GLOBAL WATER QUALITY, SUPPLY AND DEMAND: IMPLICATIONS FOR MEGACITIES

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INTRODUCTION

Water is the most immediate and critical limiting factor to both human and environmental well-being. The reason is that water supply is, essentially, fixed. Therefore, although the *real* price of supplied water is currently low, changes in price can induce changes in water uses, and, therefore, potentially large impacts through the multiplier effect. The protection of water bodies, through stewardship, acts as a binding constraint that can result in conflicts between the affected jurisdictions (e. g., some of the states of the United States sharing a common river through inter-basin transfers).

The following lists a range of issues concerning the supply and demand of water and direct effects:

WATER SUPPLY AND DEMAND ISSUES		
Issue	**Direct Effect on**	**Comment**
Water conservation	Demand	Supply of water↑ ⇒cost↓
Water supply infrastructure	Supply	Cost
Water re-use	Supply	Acceptability ↓ ⇒ cost↑
Water losses	Supply	Cost↑ ⇒ infrastructure ⇒ cost↑
Sanitation	Demand	Infrastructure ⇒ cost↑
Institutional	Supply & demand	Costs↑ ⇒ trade↓ ⇒ revenues↓
Legal	Supply & demand	Costs ↑ ⇒ property rights ⇒ environmental equity ⇒ costs↑
Food (fisheries, livestock, crops…)	Supply	Availability↓ ⇒ cost of products↑ ⇒ international trade↓ ⇒ national security
Political	Supply	Costs↑ ⇒ cost of products↑ ⇒ international trade↓ ⇒ national security
Demographic	Supply & demand	Infrastructure ⇒ cost↑
Climate change		Draughts, floods, shifts in thermal energy balance ⇒Infrastructure ⇒ cost↑ ⇒ agricultural yields shift ⇒ national security ⇒ trade↓
Agriculture	Demand	Cost↑ ⇒ cost of products↑ ⇒ international trade↓ ⇒ national security
Megacities and megalopolies	Supply & demand	Demographic ⇒ infrastructure ⇒ cost↑ sanitation ⇒ water re-use↑ ⇒ costs↓
Technology	Supply & demand	Availability↑ ⇒ cost of products↓
Protection of vital ecosystems	Supply	Availability↓ ⇒ cost of products↑
Environment/recreation	Supply	Availability↑
Energy production and reliability	Supply & demand	Costs↑ ⇒ energy availability↓ ⇒ reliability↓

There are also transitional issues, such as tendency to urban sprawl, the decline of agricultural land supply and many sub-issues. Fundamentally, water issues are sectoral, involve water transfers and affect both the inputs and the outputs of the national and international economies. Perhaps most important issue that affects projections – because they are long-term -- and thus the development of the impact of the issues on water availability is the potential (or actual) structural changes in the sectors of the national economies.

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An example of the *structural* change in the US economy that has affected the relationships between supply, demand and quality of water to this date occurred in the period 1980 to 1985. From 1950 to 1980, the patterns of water use had shown a steady *increase* that was reversed by changing to a *decrease* from 1980 to 1985. Since 1985, the water uses have remained steady (Solley, 2000). Over the period 1950 to 1995, the US population has increased at a constant rate from 150 millions to 250 millions.

The structural changes that affected water supply and demand were principally due to federal laws controlling water pollution, technological changes in processed that use water as an input (including cooling towers and a movement away from once-through cooling) and increased recyling of water. The agricultural sector improved the delivery of water for irrigation and this sector lessened its reliance on ground water because of the increased costs of pumped water. At the same time, the agricultural patterns shifted from the West of the United States to the East, and there was a concomitant decline in farmers' economy. The number of irrigated acres peaked in 1980 and has been steady from 1985 to 1995 (at about 58 million acres). In the West, the irrigated acreage was 49 millions in 1980, declining to about 45 millions; while the East has steadily increased for about 2 million acres in 1950 to about 12 millions in 1995 (Solley, 2000). Point source pollution includes mine drainage, industrial discharges, sewage overflows, pollution from feedlots, underground storage tanks leaks and spills. Non-point sources of pollution include agricultural, silviculture, construction, mining and urban run-off, pollution from septic systems and from landfills. Erosion can create a number of problems, such as decreasing water storage, affect tourism, increase dredging and irrigation costs, as well as hindering natural water filtration by hardening the crust of soils.

The supply for domestic water is decreasing, notwithstanding the increase in population, because of conservation, the detection and correction of leaks and increased price of water supplied. Domestic water uses have been approximately constant from 1980 to 1995.

The principal areas of the water situation that the on-going study paper addresses are:

- National and sectoral water demands
- National and sectoral water supplies
- Water quality and its impacts on water supply and demand at the levels adopted for supply and demand analysis.

Studying these three aspects jointly is important to define the issues and benefits that will arise from water supply, demand and quality. Demand and supply of water are linked through the costs of supply and the willingness to pay for water by the sectors of the economy; the quality of water ultimately determines the quantity of water available for private and public uses. The ideal policy scenario is to develop sustainable management practices and use management tools that, when implemented, can protect water quality and yet provide a plentiful supply of water at a reasonable social cost.

ASPECTS OF THE U.S. WATER QUALITY & SUPPLY SITUATION

It is useful to draw issues and solutions concerning global water quality and supply by studying the U.S. situation. The U.S. water situation is most clearly understood at the national, such as the Water Resources Regions or States, and sectoral levels such as water of demand by energy production, agriculture and so on.

The United States is characterized by reliance on both surface water (78%) and ground water (28%), the principal users are irrigation and livestock (41%) and thermal power generation (39%) (Solley, 2000). The prime movers for the changes were federal legislation (the Clean Water Act, 1972; the National Energy Policy Act, 1992) as well as conservation planning. The structural changes in the *aggregate* water projections were the result of the transitions from supply-side management of water to its demand-side management and increased users' awareness of the importance and costs of water (Solley, 2000). The water situation and the issues that surround it are best understood by examining water demand, supply and quality at the sectoral level. The five broad sectors used for national estimates are:

- Irrigation

- Thermoelectric power generation
- Industrial & Commercial
- Domestic & Public
- Livestock

These five categories summarize the major uses of water in the United States. Demand projections have been obtained from the Department of Agriculture; those estimates have been checked for discrepancies in the original sources from which they were developed.

