutional needs (Wong, 1999).Some agricultural water needs are now being met with treated wastewater. In Windhoek, Namibia, reclaimed water has been used to augment the potable water supply since 1968, and in drought years up to 30 percent of the city's drinking water supply is treated wastewater (Van der Merwe and Menge, 1996). The U.S. National Academy of Sciences has completed a study on appropriate uses of highly treated wastewater for indirect augmentation of drinking water supplies (U.S. National Research Council, 1998).

Israel has extensive wastewater reclamation programs. Seventy percent of Israeli wastewater is treated and used for agricultural irrigation and Shuval (1996) estimates that 80 percent recycling is likely in the next few decades. Efforts to capture, treat, and reuse more wastewater are also being made in neighboring Jordan where overall water supplies are also highly constrained (Ahmad, 1989; Salameh and Bannayan, 1993). In California, by the year 2000, over 600 million cubic meters of reclaimed water were being used for different purposes (Table 1) and this could be as high as 2,000 million m^3/yr by 2020 (Wong, 1999).

Desalination

For decades, some water analysts and observers have held out desalination as the ultimate solution to the world's water woes. More than 97 percent of the water on the planet is too salty to drink or grow food. In theory, therefore, desalination offers a limitless supply of freshwater, freeing humans from the vagaries and inconsistencies of natural freshwater supplies. Yet like the unfulfilled promise of cheap nuclear power in the 1960s and 1970s, desalination remains a minor contributor to water supply, providing only a fraction of a percent of total human needs.

The desalination of seawater or brackish water is technologically well developed, but remains hindered by high economic costs in part because of the large amounts of energy required to strip salt ions from water. While technological optimists continue to predict declining costs with improving technology, desalination is only an option at present for extremely water-short countries with substantial energy or economic resources, such as in the Arabian Gulf and North Africa, where six of the top ten desalinating countries are located. In addition, the high cost of moving water from one place to another further constrains desalination developments to areas within a limited distance from the coasts.

By early 1999, total global desalination capacity exceeded 20 million cubic meters per day (Wangnick, 1998). Figure 5 shows desalination capacity worldwide from 1950 to 1999. Waters of different quality, including seawater, brackish water, or impure industrial wastewater, can be desalinated. But desalination cannot yet be considered a reasonable solution to domestic water shortages in most regions, even wealthy ones. Whether it will eventually become sufficiently cheap for large-scale use remains uncertain.

Table 1. Use of Recycled Water in California by Category

	1987	*1989*	*1993*	*1995*	*2000**
Agricultural Irrigation	207	213	99	179	201
Groundwater Recharge	48	86	228	150	167
Landscape Irrigation	49	67	58	94	141
Industrial Uses	7	7	9	36	40
Environmental Uses	12	22	36	19	20
Other	5	5	44	76	77
Total	328	400	474	554	646

*Estimated. Amounts in million cubic meters. Source: Wong, 1999.

Summary: New Thinking, New Actions

Basic concepts and philosophies of water development are undergoing fundamental changes. Whether water is plentiful or scarce, environmental, financial, and social constraints are slowing the construction of large projects and leading planners to extend limited supplies through reallocation and efficiency improvements. Even in regions where basic human needs for water have not been met, water conservation programs are becoming an integral part of practical solutions, since they permit overall water needs to be met with fewer resources, less disruption of ecosystems, and lower costs.

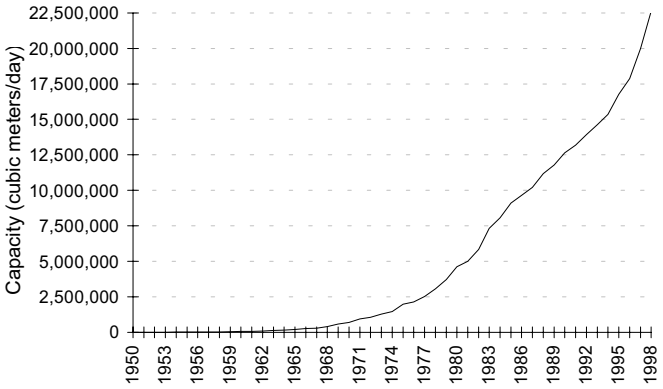

Figure 5. Cumulative Desalination capacity worldwide, 1950 to 1998. Source: Wangnick, 1998.

In many parts of the world there will continue to be strong pressures to provide major new water systems, especially if those systems are dedicated to meeting some of the basic human needs remaining in developing countries. Where providing drinking water supply or baseline hydroelectric power is still possible without enormous social dislocations or economic and environmental costs, large new projects may still be appropriate and necessary.

But large-scale projects can no longer be expected to provide the answer to most water problems. In particular, in developed countries as well as in arid and semi-arid regions that cover another 30 percent of the earth's land area, large-scale dams, reservoirs, and irrigation schemes are increasingly out of favor. Only four percent of sub-Saharan Africa's cropland is currently irrigated, yet few good dam sites remain and the economic, social, and environmental costs of large irrigation projects are high. Favorable conditions, such as high-yield groundwater basins, rivers with reliable flows, and large areas of uncultivated irrigable lands are increasingly rare.

Major new projects must now compete with innovative smaller-scale, locally managed technical, institutional, and economic solutions, including micro-dams, run-of-river hydro systems, shallow wells, low-cost pumps, water-conserving land management methods, and rainwater harvesting approaches. Such methods are often more cost-effective and less disruptive to local communities, in part because of traditional experiences of these communities. There is already evidence that new applications of traditional methods can catalyze farmers into improving management techniques, stimulating local development, and meeting local water needs in many places where large-scale irrigation projects have failed (Clarke, 1991). One estimate is that 100 million people in Africa alone could benefit from the adoption of small-scale, low-cost traditional methods, but that lack of knowledge and technology continue to hinder their widespread adoption (Postel, 1997).

More rapid changes in water policy worldwide have not occurred because economic and institutional structures still encourage inefficient use of water. Part of the problem, however, also lies in the prevalence of old thinking among water planners and managers. An ethic of sustainability will require fundamental changes in how we think about water, and such changes come about slowly. Rather than endlessly trying to find the water to meet some projection of future desires, it is time to plan for meeting present and future human needs with the water that is available, to determine what desires can be satisfied within the limits of our resources, and to ensure that we preserve the natural ecological cycles that are so integral to human well-being. Water resource planning in a democratic society must involve more than simply deciding what big project to build next or evaluating which scheme is the most cost-effective from a narrow economic perspective. Planning must provide information that helps people to make judgments about which "needs" and "wants" can and should be satisfied. Water is a common good and community resource, but it is also used as a private good or economic commodity; it is not only a recreational resource but also a basic necessity of life; it is imbued with cultural values and plays a part in the social fabric of our communities. Applying new principles of sustainability and equity will help bridge the gap between such diverse and competing interests.

About the Author

Dr. Peter H. Gleick is director of the Pacific Institute for Studies in Development, Environment, and Security in Oakland, California. Email: pgleick@pipeline.com. He is author of *The World's Water 1998-1999* and *The World's Water 2000-2001* (Island Press, Washington, DC, USA), and many scientific papers. In 1999, he was elected Academician of the International Water Academy in Oslo, Norway.

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