**Human Population and Water: To the Limits in the 21st Century**

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

Water is a vital resource, necessary for all aspects of human and ecosystem survival and health. In recent years, new alarms have been sounded about growing water scarcity and contamination and the likely inability to meet the water requirements of rapidly growing populations (Postel 1992, Gleick 1993, Engleman and LeRoy 1993). This paper briefly reviews current critical water issues, describes how these problems may worsen in the future, explores the connections between human population and freshwater problems, and proposes a new way of addressing those connections. In particular, the concept of sustainable water use is defined and discussed in the context of growing human populations.

**The Present Problem**

While there is no need to describe in detail the geophysical characteristics of the stocks and flows of fresh water (see, for example, Shiklomanov 1993), it is important to review some fundamental points. Although the Earth is often called the "water planet" because of the vast amount of water present, these water resources are unevenly distributed in space, time, and type. Ninety-seven percent of all water is salt water -- too salty to drink or grow crops. And of the other three percent, the vast majority is locked up out of practical human reach in the vast icecaps of Greenland and Antarctica and in deep groundwater aquifers. The small fraction of fresh water that is accessible to us is extremely unevenly distributed in space and time; so unevenly that society spends billions of dollars every year to move water from wet areas to drier areas, to store it in wet seasons for coming dry periods, or to clean otherwise undrinkable sources. These characteristics of freshwater use and distribution lead to a wide range of water-related problems, including interstate conflicts over access and quality, competition between urban, rural, and environmental uses, severe human health problems, and constraints on economic development.

In 1990, nearly 2 billion people in the poorer parts of the world lacked access to clean drinking water and adequate sanitation, something nearly everyone in industrialized nations takes completely for granted. Ironically, over a billion people throughout the world are served either by sewage treatment systems that do not measure up to the standards set by ancient Rome, or by no systems at all. The direct and indirect human costs of this are enormous and include extensive health problems, high labor costs, particularly for women (primarily) forced to travel long distances each day to haul water to meet even the most minimal needs, and severe limits on the extent and form of economic development. As a result of the lack of clean water and sanitation services, there are billions of cases of water-related diseases with over five million deaths every year (Warner 1995). Table 1 shows current estimates of water-related disease morbidity and mortality. These problems are getting worse. In 1991, a new cholera pandemic spread across Latin America, which had been free of cholera for more than one hundred years and which now has more cholera cases than any other continent (see Figure 1).

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| Table 1: Estimates of Morbidity and Mortality of Water-Related Diseases |
|  | Disease | Morbidity (episodes/year) | Mortality (deaths/year) |
| Diarrhoeal Diseases | 1,000,000,000 | 3,300,00 |  |
| Intestinal Helminths | 1,500,000,000 (people infected) | 100,000 |  |
| Schistosomiasis | 200,000,000 (people infected) | 200,000 |  |
| Dracunculiasis | 100,000 (people infected, excluding the Sudan) | - |  |
| Trachoma | Trachoma | 150,000,000 (active cases) | - |
| Malaria | 400,000,000 | 1,500,000 |  |
| Dengue Fever | 1,750,000 | 20,000 |  |
| Poliomyelitis | 114,000 | - |  |
| Trypanosomiasis | 275,000 | 130,000 |  |
| Bancroftian Filariasis | 72,800,000 (people infected) | - |  |
| Onchocerciasis | 17,700,000 (people infected; 270,000 blind) | 40,000 (mortality caused by blindness) |  |
| Source: WHO, 1995 |  |

**Combining Population and Water Issues**

One traditional way that hydrologists concerned with social water issues measure scarcity is by looking at per-capita water availability or use; i.e., the water available or used in a region per person. Assuming that the world's renewable freshwater supply is relatively constant (an assumption explored further below), the average amount of water available per person in 1850 was about 43,000 cubic meters per year. By 1990, this figure had dropped to 9,000 cubic meters per year, simply because of the increase in global population. When measured this way, the spatial and temporal distribution problems described above become even more evident.