Generally, the most consistent and reliable water demand projections are limited to these five sectors and are available nationally and at the level of the USG Water Resource Regions (WWRs). The unit of analysis have traditionally been the USGS in twenty water resources regions (WRRs) which are large coastal and other contiguous areas of the country. We will rely on the most recent data because of changes in the structure of the economy in past, increased efficiency and changes in the way USGS data are combined. The water resources regions (from WRR 1 to WRR 20) are also used by Guldin (1989) to develop water budgets. For water quality, however, the data are given at the state or other major jurisdiction, by the US Environmental Protection Agency

The sectoral water uses are characterized by many complex and inter-dependent relationships that affect the probable equilibria points between water supply and demand, over the period 2000 to 2020, and even more so to 2050. The fundamental unknown in those long-term predictions is the potentials for changes in the structure of the economy and in the sectors. It follows that developing the potential impact of the issues affecting water supply and demand has to account for those potential structural changes.

While population increases and shifts are a major reason for changing water demand and altering supply, style of life and aging affects the water situation perhaps more so. For instance, eating habits of the population can greatly influence water use in other sectors of the economy. Increasing consumption of meat would increase livestock water demand and agricultural water demand (a significant portion of agriculture produces feed for livestock.) The prediction of caloric intake, in the US, is to slightly increase from 3600 kcal/person in 1995, to approximately 3750 kcal/person in 2025. Combined with population increases, this change in dietary habits would lead to increase in agricultural and livestock water demand. The cereal’s yield is also projected to increase from 5 tons/ha in 1995, to 6 tons/ha in 2025. Increases in production efficiency within the agricultural sector of the economy can mean greater demand on water supply. Increases in agricultural water use leads to increased contaminated runoff.

The demographic effects of an aging population can affect the supply of water in a number of ways including the potential for retirees will move out of communities where the supply and quality of water are poor. There is relatively little transitional cost involved in those moves and therefore the speed of the move can be almost instantaneous – at the scale of 20-year forecasts. In terms of research on the infrastructure, the quality of the roads and their numbers, traffic volumes and congestion are the largest contributors to development than the networks that supply ad treat water. A critical unknown is the effect of draughts on supply, the dislocation that such droughts can cause and the local and regional resilience to draught effects.

Unit of Analysis

We find that water quality problems are local and regional. Although there are global phenomena that affect water availability the solutions are most likely to be geared to water basins because the effect of global changes is neither uniform nor has the same intensity and severity. There are 2149 basin watersheds in the United States, the smallest being 700 sq. mi. Multiple water uses, different and heterogeneous landscapes and multiple users characterize these basins with often conflicting interests. Watersheds are targeted for funding by the US federal government, as exemplified by watershed assistance, watershed restoration action strategies, watershed pollution prevention, and watershed assistance grants. Depending on the availability of data, our work will use WRRs as the units of analysis for water demand and supply as well as state-specific information. For water quality we will use the states of the United States and such jurisdictions as Puerto Rico and Washington D.C. because the data provided by these jurisdictions are relatively consistent, are reviewed by the US EPA and can be matched to the USGS Water Resources Regions.

A brief description of the coastal and non-coastal zones of the United States is (President Clinton's Clean Water Initiative (1994), Table 3):

Descriptive Statistics of the Coastal and Non-coastal Zones of the US				
	Total U. S.	**Coastal zones**	**Non-coastal zones**	**Non-coastal zones as a % of total**
Counties (1990)	3,130	678	2,452	78.3
Population (1990)	246,750,237	127,351,147	119,399,090	48.4
Land area, (1990) mi^2	3,521,131	635,166	2,885,965	82.0
Surface water, (1990) mi^2	241,151	122,402	118,749	49.2
Farms (1987)	2,081,085	405,844	1,675,241	80.5
Farm land, (1987) acres	958,775,957	98,677,897	860,098,060	89.7

The urban population of the United States is 185.7 million, the rural population s 61.4 million, there are 93.9 million households in the U.S. with 2.63 persons per household and there are 23.2 million rural households. Approximately 60 million households are served by urban/storm water systems and about 10.5 million households have non-urban storm water (President Clinton's Clean Water Initiative, 1994, p. D-8). It has been estimated that each 1 billion of environmental investment creates 13,000 direct and 20,000 indirect jobs. The pollution control industry employs approximately 460,000 people (EPA, 1993), the national expenditures under the Clean Water Act are approximately 50 billion dollars (annualized at 7% per year, in $1992) and about 5 billions for drinking water (1992 $, at 7%) (EPA, Environmental Investments: The Cost of a Clean Environment, 1990)

Physical and Economic Scarcity of Water

The scarcity of water can be physical as well as economic: the fundamental difference for this Work is that economic scarcity depends on the state of the technology and the costs associated with it. Physical scarcity is something that is outside our immediate control and thus cannot be realistically changed. The fundamental questions are: when will there be gaps or disequilibria between the supply and demand for water and what are the determinants of the shift for the sectors of the economy considered in this Work? The predictions that we have developed in this work suggest that most impacts will be essentially gradual: no critical discontinuity is expected in the period 2000 to 2020. However, the gradual pattern will probably not be maintained if the time horizon of the predictions is moved to 2050 because of local and regional impacts of climate change.

Our analyses are based on the data compiled by the USGS and other agencies. The USGS data is used because it provided the most consistent national compilation of water use data since 1960. In addition, all other major water studies reviewed for this report relied on the circulars provided by the USGS; while predictions have varied, use of common data allows for higher accuracy of analysis when comparing reports. (Water Resources Council, 1978; Solley et al., 1983, 1988, 1998; Brown, 2000). The USGS has defined the following classes of water use (Brown, 2000); where "with." stands for withdrawals (consumptive + return flows/recharge): livestock, domestic and public, industrial and commercial, thermoelectric and irrigation. The trends and the critical uncertainties are:

Water Demand by User	**Uncertainties**	**Trends**
Livestock	Taste, income, diseases,	Insufficient data for 1990, 1995: possible higher increases in water uses.
Domestic and public	Housing stock, modernization, conservation, epidemics.	Historical rates of change: 1.5%, 0.9%, 0.8%, 0.3%. Cannot establish a reliable number.
Industrial and commercial	Efficiency, consumer confidence, employment rates, taxes.	Stable: 5% per year.

