Incorporating long-term trends in water availability in water supply planning

D. Luketina*,**, and M. Bender*

* Water Resources, Technical and Research Center Paris, ONDEO Services, 38 rue du President Wilson, Le Pecq-sur-Seine, 78230, France
** Asian Institute of Technology, School of Civil Engineering, Water Engineering and Management Program, PO Box 4, Klong Luang, Pathumthani, 12120, Thailand

Abstract This paper examines factors affecting water availability and hydrological trends of water supply. The relative impacts of the different factors have been assessed on a planning time frame of around 30 years. It is demonstrated that the non-greenhouse processes of multi-decadal climate change and El Niño-la Niña climate change will almost certainly be more significant than greenhouse induced climate change. Further, in developing countries, increased water consumption, population growth, and urbanization are likely to be the dominant factors when considering water availability. The type of responses that a water supply organization can make are discussed.

Keywords Water availability; water demand; water scarcity; water supply planning

Introduction

Water scarcity is a growing concern. Information on the availability of water and on trends in water availability is important to provide a context for governments and water managers as they address a variety of contemporary water-related challenges. This paper examines factors affecting water availability, and examines hydrological trends of water supply. Possible management responses are also identified. The focus of this paper is on global water supply availability and how a water supply organization could respond.

The main factors influencing global water availability are population growth, increased consumption rates, climate changes, the limitations of water storage to offset annual water supply variability, water pollution, and land use changes. Population growth and higher demand per capita results in increased demand for water. Climate change, on the other hand, adds to the problem of water stress since it can potentially reduce the available water supply. In addition, water pollution and other factors can combine to further reduce the available supply of clean water. The significance of population growth and climate change varies by region. Each major factor is presented below.

The relative impacts of the different water availability factors have been assessed on a long-term planning time frame (e.g. around 30 years). The types of management responses to current water availability trends are discussed. These responses are: institutional, technological, and socioeconomic. Specific recommendations are made with regard to: institutional changes, water demand management, water treatment, storage management, water transfer, and integrated management.

Factors affecting water availability

Consumption

Based upon a commonly used definition, water scarcity begins when the water supply of a country falls below 1,000 cubic metres per person. Based on this criterion, 26 countries are currently facing the problem of water stress. The world population is expected to be in the range of 7.3 to 10.7 billion by the year 2050. This is compounded by the world water
consumption rising twice as quickly as the world population. The consumption rate is still growing in the developing countries, but beginning to stabilise in the industrial countries. Experts project the number of people living in water scarce countries will be between 653 and 904 million in 2025, compared to 132 million in 1990 (Shiklomanov, 2000).

**Climate changes**
The global mean surface air temperature has increased by 0.3 to 0.6°C since the late 19th century. Due to this increased temperature, precipitation has risen during winter over land in the high latitudes of the Northern Hemisphere, glaciers are melting in the Himalayas, and the global sea level has risen 10 to 25 cm over the past 100 years.

Despite evidence indicating global warming, predictions of continued warming are uncertain due to difficulties in: modelling microscale phenomena using global climate models; predicting the climatic response of changes in greenhouse gas emissions; and in the difficulty of predicting future greenhouse gas emissions. Despite these uncertainties, most experts (e.g. see UNDP, 2001; IPCC, 1996) conclude that by the year 2100, the global temperature will rise by about 1 to 3.5°C. As a result of this temperature increase, global rainfall patterns will change and some areas will become wetter while others will be drier (see Table 1).

However, looking at a 30-year time horizon, the non-greenhouse processes of multi-decadal climate change and El Niño-la Niña climate change will almost certainly be more significant than greenhouse induced climate change.

El Niño and La Niña describe the periodic warming and cooling of the eastern South Pacific Ocean, every three to seven years. El Niño is the warming trend, usually followed by the La Niña cooling trend. During El Niño, the most obvious and direct impact occurs around the Pacific rim where serious flooding occurs along the west coast of South America. However, the effects of El Niño and La Niña events are felt around the world. Some climatic impacts are (National Geographic, 2000):

- Cool, wet summers in Europe;
- Increased frequency of hurricanes and typhoons in the western Pacific and South China Sea;
- Drier conditions in north-eastern South America;