Figure 2 shows the great variations in current per-capita water availability for each continent. Oceania has over 70,000 cubic meters per person per year (m3/person/year), the average for all of Africa is under 7,000 m3/person/year, while that of Asia is only 3,400 m3/person/year. Even greater disparities are noticeable if one looks at a national or regional basis. For example, Iceland, Norway, Canada, and New Zealand all get more than 100,000 cubic meters of water per person per year; some countries in Northern Africa and the Middle East have less than 100 m3/person/year (Gleick 1993). Parts of the eastern United States get two or three times the amount of water that California gets, and many times the amount received by the arid southwestern U.S., per person.

Just as physical water availability is unevenly distributed around the world, per-capita water use also varies widely for physical, economic, and social reasons. North Americans use over 1,600 cubic meters per person per year, while the average in Europe is 725 m3/person/year (Figure 3). In Africa the average water withdrawal is under 250 m3/person/year, reflecting the limited physical resources available, the large populations, and poorly developed water-supply systems.

Using per-capita water availability or water use figures as measures of scarcity explicitly raises the issue of population. When the total amount of water available is relatively fixed, larger and larger numbers of people will reduce total per-capita water availability over time. This simple observation has spawned a substantial literature, ranging from the early work of Falkenmark and Lindh (1974) in which regional water availability is compared to water demands under different population scenarios, to the more recent study of Engleman and LeRoy (1993, 1995 revision), which takes national water availability data from Gleick (1993) and combines them with UN population projections to the year 2050 to highlight those regions where scarcity either already exists or is likely to develop in the coming decades.

Table 2 from Engleman and LeRoy (1995) shows the 1990 population living in regions with water "scarcity" and water "stress," usually defined as regions with less than 1000 and 1667 cubic meters per person per year respectively. Using United Nations low, medium, and high population projections, this Table also shows how those populations will increase up to the year 2050. If population growth is closer to the high population track than the low projection, 250 million more people will be subject to severe water scarcity in the year 2025.

**Table 2: Populations in Water-Scarce, Water-Stressed, and Water-Abundant Regions (thousands)**

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| --- | --- | --- | --- | --- |
|  | **1990** | **2000**  | **2025** | **2050** |
| **Low UN Projection** |  |  |  |  |
| Scarcity | 132,402 | 276,535  | 652,791 | 1,059,349 |
| Stress | 205,698 | 269,594  | 2,007,893 | 2,446,274 |
| Abundance | 4,935,262 | 5,520,657  | 4,922,119 | 4,389,776 |
|  |  |  |  |  |
| **Medium UN Projection** |  |  |  |  |
| Scarcity | 132,402 | 281,188  | 945,164 | 1,928,324 |
| Stress | 205,698 | 273,256  | 2,378,694 | 2,457,776 |
| Abundance | 4,935,262 | 5,588,804  | 5,057,208 | 5,420,179 |
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| **High UN Projection** |  |  |  |  |
| Scarcity | 132,402 | 285,227  | 903,696 | 2,429,339 |
| Stress | 205,698 | 277,193  | 2,590,821 | 5,270,191 |
| Abundance | 4,935,262 | 5,657,318  | 5,459,772 | 4,179,383 |
|  |  |  |  |  |
| Data from Engleman and LeRoy 1995. |  |  |  |  |
| *Scarcity: less than 1000 cubic meters per person per year availability.* *Stress: less than 1667 cubic meters per person per year availability Abundance: more than 1667 cubic meters per person per year availability* |

There are, however, some important limitations to these kinds of assessments. First of all, they are based on net water availability data for large areas, which have some significant holes: they usually do not include water for rainfed agriculture, they are often based on computed data, not measured data (see Gleick 1993), they often include water either committed to riparian countries lower on a river or already used by a riparian neighbor upstream, and they hide important smaller regional differences (Engleman and LeRoy are aware of, and discuss many of these limitations in their report, but approaches for dealing with many of them have not yet been adequately developed.). For example, India, China, and the United States, among other countries, have regions that are already extremely water-short. Yet average data for these countries do not reveal immediate problems (Engleman and LeRoy 1993).