Thermoelectric power	Efficiency of production, appliances and telecommunication, federal and state policy.	Historical rates of total energy uses: 6%, 3%, 1.1%, 0.4%. Used 0.6% to 0.14%. Use 1.3% to 0.6%.
Agricultural irrigation	Urban sprawl, energy costs, technological changes, taste, income, transportation, climate change, federal and state policy.	East: 0%. West: 0.08$ to 0.04%.

The summary of the aggregate projections made by Brown (1999, 2000) are:

1995 Baseline Water Use (BGD is billion gallons per day; gpd is gallons per capita per day)	**Source of Water**	**Year 2040 projections, as intervals, if available, Middle pop. Forecasts by Census**	**Key Predictors of Water Use.**
Livestock (≈ 5.5 BGD); (21 gpd; constant '60 to '95)	Self-supplied	[5.5 BGD (1995) to 7.7 BGD (2040)]; 21 gpd.	Population; (withdrawals/capita)
Domestic and public (≈32 BGD); 121 gpd	Self-and public-supplied	[32 BGD (1995) to 45 BGD (2040)]; 121 gpd.	Same
Industrial and commercial (≈36 BGD);	Self- and public-supply	[37 BGD (1995) to 39 BGD (2040)]; [7.4 gpd to 3.9 gpd]	Population; per capita income; withdrawals/$ of income
Mining	Self-supplied	NA	None stated
Thermoelectric (≈ 130 BGD)	Self-supplied	[132 BGD (1995) to 143 BGD (2040)]; [504 gpd to 389 gpd]	Population; KWh/capita; freshwater KWh /Total KWh;
Hydroelectric power (	Self-supplied	NA	None given
Agricultural Irrigation (≈ 130 BGD)	Self-supplied	[134 BGD (1995) to 130 BGD (2040)]; [514 gpd to 354 gpd].	Acres irrigated; withdrawals/acre.

Sources: various Tables and discussion in Brown (1999, 2000).

Overall, the *consumptive* use in 1995 was about 100 BGD, approximately 29% of the total water withdrawals (Brown, 2000). Broadly, from 1900 to 1990, population increased by about 1.2% per year while water withdrawals increased at a faster rate, approximately 2.4% per year; in terms of gallons per capita per day (gpd), Americans withdrew, in 1900, 430 gpd but 1350 gpd in 1990. In this time period, relative to the total, withdrawals from public supply was approximately constant (at 12%), self-supply by industry decreased from 25% to 6%, irrigation declined from 50% to 40% but thermoelectric demand increased from 12% to 40% (Brown, 1999, 2000). The demographic projections use the Bureau of the Census data (1992) and from the Bureau of Economic Analysis (1992) as developed to the state and county levels by T. C. Brown (1999, 2000). The income data are developed from data developed by the Bureau of Economic Analysis (1992) and aggregated to the WRR by Brown (1999, 2000).

Predictions of Fresh Water Surpluses and Deficits, by WRR

The following discussions summarize the water surplus and deficits (measured in billions of gallons per day, BGD) and total fresh water withdrawals – based on the population forecasts by the US Bureau of the Census. Guldin (1989) excludes Alaska and Hawaii. His estimates of the population is higher than Brown (a difference of approximately 10 million people in 2000) and the total water withdrawals differ by approximately 30 BGD in 2000. However, the two Authors' numbers are very close to one another, relative to the best known projections by Water Resources Council (1968), Wollman and Bonem (1971), the Senate Select Committee (1961), National Water Commission (1973). The population and water withdrawals projections by Wollman and Bonem (1971), the Water Resources Council (1968), the Senate Select Committee (1961) and National Water Commission (1973) range from approximately 310 to 330 million people (in year 2000), while water withdrawals were projected to range from 550 BGD to 1000 BGD, also in 2000. The 2000 water withdrawals projection for 2000 made by the National Water Commission (1978) is the lowest of all projections (about 310 BGD), even though the population is slightly higher than Brown's. We concluded that for the purpose of developing research products for EPRI, the numbers provided by Guldin (1989) and Brown (1999, 2000) and their projections are consistent with what is currently understood about the influence of water supply and demand. Guldin (1989) and Brown (1999, 2000) numbers are shown next:

	Surpluses and Deficits (-) in Billions Gallons per Day, BGD, from Alternative Demand Projections in 2020, by WRR, Given Average Rainfall Conditions and (Global Climate Change) Effects (Guldin, 1989). Percent Change in Total Withdrawals, Given Low, Middle and High Census Population Forecasts from 1995 to 2040, (Brown, (1999)					
Water Resource Region (WRR)	**20% Lower Demand, BGD**	**Low Pop.(% change)**	**Normal Demand, BGD**	**Middle Pop. (% change)**	**20% Higher Demand, BGD**	**High Pop. (% change)**
New England	7.65 (3.15)	-11	7.54 (2.88)	15	7.43 (2.61)	42
Mid-Atlantic	24.32 (19.37)	-17	23.71 (18.73)	7	23.1 (18.09)	32
South-Atlantic Gulf	17.86 (-3.76)	2	16.37 (-5.33)	26	14.88 (-6.90)	52
Great Lakes	9.64 (3.82)	-22	9.23 (2.92)	2	8.83 (2.02)	28
Ohio	14.92 (7.07)	-20	14.25 (6.18)	3	13.58 (5.30)	28
Tennessee	4.33 (-0.04)	-10	4.21 (-0.17)	19	4.09 (-0.30)	50
Upper Mississippi	9.64 (5.21)	-18	9.15 (4.61)	6	8.66 4.01)	31
Lower Mississippi	69.9 (-35.18)	13	60.45 (-43.85)	27	51 (-52.51)	42
Souris-Red-Rainy	3.5 (3.09)	12	3.47 (3.05)	29	3.44 (3.01)	47
Missouri	14.79 (3.57)	-6	10.85 (0.19)	3	6.9 (-3.20)	12
Arkansas-White-Red	8.87 (-2.66)	-16	6.42 (-4.81)	-5	3.98 (-6.96)	7
Texas-Gulf	7.17 (-3.59)	-12	5.44 (-5.33)	6	3.7 (-7.06)	25
Rio Grande	-0.2 (-1.87)	-28	-0.75 (-2.47)	-25	-1.3 (-3.06)	-22
Upper Colorado	-0.52 (-5.70)	28	-1.11 (6.35)	30	-1.69 (-7.00)	32
Lower Colorado	-7.82 (-13.23)	-1	-9.62 (-15.04)	5	-11.42 (-16.85)	12
Great Basin	0.89 (-1.18)	4	-0.06 (-2.13)	9	-1.01 (-3.08)	15
Pacific Northwest	65.22 (34.08)	-9	62.42 (30.77)	0	59.63 (27.47)	9
California	34.55 (18.53)	-4	28.57 (12.94)	3	22.59 (7.36)	9
Total Contig. U.S.	223.88 (74.37)	-8	197.82 (48.31)	7	171.75 (22.25)	24