**Table 1** Summary of predicted consumption and climate changes on water resources

<table>
<thead>
<tr>
<th>Regions</th>
<th>Water consumption increase from 2000 to 2025 (%)</th>
<th>Climate change effects on freshwater (based on 1.5 to 4.5°C temperature change)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Precipitation</td>
<td>Runoff</td>
</tr>
<tr>
<td>World</td>
<td>27</td>
<td>Increase 3–15%</td>
</tr>
<tr>
<td>North America</td>
<td>11</td>
<td>Increase precipitation</td>
</tr>
<tr>
<td>Europe</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>South America</td>
<td>25</td>
<td>Less consistent information</td>
</tr>
<tr>
<td>Asia</td>
<td>29</td>
<td>Small change</td>
</tr>
<tr>
<td>Australia</td>
<td>19</td>
<td></td>
</tr>
</tbody>
</table>
• Unusually severe winter weather at the higher latitudes of North and South America; and drier conditions in southern Africa.

It is only recently that climatic oscillations having a period of around 30 years have been identified – in particular, the Pacific Decadal Oscillation and the North Atlantic Oscillation.

The Pacific Decadal Oscillation (or Interdecadal Pacific Oscillation) is defined by anomalous large scale warming and cooling in the North Pacific Ocean on a timescale of around 30 years. From 1945 to 1975 there was a cooling phase, while from 1975 to the present there has been a heating phase. This heating and cooling pattern is correlated with weather patterns, streamflow variability and drought (Nigam et al., 1999).

The North Atlantic Oscillation is a periodic increase and decrease of atmospheric pressure over the Arctic and subtropical North Atlantic Ocean. When the Arctic pressure is low, the eastern US and northwestern Europe experience mild winters. The opposite phase results in mild winters in eastern Canada and Greenland. The current low-pressure phase has lasted for 30 years (National Geographic, 2000).

These oscillations can have a dramatic impact on the availability of water resources. For example, the runoff to the reservoirs supplying Perth, Australia has been 40% lower over the 25 years since 1975 than the 25 years prior to 1975 and has resulted in unforeseen water shortages (Hughes et al., 2000). This impact is greater than any from greenhouse effects over this period.

Sea-level rise
For the year 2030, the predicted sea-level rise is 4, 12 and 26 cm for the low, middle and high estimates respectively (IPCC, 1996). The unchecked and uncontrolled rise of the sea level will cause problems, as it will inundate and displace wetlands and lowlands, raise water levels in rivers as they near the ocean and increase salt water intrusion into estuaries and coastal groundwater supplies (Rogers, 1994). In other words, the sea level will have pervasive impacts for water resources in or near coastal zones.

Storage
The ability to store and control fresh water supply in wet seasons so that it can be used in dry seasons is a significant and increasingly difficult challenge. As precipitation patterns are influenced by climate changes, greater storage will be needed to meet the demands of large urban and industrial centers. More surface reservoirs, however, may not be the answer since the construction of large dams is becoming increasingly difficult in developed countries. Furthermore, the effective storage of the existing reservoirs is slowly being reduced through the natural process of sedimentation and reallocation to competing water uses.

Water pollution
Water pollution contributes to the availability of clean water. Lack of development controls, especially in developing countries, is leading to increased discharge of untreated effluent into rivers and lakes. Runoff from agricultural areas also contains high pollutant loads. The pollution results in poor water quality and accelerated eutrophication of lakes and reservoirs.

In South East Asia and other developing parts of the world, little attention is currently paid to the issue of pollution from urban wastewater, where rapid urbanisation is likely to substantially increase the amount of urban wastewater, and where increasing amounts undergo little or no treatment. The high growth areas of Asia are expected to have increases in water pollution loads over the next decade as high as 16 times for suspended solids, 17...
times for dissolved solids and 18 times for biological pollutant loading (ADB, 1999). This will be compounded by the current Asian economy crises which will only exacerbate urban disorder and delay the provision of treatment plants (Jones, 1999). The net result is that the quality of water available for potable consumption in developing countries will generally decline.

The transition from worsening water quality (as a country develops) to improving water quality is a common occurrence (once a country is sufficiently wealthy). For example, the level of fecal coliform bacteria in rivers (one measure of water pollution) tends to peak when the per capita income reaches $US1400 per year (Bailey, 2000). This statistic is representative of the differences between an agrarian society and an urban society. Fecal coliforms typically result from livestock. So lower coliform values in high income countries are representative of their lower reliance on agriculture. Of course, the statistic reported by Bailey may not account for intensive agriculture in some high income countries, or the human waste from cities without adequate wastewater treatment.