Because of these limitations, the long-term goal of water planners must be to move beyond simple per-capita evaluations and to rethink the population and environment debate by helping to place population processes and water problems in their social, political, and economic settings. Below, some principles of sustainable water use are presented that may prove more useful in both evaluating regional problems and in offering solutions.

**Principles of Sustainable Water Use in the 21st Century**

Water is not only essential to sustain life, but to support ecosystems, economic development, community well-being, and cultural values. How are all these values, which sometimes conflict, to be prioritized? What is to be sustained? For how long? What are the benefits? Who are the beneficiaries? In the context of fresh water resources, any discussion of sustainable development requires that we understand both the physical resource and the benefits or services that those resources must provide.

As described above, fresh water resources are widely and unevenly distributed around the world. The water available for use in any place or by any group of users is not constant, but varies widely over time and space due to both natural fluctuations in the global hydrologic cycle and the non-natural fluctuations caused by human interventions. In the absence of any human interventions, natural ecosystems have evolved and adapted themselves to these natural hydrological fluctuations. The imposition of human systems often alters both the natural hydrologic regime and the ecosystems that depend upon them.

The simplest assessment of a desirable situation is described by the per-capita measure discussed above. Using this measure, any increase in population will lead to a decrease in per-capita water availability, which has usually been assumed implicitly to be bad. A better definition of sustainable water use is the maintenance of a desired flow of benefits to a particular group, undiminished over time. (Note that there is a difference between water use and the benefits of water use. There are several ways in which declining water use can occur without a decline in the benefits of water use, such as through improved efficiency of use. This distinction is often ignored by water analysts.). Refining this further requires that the sustainability of current benefits be maintained without affecting the ability to provide comparable benefits into the future to all groups -- similar to the more general definition developed during the work of the World Commission on Environment and Development and widely quoted:

"Humanity has the ability to make development sustainable -- to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED 1987)

The desired set of benefits provided by water does not have to be, and is unlikely to be, the same across different users or periods of time. Indeed, such benefits vary widely given political, religious, cultural, and technological differences. But in any realistic discussion of sustainability, the benefits to be provided must be explicitly evaluated. Using the definitions above, water use is unsustainable if the services provided by water resources and desired by society diminish over time. Equity requirements would also require that a reduction of services over time to one user group be declared "unsustainable" even if other users are able to maintain their desired services.

There are two ways in which unsustainable water use can develop: (1) through alterations in the stocks and flows of water that change its availability in space or time; and (2) through alterations in the demand for the benefits provided by a resource, because of changing standards of living, technology, population levels, or societal mores.

The first factor -- water availability -- is affected by both natural and anthropogenic factors, including climatic variability and change, population growth that reduces per-capita water availability, contamination that reduces "usable" water supplies, physical overuse of a stock, such as groundwater overdraft, and technological factors. Similarly, the second factor -- water demand -- is not constant, increasing with growing populations, changing as social values and preferences change, and increasing or decreasing with technological innovation and change.

Finally, sustainable water use also involves the management of the distribution of water in space and time. Social systems to control water resources must be capable of coping with changes in supply and demand, and in responding to varying priorities of water use under different conditions. Given all of these issues, a working definition of sustainable water use is:

*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. (Gleick et al. 1995)*

This definition of sustainable water use provides an overarching framework by which decisions about human water use can be judged. By itself, however, it is too general to offer guidance for water managers, planners, and scientists. In order to make decisions about how to allocate and use water resources, other goals and criteria need to be identified. Explicit criteria and goals for the sustainability of freshwater resources are presented here in Table 3. These criteria lay out human and environmental priorities for water use, taking into account not only the needs of the current populations, but also those of future generations.