Developed From Table 23, Guldin (1989) and Table 7, Brown (1999). Table 23 in Guldin (1989) provides additional information to 2040.

WATER SUPPLY AND DEMAND ISSUES

The most obvious factors affecting water budgets are short- and long-term climatic variations and changes as well as precipitation and human activities linked in complex ways. This section contains a discussion of the factors that create issues with the numbers developed from Guldin (1989) for freshwater as groundwater and as surface water. The following lists the specific issues that affect water supply availability and quality:

- Pollution
- Draughts
- Floods
- Excess water
- Trans-boundary
- Pollution control

- Water treatment and other infrastructure improvements
- Investment
- Ecosystems at risk
- Changes in the hydrological cycle
- Rehabilitation of degraded areas
- Food management
- Supplemental irrigation
- Strengthening of: economic, legal, institutional arrangements at local, regional, state, national and international levels
- Capacity building
- Climate change
- Biotechnology applied to crops and livestock
- Low consumption crops
- Population growth in urban areas
- Sanitation
- Irrigation
- Demand management
- Water use conflicts
- Energy supply and cost
- Policy

The following functions will affect the supply and demand of water:

- Integration between appropriate jurisdictions
- Financial viability
- International effects
- Trade effects
- Sectoral shifts

Watershed Management. This is a key issue because watershed management maintains or improves the quality and quantity of water flows. Watersheds are critical to sustain development and ecological well-being. In the United States, 28% of the watersheds are classified as Class I (regimen attainment), 50% are in Class II (special emphasis) and 22% are in Class III (investment emphasis). Class III watersheds require technological investments to attain the goals of resources management (Guldin 1989, at 11, 12). Those investments should be directed towards environmental, economic and social goals such as rehabilitation including reforestation, land use planning, farm conservation, stabilization of channels and streams, as well improving the local economy. Class I watersheds have attained a dynamically stable equilibrium that is consistent with average precipitation and drainage, as well as productivity. Class II watersheds do not require capital investment to reach the equilibrium of Class I watersheds, but can particularly sensitive to cumulative changes in certain activities (such as events that have little impact at the acre level) and are not resilient to either cumulative impacts or sudden changes in exploitation.

Loss of Wetlands. The losses are due to conversions to urban and suburban uses as well as changes in the agricultural patterns at the regional level. Roughly, using the OTA numbers (1984) in Guldin (1989) the loss of wetlands to agriculture is about 12 million acres, due to urban development it is about 1 million acres while the gains are about 1 million acres for agriculture. Most of the losses of various types of wetlands (approximately 95% of the losses) are due to human activities with the rate estimated to be approximately 300,000 acres per year (1989), down from 550,000 acres per year in the period 1950 to 1970. In the US about 5.2 million acres of wetlands have a good potential (and about 17 million have some potential) for conversion to productive purposes such as agriculture but the Food Security Act of 1985 contains language that can prevent some conversions from taking place by withdrawing farm support funds.

Irrigation: This is the largest use in terms of withdrawals and consumptive uses. Irrigation accounts for approximately half of the groundwater withdrawals. The critical issue is the sustainability of those withdrawals, given land use changes, local climactic changes. The net result from these is that water prices will increase too much, affecting development. The total water withdrawals range from 142,500 Mgpd in 2000 to 173,400 Mgpd in 2040, including relatively minor quantities as wastewater. Irrigation (gravity or pressure-fed) and is deemed to increase at a lower rate from 2000 to 2040. The reasons are that pumping costs are increasing, as are energy costs and aquifer yields are declining. The rate of return from agriculture is also decreasing; if these trends change then irrigation may become attractive again (Guldin, 1989). The pricing policies of the US Bureau of reclamation may change because they are not user-favorable and some subsidies cause disequilibria. In any case, increases in cost will force technological changes and innovation opening a window of opportunity for EPRI.

Instream uses: Supply of water and uses (such as navigation, hydropower generation and cooling, recreation and dilution) are affected by changes in flow regimens. Ecological activities and the very survival of some species can be threatened, depending on the length of the water shortages. The preferable remedy is watershed management, rather than capital investments.

Surface water: Most of the water for supply is stored in reservoirs (approximately 90%). Such storage is affected by diminishing marginal returns and the availability of water, when needed, may fail because of drought or other factors. The construction of reservoirs is increasingly constrained by local activities.

Groundwater: There are approximately 5,000 cubic miles (55,000 trillions gallons) of ground water in the coterminous US, with a recharge rate of about 1 trillion gpd (Guldin, 1989). The fresh water pumping rates in 1985 was about 83 billion gpd and the overall water supply for the US is positive, but there are issues. One of them is that agricultural irrigation is the largest user of this water, namely about 56 billion gpd (or abut 24% of the total withdrawals) with the highest users in California, Texas, Nebraska, Arkansas, and Florida. (Guldin, 1989). The rates of withdrawals have increased from 1960 to 1980 because of irrigation in the east using central pivot systems, urbanization, energy production droughts, and increased inability to build reservoirs and for inter-basin transfers. The municipal water withdrawals are expected to increase from 20,000 Million Gallons per Day (Mgd) in 2,000 to 34,000 Mgd in 2040. Thermoelectric water withdrawals from groundwater will increase from 700 Mgd in the year 2000 to 676 Mgpd in 2040, and cooling withdrawals will decrease from 703 Mgd in 2000 to 676 Mgd in 2040. Irrigation will increase from 56,000 Mgd in 2000 to 64,000 Mgd in 2040 and livestock will change from 1,500 Mgd in 2000 to 1,800 in 2040.