**Land use**

The land use in many parts of the world is a major factor affecting water resources, and is closely related to population growth and urbanization. Processes such as deforestation and desertification (including dryland salinity) affect increasingly large areas around the globe. The runoff from deforested land tends to carry a much higher sediment load compared to runoff from forest areas. This means that deforestation can also accelerate the accumulation of sediment in reservoirs, reducing the storage capacity and life span of water supply reservoirs.

Studies show that human activities may influence the nature of water resources through changes in local vegetation cover. The direct influence of deforestation has been studied extensively. Almost all research suggests an increase in runoff (water yield) due to lower evapotranspiration after forest removal. Research covering a variety of climates, including temperate, semi-arid, and tropical suggests that the increase in water yield will not exceed 20% for every 10% reduction in catchment canopy cover (Bosch and Hewlett, 1982). Other impacts of deforestation include larger floods, more severe droughts, redistributed snowpack, a higher water table, and increased sediment yield.

**Management responses**

The global water availability is currently under some stress, and will continue to be. The following sections describe some management responses and opportunities for controlling water stress.

Every nation in the world, regardless of their economic status, is gradually identifying the need to establish a coherent, dynamic, and practical national water policy. They also recognise the need for incorporating technological, ecological, social, institutional and economic issues in the national, regional, state and local water policy.

The World Water Vision recently convened four thematic panels (institutions, biotechnology, energy technology, and information technology) to suggest actions and outcomes that will address the problems of global water stress. The major findings from these panels and their expected actions and outcomes are summarised in Table 2 (World Water Vision, 2000).

The available management responses for dealing with the issues outlined in Table 2 are grouped here as institutional, technological, and integrated management responses. These three response types are described in the following sections.
Institutional responses

The developing countries are the most at risk in the 21st century because they lack the financial and technological capacity to adapt to this change (Goklany, 2000). Moreover, they also have large areas of low-lying land that are affected by sea level rise, and large areas of arid and semi-arid land prone to desertification. Yet, global climate change is not a main concern of developing countries because they have other more pressing priorities, such as national political integrity, population growth, economic growth, health and poverty. Some of the Asian countries which are financially better off than others, like Malaysia and Singapore, are beginning to recognise the present environmental concerns.

Institutions in the next 25 years will evolve even further (World Water Vision, 2000):

- Integrated water management techniques at river basin scales will be adopted worldwide to meet society’s economic, environmental and social needs.
- Cities will be handed the legal status and financial responsibility to respond to water supply challenges.
- Programs should be undertaken to alleviate urbanization through rural economic development and promotion of medium-size cities.
- International systems will promote information exchange, serve as a source of data and best practices, raise general awareness of the issues among the world population, and facilitate conflict resolution.
- Trade liberalisation will ensure food security in water scarce areas.
- Technological developments will be harnessed to increase freshwater supplies, reduce demands, and improve the environment.

Technological responses

There are a number of interesting technological responses to water stress. While this paper is not intended to be a complete list of such responses, the following are a selected number of important technological responses:

- Interbasin transfers of water will become increasingly common. Recently the United States requested Canada to supply water (Canada possesses one-quarter of the world’s freshwater). Interbasin transfer opens up some interesting trade possibilities. For example, Uzbekistan have announced that they are willing to supply Kyrgyzstan with natural gas to help make up energy deficits if Kyrgyzstan operates their reservoirs to aid downstream Uzbeki agriculture rather than to generate hydropower (O’Hara, 2000). Thus, there is the possibility of integrated water and energy management. Water...
pipelines and river diversions may be supplemented by innovative technologies such as water bags (Gleick, 1998). Although water is being delivered in a few locations via bags, and bags of 3,000 m³ have been tested with reasonable success, large-scale transportation will be necessary to make the use of bags economically feasible. Water bags could deliver fresh water to extremely water-short coastal regions with a reliable demand for expensive water and in emergency situations such as droughts, natural catastrophes, or health disasters.

- Desalination technology is gradually moving towards the point where it is affordable to be used to supply water for drinking and household consumption. However, more than 85% of the water available to serve humans is used for agricultural and industrial purposes. Desalinated water is much too expensive for these uses, except perhaps in the oil-rich nations in the Middle East (Simon, 1998). Energy costs can have a significant impact on the development of new technological responses such as desalination and ultrafiltration techniques due to their large energy demands. If energy were sufficiently cheap, desalination could become the most economic option for water supply to coastal cities, and water treatment may well be based on filtration techniques.