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| **Table 3: Sustainability Criteria for Water** |
| 1. A minimum water requirement will be guaranteed to all humans to maintain human health. |
| 2. Sufficient water will be guaranteed to restore and maintain the health of ecosystems. Specific amounts will vary depending on climatic and other conditions. Setting these amounts will require flexible and dynamic management. |
| 3. Water quality will be maintained to meet certain minimum standards. These standards will vary depending on location and how the water is to be used. |
| 4. Human actions will not impair the long-term renewability of freshwater stocks and flows. |
| 5. Data on water resources availability, use, and quality will be collected and made accessible to all parties. |
| 6. Institutional mechanisms will be set up to prevent and resolve conflicts over water. |
| 7. Water planning and decision-making will be democratic, ensuring representation of all affected parties and fostering direct participation of affected interests. |

These criteria and goals are the result of considerable dialogue and analysis with academic, governmental, and non-governmental interests working on regional, national, and international water problems. They are not, by themselves, recommendations for actions; rather they are endpoints for policy -- they lay out specific societal goals that could, or should, be attained. In particular, these criteria can provide the basis for alternative "visions" for future water management and can offer some guidance for legislative and non-governmental actions in the future (Gleick et al. 1995).

The first criteria deserves some special mention in the context of growing populations. As stated, all humans should be guaranteed access to sufficient water to maintain human health, independent of the size of the population. While ever-increasing populations could ultimately make it harder and harder to provide even this small amount of water -- about 40 to 60 liters per person per day for drinking water, sanitation services, and modest domestic use -- moral and ethical responsibilities make it a fundamental right (Gleick 1996, in press). The actual amount of water required to meet this minimum is low, however, and unlikely to press up against availability limits in almost all regions. Far more difficult will be providing the social and economic structures and the institutional resources to provide this water in poorer regions of the world.

**The Role of Different Policies in Reducing Water Stress**

Two problems deserve special attention: increasing populations that lead to both decreasing per-capita water availability and increasing overall demand, and changing conditions (particularly technology and climate) that affect both water supply and demand. In the first case, assuming constant levels of total water availability, increasing populations lead directly to decreasing per-capita water availability and pressures on the levels of benefits or the mix of benefits that water provides. Ultimately, unlimited population growth must lead to decreasing water availability, the reallocations of water from one user or sector to another, the unsustainable "mining" of non-renewable stocks of water, and, in the end, decreasing overall human well-being.

In the second case, technological developments can alter water availability and affect levels of water required to satisfy demands. In theory, practically unlimited quantities of fresh water are available by mining water currently trapped in glaciers and icecaps, or on an even larger scale, through the mass desalination of seawater. In practice, however, increases in overall water supply will occur only where the value of water exceeds the economic and environmental costs of supplying that water through new technology.

The other basic assumption -- that overall water supply is fixed -- is now being challenged by the problem of global climatic change. As evidence accumulates that climatic changes are a serious concern, hydrologists and water managers must rethink old assumptions about the reliability of supply. While total water availability has always been stochastic, existing systems are designed and built to accommodate that known variability. But some of the largest changes expected from the greenhouse effect will be associated with the hydrologic cycle and water availability (Schneider et al. 1990, IPCC 1992, IPCC 1995).

One option touted by analysts focusing on the population debate is to address the water problems described earlier, or indeed any resource problem, by addressing population. Their argument, to put it in its most simple form, is that fewer people will place less pressure on scarce and finite resources. This argument is certainly true, as far as it goes. But it doesn't go far enough. As critically important as population is, it isn't the whole picture. Population rarely, if ever, acts alone to produce water scarcity and looking at it in isolation shifts attention from policies that may be equally or more effective. By ignoring the related roles of consumption levels, the form of resource use, and the role of economics, technology, and culture, such an approach often misses many of the most important and effective policies for solving problems.

Rather than repeat the oft-heard remark that "more people will require more water," it is time to begin thinking in a new way about what humans need, what they want, and how much water is required to meet these demands. Population, human welfare, water availability, and use must be considered to be dimensions of the same complex problem.