Thermoelectric steam cooling: This is the second largest water use with the total (surface and groundwater) withdrawals estimated range from 157,000 Mgd in 2000 to 228,000 Mgd in 2040.

Water shortages. These are expected to occur by the year 2040 and principally affect the Lower and Upper Colorado River, the Rio Grande, the Great Basin, California and the Lower Mississippi River. In particular, irrigation is the predominant water use in the areas likely to experience shortages. A possible solution to the scarcity problem is through market instruments, an area in which EPRI has considerable experience. Specifically, the lower region of the Colorado River – even during average conditions – aces significant water deficits; in dry years the deficit are about 300% of the in-stream flow and the groundwater overdrafts are about 400%. The Rio Grande region is characterized by high water use. The Great Basin region will incur water deficits due to the growth in irrigation demand as will California.

Groundwater shortages are predicted for the High Plains of Texas, Oklahoma, Kansas, Nebraska, Wyoming, Colorado and N. Mexico. The Central Valley of California can also experience shortages. Similarly, the Southeastern and Atlantic Coastal Plains are expected to face shortages, as will the lowlands of Arizona. The adverse effects include land subsidence, salt-water intrusions, changes to the local flow patters, damage to property and so on (Guldin, 1989). The water quality aspects of the work that we develop in this work are summarized below in terms of the amount and percentage of designated uses met – in 1987 -- by type of water body:

THE STATUS OF THE UNITED STATES WATER QUALITY

This discussion that follows deals with the quality of waters in the United States at the national and state levels, including however some principal jurisdictions that are not states of the Union. The differences in units of analysis, namely the WRRs for the water supply and demand, and the states for quality are not particularly significant because our on-going work is directed to long-term projections. Thus, the overall sense of the directions and magnitude of potential changes can be captured with the currently available information.

There is considerable difference between the reports that attempt to characterize the water quality of the United States. For our work, we have selected the data sets that the states provide to the U EPA, under section 305(b) of the Clean Water Act. This data set is increasingly homogeneous with respect to the protocols that the states and other jurisdictions have adopted and include the input from a number of stakeholders, such as Indian Tribes. Nevertheless, this apparent homogeneity has some problems; these include differences in the summaries developed by each jurisdiction and provided to the US EPA, changes in the monitoring networks, or stations or both, differences in the methods for assessment. Nevertheless, the information developed by the US EPA, on these reports, is the best available for the purpose of our work.

According to the National Water Quality Inventory (1998), the majority of the water bodies in the US are adversely affected by "moderate to high levels of agricultural run-off." Furthermore, about 1/3 of the US waters are characterized by fish advisories leading to no fish consumption; and about 1/5 of the country has high levels of wetland loss (p.4). The status of American waters in 1996 is summarized as follows (from sampling data, US EPA (1998)

	Status and Percentage Meeting Overall Water Quality[1] in 1996			
Water Body	**Full support all uses (*Good*)**	**One or more uses are threatened (*Good*)**	**One or more uses are impaired (*Impaired*)**	**Not Attainable**
Rivers and Streams	56%	8%	36%	< 1%
Lakes, Ponds and Reservoirs	51%	10%	39%	< 1%
The Great Lakes	29%	1%	97%	< 1%
Estuaries	58%	4%	38%	< 1%
Ocean Shoreline Waters	79%	9%	13%	0%

[1] Developed from Figures 3, 6, 9, 12 and 15, US EPA (1998a); *Good*, *Impaired* and *Not Attainable* are short descriptions used by the US EPA to characterize the status in the columns' headings.

The wetlands of the Nation are affected by sediments and siltation, nutrients, filling and draining, pesticides, total suspended solids, chlorides and pollution from metals, habitat and water flow changes, as well as increased salinity. The principal causes of water pollution are agriculture, hydrological changes, urban run-off, construction, resources extraction and grazing. The US EPA 1998 has ranked (1 being the highest) the five principal causes of water pollution as (US EPA (1998), Table 2, p. 9 and Table 4, p. 13; Figures 4, 7 and 13) and EPA (2000) Figures 4, 7, 10, 13 and 16:

Rank	**Rivers (Percent impaired)**	**Lakes (Percent impaired)**	**Estuaries (Percent impaired)**	**Ranking of Major Sources of Pollution**
1	Siltation (18%)	Nutrients (20%)	Nutrients (22%)	1. Agriculture
2	Nutrients (14%)	Metals (20%)	Bacteria (16%)	2. Point and non-point sources
3	Bacteria (12%)	Siltation (10%)	Priority toxic organic chemicals ((15%)	3. Municipal point sources
4	Oxygen-depleting substances (10%)	Oxygen-depleting substances (8%)	Oxygen-depleting substances (12%)	4. Upstream sources
5	Pesticides (7%)	Noxious aquatic plants (6%)	Oil and grease (8%)	5. Agriculture

The principal sources of pollution affecting the Nation's water are (US EPA, 1998, Tables 3, 4, pp 12, 13):

Sources	Example	Body Principally Affected
Industry	Pulp and paper, heavy industry, food processors, textiles	Estuaries
Municipal	Public sewage treatment overflows	Rivers, lakes
Combined sewer systems	Outflows	Rivers, lakes, estuaries
Storm water and urban run-off	Paved or other hard surfaces	Lakes, estuaries
Agriculture	Pastures, crop production, feedlots, animal operations	Rivers, lakes and estuaries
Silviculture	Forest management, logging, roads	Rivers, lakes
Construction	Land and road development	Rivers, lakes
Resources extraction	Mining, drilling oil, tailings run-off	Rivers
Land disposal	Leachate and discharges	Rivers
Hydrological modifications	Open channels, dredging, reservoir construction, flow regulation	Rivers, estuaries and lakes
Habitat modification	Riparian vegetation, stream-bank, wetlands drainage or filling	Rivers

Agriculture, industry, poor sewage treatment (such as septic tanks), leaking underground storage tanks and landfills affect the ground waters of the Unite States. A fundamental concern is the stewardship of natural resources; there is a unified watershed policy (DOI)[2]. The concern is quantified by noting that about half of the American watershed have from serious to moderate water quality problems. It follows that an important area of concern is the credibility of the water data used (e. g., what is the credibility of the data in such data bases as STORET, the National Geographical Data, the Watershed Boundary Data, the National Elevation Data, the Land Cover Data).