- The use of rainfall forecasting will allow more efficient use of reservoirs. It is expected that rainfall-forecasting techniques will be sufficiently accurate in the next decade for medium range (several months) reservoir operation (Schultz, 2000). Further, the use of radar will allow real-time flood forecasting so that reservoir water can be released just prior to flood events. In turn, this means that the maximum operating water level can be raised in reservoirs that are used for both water supply and flood control, thereby providing a greater useable volume for water supply.

- Water reuse applications include: irrigation of restricted crops; irrigation of unrestricted crops, vegetables eaten raw; urban uses for irrigation of parks, sport fields, golf courses; groundwater recharge; dual distribution for toilet flushing; indirect and direct potable use (Shelef and Azov, 1996).

- Food production and agriculture are closely linked. Technology is expected to provide crops having higher yields and that are more water efficient. It is worth noting that if the average corn yields currently being achieved in the US were to apply to farmers globally, there would be enough food to feed a (projected) population of ten billion with only half of today’s cropland (Bailey, 2000). This highlights the fact that dissemination of technology to developing countries is an important and crucial aspect.

- Aquaculture is playing an increasing role in feeding the world’s population. It now contributes around 30% of the total food fish and shellfish and is one of the world’s fastest growing industries with an annual growth rate of around 10% (De Alessi, 2000).

- Treatment of raw water and wastewater in developing countries requires technologies such as stabilisation ponds, wetlands, soil-aquifer treatment and infiltration-percolation since they are effective, inexpensive and affordable technologies that are relatively easy to operate. Developed countries will benefit from the refinement of emerging technologies, depending on energy costs and treatment capacity.

**Integrated water management**

In many places, the water abstraction limits have already been reached (e.g. North Africa and South West Asia). Therefore, the major challenge of the 21st century will be to develop appropriate techniques for effective management, allocation and protection of the water resources of each basin and aquifer (Albernethy, 1997).

Integrated water management practices provide a useful response to the shifting institutional paradigm that increasingly treats water as both an economic and social good. As a result, the principle of integrated water resource management has been accepted and is
starting to be applied in many locations. Table 3 lists some of the differences between a tra-
tional planning approach and an integrated planning approach.

Demand reductions delay the need for capital expenditures. While this is a long-term
benefit, there may be a short-term reduction in revenue (Moreau, 1998). Water demand pat-
terns can be altered to improve the utilization of the available water supply. The future will
continue to see increasing use of demand management practices and, in turn, demand
analysis in the form of utility planning models (Beecher, 1998).

Conclusions
On a global basis, factors such as population, urbanisation, technology, economic condi-
tions, social and political factors are likely to combine to play a larger role in altering water
availability trends compared to climate change. The major factors in developing countries
will be population growth, increased water consumption and urbanization. In developed
countries however, where the population size and water usage per capita is more stable, cli-
mate change will have a stronger influence on the level of water stress.

To adequately address the future water availability problems, careful water resource
management will be necessary. The future will see greater use made of various technolo-
gies and techniques.

The bottom line is that different factors will dominate in different locations and, as such,
a variety of solutions will be required. Further, “secondary” factors such as the price of
energy can affect the feasibility of each solution.

References
and Cooperation, No. 2, pp. 8–13.
New York.
Bosch, J. and Hewlett, J. (1982). A review of catchment experiments to determine the effect of vegetation
changes on water yield and evapotranspiration. J. Hydrology, 55, 3–23.
Press, Washington D.C.
Goklany, I.M. (2000). Richer is More Resilient: Dealing with Climate Change and More Urgent
Environmental Problems, in Earth Report 2000: Revisiting the True State of the Planet, ed. R. Bailey,

Table 3 Traditional planning and integrated planning compared (from Beecher, 1998)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Traditional planning</th>
<th>Integrated planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource options</td>
<td>Supply options, little diversity</td>
<td>Supply and demand options, diversity is encouraged</td>
</tr>
<tr>
<td>Resource evaluation criteria</td>
<td>Maximise reliability, minimise prices</td>
<td>Multiple criteria, including resource diversity, risk management, environmental quality and public acceptance</td>
</tr>
<tr>
<td>Resource selection</td>
<td>Based upon a commitment to a specific option</td>
<td>Based upon the development of a mix of options</td>
</tr>
<tr>
<td>Resource ownership and control</td>
<td>Centralised, utility-owned</td>
<td>Decentralised, water utilities and others</td>
</tr>
</tbody>
</table>