But how effective would other factors be in altering water needs? Society is constantly making conscious and unconscious decisions that affect demand and supply of water. The goal of water managers should be to start setting goals and making decisions on purpose. Some of the factors worth looking at include improvements in the efficiency of water-using technologies, new technology for water use, changes in lifestyles and personal preferences, different agricultural policies, and so on. Below, I explore the effectiveness of a few of these alternatives.

**Improvements in Water-Use Efficiency**

Studies are only now beginning to be done on the potential for extensive water efficiency improvements. The least work has been done in developing countries and in the agricultural and domestic sectors -- paralleling the problems in quantifying potential energy efficiency improvements in the 1970s and 1980s.

A good example is Egypt, which is entirely dependent on the Nile River for its water, ninety-seven percent of which originates outside of Egypt's border. Egypt is already at the limits of its water supply. Because of Egypt's limited options for new supply, efforts are being made to improve the efficiency of their agricultural and urban sectors. Egypt also is faced with a high and rapidly growing population. This combination is already causing water stresses throughout the country. Figure 4 shows how total water demands would rise under the medium and low United Nations population projections through the year 2025, if the per-capita water use remained constant. As this Figure shows, the difference between the two scenarios is quite small.

In reality, of course, Egypt is unlikely to reach even this level of water use because of absolute constraints on availability. In the absence of inexpensive desalination, their only alternative is therefore to see declining per-capita use of water. This can happen in two startlingly different ways, however: with declining benefits resulting from continued inefficient use of water in traditional ways; or with constant or improving benefits resulting from improving water-use efficiency and changing water policies.

Figure 5 shows how total water demands would be affected by annual improvements in water-use efficiency of only one percent per year, a number considered by many to be both plausible and achievable (Abu-Zeid and Seckler 1992). In this case, using the medium UN population projections, total water demands drop more than 20 percent.

Figures 6 and 7 show the same pictures for Iran, a country not yet at the limit of its water resources, but which also has a rapidly growing population. In the case of Iran, water demands under the UN population scenarios, assuming constant per-capita water use, increase to the point where demand begins to exceed water availability. Under the assumptions here, this point is reached sometime just after the turn of the century. The time at which this occurs under the low and medium population scenarios is almost identical. If water use efficiency in Iran improves by one percent annually, however, the time at which demand and supply are equal is delayed nearly a decade. While Iran and the many countries in a similar position will ultimately have to take more aggressive actions to resolve future water problems, they will have more time to consider appropriate actions to take if they combine water-efficiency and water-management policies with population policies.

**Conclusions**

If we cannot solve the population problem, we inevitably face declining per-capita water availability and use, and eventually, declining quality of life and benefits. As a result, policies to reduce rapid population growth in water-short regions are necessary and inevitable. But such policies cannot and should not be the only approaches taken to address water problems. Indeed, in the short run, they may not prove to be the most effective, equitable, or just.

In the near-term, policies to reduce population growth (short of intensely repressive policies or some severe health crisis) will not be sufficient to prevent serious water-related problems from getting worse, particularly human health problems, ecological disasters, and interstate conflicts. In addition, reducing the population growth rate, even to zero, is no guarantee that sustainable and equitable water use will result. This is a classic case of something that is necessary but not sufficient. Even in a zero-population growth situation, society can still have social inequities, contamination of water supplies, intentional manipulation of water, political conflict, and loss of aquatic ecosystems, unless these problems are directly and quickly addressed.

The final piece of this puzzle is to develop a new way of thinking about long-term sustainable use of water. This requires that we think about how human societies and ecosystems use water and how to meet basic needs before satisfying a broader and higher level of water demands. The definition of sustainable water use presented here, together with the sustainability criteria for water policymakers should help water planners set explicit goals for water supply. By taking a broader approach to the population-resource debate, and specifically the population-water debate, more equitable and sustainable solutions will result.