Much work has been committed to establish the nature of the water pollution problem in the United States (US EPA 1998). The objectives of this Work are met by summary measures of water quality such as those described by indices of water quality. The US EPA (1998) has reported at the state level and other jurisdiction, rather than at the Water Resource Region, using watersheds as their unit of analysis, the first use of such index. This Section is based on that information. That information is mandated under Section 305(b) of the Clean Water Act. This index combines seven indicators of condition of a watershed and eight indicators of the vulnerability of the watershed’s rivers, lakes and estuaries. It is a linear aggregate of the fifteen indicators, shown below. The minimum set of indicators that was used to produce the IWI was a weighted combination of “[a]t least 4 of 7 condition indicators and 6 of 8 vulnerability indicators … ” with the indicator determining the “rivers meeting all designated uses “ was given a larger magnitude than any other indicator (US EPA 1998, p. 55).

Water Quality Summary

Earlier results about the quality U. S. water consist of data for 1988 (US EPA, EPA 440-4-90-003 (1990), which provide the initial condition for understanding the quality of the waters of the United States. This data is summarized in the Table below:

Percent of Individual Uses Supported, adapted from US EPA, EPA 440-4-90-003 (1990) – Numbers are percentages

	Rivers and Stream		**Lakes, Ponds & Reservoirs**		**Estuaries**		**Great Lakes Shorelines**		**Ocean Shorelines**	
Use supported	Good (%)	Fair (%)	Good (%)	Fair (%)	Good (%)	Fair (%)	Good (%)	Fair (%)	Good (%)	Fair (%)
All uses	70	20	74	17	72	23	8	18	NA	NA

US Environmental Protection Agency (1990), Tables 1-1, 2-1, 3-1 Good is *fully supporting* and fair is *partially supporting*. All uses means designated uses: fisheries, contact recreation and drinking water. NA is not available.

The 1988 assessment is based on about 520,000 assessed miles of rivers (48 jurisdictions), 16,000,000 assessed lake-acres (40 jurisdictions); and 26,700 square miles of assessed estuaries (23 jurisdictions).

In 1988, the major causes of river pollution were (rank ordered from highest percent of river-miles impacted): siltation, nutrients, pathogens such as bacteria, organic matter, metals, pesticides, suspended solids, salinity, flow alterations, habitat modification pH and thermal discharges. The Table shown next depicts the national aggregate *percentages of impaired waters* (aggregated over major, moderate and minor impacts) (US EPA, EPA 440-4-90-003, 1988):

Summary of Percent of U. S. Impaired Waters 1988 by Cause of Pollution – All numbers are percentages.											
Waters	Silt	Nutr'ts	Bact.'a	Organic Enrich't	Metals	Pesticd's	SS	Salt/ OG*	Flow	Habitat Modif.	pH	Thermal/ Flow Alter#
Rivers	42	27	19	15	11	10	6	6	6	6	5	4
Lakes	25	49	9	25	7	5	8	14	3	11	5	$3^{\#}$
Estuar.	7	50	48	29	10	1	NR	23*	NR	NR	<1	#

Developed from EPA 440-4-90-003 (1990), Tables A-1, 2-2, and 4-2. SS is suspended solids. # is Flow Alteration, there is no thermal effect reported for lakes. * is oil and grease (OG). Percentages are calculated as the sum of the quantities (in miles or acres) of pollution-specific impaired miles or acres divided by the total impaired miles or acres, for all jurisdictions. Lakes are affected by priority organics (8%). Estuaries are affected by priority organics (4%), unknown toxicants (5%) and other inorganics (<1%).

The 1988 water quality of the Great Lakes (meaning Illinois, Indiana, New York and Ohio) is that priority organics are the major pollutants affecting 761 shoreline miles, out of 819, the second is metals affecting 215 miles, and the third is nutrients, affecting 76 miles (US EPA, EPA 440-4-90-003, 1988).

The ground water withdrawals in 1985 were approximately 76 BGD, the bulk of the withdrawals occurred in California, (10 BGD), followed by Arizona (4 BGD), Arkansas (4 BGD), Idaho (4BGD), Kansas (4 BGD and Nebraska (4 BGD) that water being supplied principally to agriculture. The national trend is an increase in ground water withdrawals, from 33 BGD in 1955 to a maximum 82 BGD in 1980, declining to 76 BGD in 1985. (EPA 440-4-90-003, 1988, pp 121, 122). In 1988, 9 states reported excellent ground water quality, and 17 reported good ground water, the remaining states giving no opinion (EPA 440-4-90-003, 1998, p. 122). Most states and other jurisdictions indicated that UST were the sources of pollution with the highest priority, followed by abandoned waste sites, agricultural activity and by septic tanks, Municipal landfills were sixth in priority, followed by oil and gas brine pits. Mining waters, sewer leaks, cyanide heaps, construction and manufacturing were also of equal and highest priority.

The EPA has more recently developed the IWI indicator/index system with such stakeholders as the states, Indian tribes, and others. The index is based on indicators of individual beneficial uses of water: aquatic life and wildlife habitat support, fish and shellfish consumption, drinking water supply, recreational swimming, boating, agricultural irrigation, livestock consumption, ground water recharge, and cultural benefits as a function on the degree of well-being of the water bodies for those uses. The information described below was reported to the US EPA by the states, Indian tribes and other jurisdictions mandated to do under the CWA Section 305(b). The Environmental Protection Agency (1998) reports the overall status of the Nation's waters, in 1996, as:

1996 Percent of Individual Uses Supported, adapted from US EPA EPA841-R-97-001 (1998) – Numbers are percentages										
	Rivers and Stream		**Lakes, Ponds & Reservoirs**		**Estuaries**		**Great Lakes**		**Ocean Shorelines**	
Use supported	Good (%)	Fair (%)	Good (%)	Fair (%)	Good (%)	Fair (%)	Good (%)	Fair (%)	Good (%)	Fair (%)
Aquatic life	60	23	55	25	61	27	12	9	91	3
Fish consumption	84	14	60	32	75	22	2	34	91	5

Swimming	76	10	63	21	83	15	96	3	82	5
Secondary contact	78	16	62	23	76	22	96	4	93	5
Drinking water supply	79	19	81	7	NA	NA	98	<1	NA	NA
Shellfishing	NA	NA	NA	NA	69	16	NA	NA	84	6
Agriculture	93	3	84	10	NA	NA	89	11	NA	NA

US Environmental Protection Agency (1998), Tables 2-3, 3-3, 4-3. 4-8 and 12-4. Good is *fully supporting* and fair is *partially supporting*.

The Table immediately below has also been developed from water quality data provided by the US Environmental Protection Agency (2000):

1998 Percent of Individual Uses Supported, adapted from US EPA EPA841-S-00-001 (2000) – Numbers are percentages

	Rivers and Stream		**Lakes, Ponds & Reservoirs**		**Estuaries**		**Great Lakes**		**Ocean Shorelines**	
Use supported	Good (%)	Fair (%)	Good (%)	Fair (%)	Good (%)	Fair (%)	Good (%)	Fair (%)	Good (%)	Fair (%)
Aquatic life	58	20	58	23	54	29	36	12	87	4
Fish consumption	87	5	54	35	63	34	4	29	84	10
Swimming	69	11	69	15	88	5	97	2	80	8
Secondary contact	76	14	78	10	81	15	99	1	93	5
Drinking water supply	87	6	82	9	NA	NA	98	0	NA	NA
Shellfishing	NA	NA	NA	NA	70	14	NA	NA	89	11
Agriculture	97	2	89	3	NA	NA	100	0	NA	NA

US Environmental Protection Agency (2000), Figures 3, 6, 9 12, and 15. Good is *fully supporting* and fair is *partially supporting*.

The assessment of ground water quality, hence availability for supply, suggests studying the potential contamination from a number of sources, such as leaking underground tanks, septic systems and so on. This nation-wide effort it is based on state-specific and other stakeholders' efforts. Because of the differences, namely: no reports, reports at the hydrological unit, reports at the state level only and so on, an "evaluation of ground water quality data is not possible."(US EPA, EPA-816-R-98-011, 1998, p. 24). Nevertheless a qualitative understanding of the ground water situation for 1996 (Modified from US EPA, EPA-816-R-98-011, 1998, Table 1, p. 24, 25), based on 162 aquifers and other hydrological units in twenty-nine states, is as follows:

Number and Source of Ground Water Contamination in the U. S. (1996)

Sources of Contamination	**Number of sites**	**Sites listed and/or with confirmed releases**	**Sites with confirmed ground water contamination**	**Sited with completed cleanup**
Leaking UST	100,921	40,363	17,827	19,379
UST sites (no releases found)	2,210	NA	NA	NA
Septic Systems	10,656	10,594	NA	NA
State Sites	7,017	5,751	2,614	3,166
Underground injections	5,006	1,077	911	204
CERCLIS	2,399	1,332	645	49
RCRA Corrective Action	2,114	283	289	52
MN Dept. Agriculture	600	164	50	NA
DOD and DOE	404	234	166	39
Miscellaneous	229	905	514	32

Non Point Sources	171	190	62	36
National Priority List	167	250	204	24
Landfills	149	78	74	0
Wastewater land application	116	NA	24	0

UST is Underground Storage Tanks; NA is Not Available; CERCLIS is the Comprehensive Environmental Response, Compensation and Liability Information System; RCRA is the Resource Conservation and Recovery Act; MN is Minnesota.

The ground water quality is determined from finished water from PWS wells (61%), untreated water from PWS wells (24%), ambient monitoring networks (52%), untreated water from private wells (36%), special studies (6%) and facility monitoring wells (EPA–816–R – 98 -- 011, 1998, p. 31, 32 and Figure 19, p. 32). The quality parameters include nitrate, VOC, SVOC, bacteria, pesticides ionizing radiation, a number of metals, inorganics, TDS, hardness, specific conductivity, alkalinity, nutrients and so on. The Table below provides a summary of the number of wells impacted and the rank-ordering of the ground water pollutants, at the national level, based on the number of reporting states:

MONITORING TYPE	**Wells with number of MCL exceedances and (number of states reporting exceedances/total number of states reporting) rank-ordered by importance (I highest) for:**					
	I. Nitrates	**II. VOCs**	**III. SVOCs**	**IV. Pesticides**	**V. Metals**	**VI. Bacteria**
Networks	267 (8/15)	30 (7/10)	5 (3/3)	5 (2/8)	195 (7/11)	10 (1/3)
PWS untreated water	85 (5/7)	77 (5/6)	10 (3/4)	2 (1/2)	100 (2/2)	1 (1/1)
Private untreated water	2,233 (9/10)	96 (2/3)	4 (1/3)	101 (4/5)	113 (1/1)	0 (0/1)
PWS finished water	230 (11/18)	152 (6/17)	18 (3/14)	0 (0/1)	175 (4/6)	404 (3/3)
Special studies	309 (2/2)	19 (1/1)	0 (0/0)	0 (1/1)	0 (0/0)	101 (1/1)

Tables 3 through to 8, EPA 816-R-98-011 (1998), pages 34 though to 39. The MCLS for individual constituents of VOCs, SVOCs, metals, pesticides and bacteria are omitted for brevity's sake. The MCL for nitrates is 10 mg/L of water.

COSTS

The study of water demand, supply and quality must include the costs associated with treatment. For public wastewater treatment, the nation-wide monetary needs have been estimated to be (US EPA EPA841-R-97-008, p. 403):

Needs for Publicly Owned Wastewater Treatment Facilities and Other Concerns ($ 1996)	
Category of Need Under Title II Clean Water Act	**Total (in billions $ 1996)**
Secondary treatment	26.5
Advanced treatment	17.5
Infiltration/flow correction	3.3
Replacement/rehabilitation	7.0
New collector sewers	10.8
New interceptor sewers	10.8
Combined sewer overflows	44.7
Storm water	7.4
Non point sources from agriculture and silviculture	9.4
Ground water, estuaries, wetlands, urban runoff	2.1
Total	139.5

Adapted from Table 14.1; (EPA 841-R-97-008, 1998, p. 404).

Another aspect of costs is that associated with either remediation or prevention. For instance, in Massachusetts, gasoline contamination from underground storage tanks releasing about 2000 to 3000 gallons resulted in about 5 million dollars cost and took approximately 10 years to complete the aquifer remediation. In New Jersey, the costs associated with establishing a new well-field to replace a system contaminated by a landfill was about $500,000 per well ($ 5,000,000 total). The UST federal program (LUST Trust Fund) has disbursed approximately $570,000,000 from 1986 to 1996. The states have raised approximately 1.3 billion dollars (1997) for these cleanups. The total number of sites is approximately 400,000, of which 162,000 were cleaned-up and 115,000 are being cleaned (EPA - 816-R- 98-011, 1998, p. 66). The Sole Source Aquifer program has ranged from approximately $570,000,000 in 1992 to approximately $ 1.8 billion in 1996; these moneys are allocated as federal financial assistance to prevent significant public health risks (EPA –816-R-98-011, pp. 58, 59 (1998)). It also appears that the National Priory List Sites (CERCLA/Superfund sites) where the ground water was classified (453), 426 of these do not affect the ground water. However 622 NPL sites do report ground water contamination; overall 702 of 1121 NPL sites are associated with ground water contamination (EPA –816-R-98-011, 1998, p. 69).

Since 1972, when about 40% of the US population was served by municipal wastewater treatment, the EPA has spent over 64 billion dollars in that form of treatment, US EPA (EPA, EPA841-R-97-008 (1998)). The percentage increased to over 60% of the population, by 1992.The annual expenditure portfolio under the Clean Water Act (Table 19.1, p. 510 and Table 22, President Clinton's Clean Water Initiative (1994)) is:

Quantified Current and Planned Spending, in million dollars per year

	Private	**Municipalities**	**Agriculture**	**State Water programs**	**Federal Agencies**	**Total**
Pre-1987 Act[1]	25,286	17,190	191	373 (560)	9,564	52,604 (52,791)
NPS Control and Watershed	NR	389 – 591	240 – 389	125 (150)	234	988 – 1,339 (1,013 – 1,364)
Storm Water Phase I	3.990 (16,235)	1,650 – 2,555 (1,785 – 2, 760 P. II)	NR	NR	NR	5,640 – 6,545 (18,020 – 18,995)
CSOs	NR	3,450 (14,140)	NR	NR	NR	3,450 (14,140)
Other Costs	943 – 1,073	88	NR	NR	NR	1,031 – 1,161
TOTAL	30,219 – 30,349 (46,454 – 46, 584)	22,767 – 23,874 (35,242 – 37,324)	431 – 580	498 (710)	9,798 (11, 181 – 14,279)	63,713 – 65,099 (94,018 – 99,577)

[1] Administrative cost to the EPA only, not to be used for projections. Abandoned mines are not included in Table 19.1, but the total spending in parentheses includes them; the costs in parentheses are *current and potential spending,* not *current and planned spending*..

Some of the benefits from fishing include 19 billion dollars in wages and approximately 1.3 million jobs; about 50 million angles spent about 24 billion dollars on fishing –related activities. (Sport Fishing Institute, 1994). Commercial fishing contributes approximately 17 billion dollars to the US economy, with shellfish contributing almost half of that value.

The US EPA has estimated the range of benefits from controlling urban run-off, toxicants to human health from swimming and fishing, and CSO (President Clinton's Clean Water Initiative (1994)), as shown below:

Aggregate Benefits of Pollution Control for Urban Sources (CSOs, storm water and toxics) in millions of 1993 dollars.

Freshwater recreational fishing and swimming	650 – 4,670
Marine recreational fishing	40 -- 440
Marine non-consumptive recreation	30 - 300
Marine and freshwater commercial fishing	40 - 190
Withdrawals and diversions	30 - 80
Human health effects	40 - 320
Undiscounted total benefits	820 – 6,000
Total benefits at 7%, 15 years	560 – 4,100

Total benefits at 3%, 15 years	660 - 4,900

Modified from *President Clinton's Clean Water Initiative* (1994), Table ES-6.

This data excludes many non-monetized benefits such as marine boating, restoration of biodiversity, other human health effects and so on. On the basis of the discussions provided by the EPA, the numbers underestimate the annualized benefits. In 1986, for instance, the states spent between less than $5 per capita to more than $15 per capita in water quality and quantity related programs; the percentages of the states budgets dedicated to water programs ranged from less than 0.1% to more than 0.3% (EPA 440-4-90-003, Table 12-1, p. 179).

Types of Adverse Events Affecting Water Supply, Demand and Quality and Strategies

There are different types of adverse events (accidental or premeditated) that can affect water quality and quantity. These include:

Transient events, (such as spills or other types of releases), that can be contained rapidly.

Rare events, such as the unsuspected arrival of a contaminated ground water plume that either cannot be contained rapidly or at all, or events that disappear rapidly but have significant or catastrophic outcomes.

Routine events, such as the severing of a water main during construction, that are characterized by small overall cost, and that are possibly unavoidable.

Gradually-increasing events, such as regional response to climate change or other long-term conditions and that affect the supply of water.

In terms of predictions, water quality and quantity vary temporally and spatially. The unpredictability of transient event, the variability in events that are caused by relatively slow changes (such as global climate change) and the associated inactivity due to the uncertainties all contribute to a complex situation. The vulnerability of water sources and resources, limitations to the yields and the potential for depletion require competent management that must include collaborative efforts that involve the private sector.

- Ensuring viable and sustainable water flows for in-stream uses such as fish and wildlife and tourism.
- Improve the quality of the watersheds by maintaining water quality and quantity, managing run-off, improving riparian areas and soil productivity.
- Use non-structural methods to avoid flood damage.
- Implement non-point sources abatement and control for activities such as silviculture and range management.
- Increase the protection and the stock of wetlands.

The obstacles to these strategies include some subsidies that distort the price structure and therefore limit competition, raise prices. However, removing such obstacles can require a fundamental change in current practices. Water managers should give high priority to activities and interventions that optimize off-stream uses. Monitoring of water systems at the watershed level for channel conditions should be in place. The reduction of non-point pollution through TMDLs is increasing. Income, property and other taxes should be designed to increase the stock of wetlands and other non-glamorous resources.

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