Fresh water is never too expensive

by Marcia Merry

Think of a glass of water. If you consider where it comes from, and how it gets there, you have an overview on what is required to provide enough water per person, per household, and per area, and at what cost.

Every day you need to drink about eight glasses of water, which is more or less two liters (about half a gallon). Without water, there is no life. The body of an average size adult male consists of 65% water. You can subsist without food for much longer than you can without water.

Secondly, drinking water must be safe. It must not contain, beyond a certain quantity per volume of water, foreign substances—salts, micro-organisms, debris. Otherwise, sickliness and death results. Safe water is also needed for other personal uses—hygiene, cooking, dishwashing, etc. A total amount of about 140-200 liters (40-60 gallons) a day per person is needed on average for household functions. (See **Table 1** for conversion factors.)

Beyond that, water of lesser quality, but in greater amounts, is needed to supply the food, material needs (shelter, transport), and social services (health care, schooling) required to maintain each person in the society, and the potential for future societies.

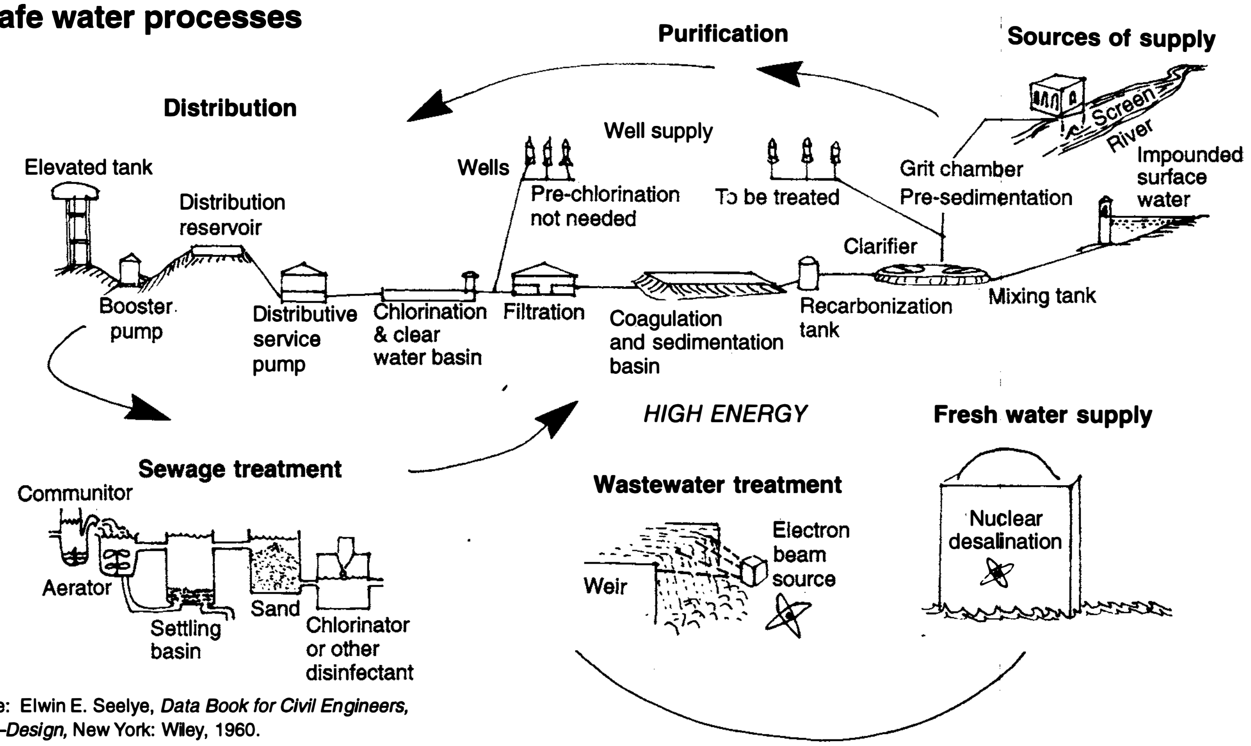
Table 2 shows the annual water usage standards for the United States, in amounts used per person, per thousand households, and per unit of urban area.[1]

While the highest-quality water is needed for household uses, water for industrial use can vary widely in quality, ranging from pure water needed for electronics processing, to low-quality water for automobile manufacturing. Agriculture can also use a wide range of water quality, depending on whether it is going for livestock, grains, truck gardening, or hydroponics. Power generation requires only low-quality coolant water.

Therefore, if you start with drinking water, and consider what costs are involved in supplying the quantities and qualities required, you will at the same time have an overview of what it takes to supply all the categories of water needed to

FIGURE 1

Safe water processes



Source: Elwin E. Seelye, *Data Book for Civil Engineers, Vol. I—Design,* New York: Wiley, 1960.

support a productive society. We begin with conventional, modern water treatment.

Local water treatment

Figure 1 is adapted from the standard civil engineering handbook.[2] It depicts what is involved in providing safe drinking water from the local vantage-point, disregarding national or continental considerations. Wherever lower standards of water are usable—for example, in agriculture or some manufacturing processes—treating the water is even less complicated and cheaper.

The diagram begins at the top right, going counterclockwise, and indicates the requirements of taking water from its source, to purification, to distribution, to sewage treatment, which are the standard steps. Also shown are the high-energy forms of wastewater treatment and desalination which are possible today.

The following summarizes the processes involved, and how they figure in the costs of a conventional modern system.

Sources of supply

The steps involved in acquiring the water are relatively straightforward, given the type of supply. Engineering design and operating costs involve preventing algae and other biotic life from clogging the works in the still water, preventing debris from entering the works from stream flow, and dealing with sediment. Well water and spring water must be monitored for quality, and the reliability of the supply is a constant issue. The need to dig deeper wells, construct new reservoirs, and repair and replace water tunnels, all show up in costs.

Purification

The extent of treatment of water required to bring it to acceptable standards for use, depends on how contaminated it is with bacteria, and its turbidity and other characteristics. Some locations may have water requiring no treatment at all, or minimum treatment with chlorine or an equivalent disinfectant process, in order to bring the bacteria count down to safe levels. Other water supplies may need "the works"—prolonged sedimentary storage, filtration through sand or another medium, disinfection, etc.

Thus, the costs vary with the condition of the water supply, and with the energy needed to clean it up. However, with distilled water from desalination processes, little or no additional purification may be required. Recommended standards for water quality are set by many national and international health agencies; **Table 3** gives the World Health Organization standards for drinking water.

The history of the introduction of modern water treatment processes shows a spectacular fall in death rates. **Figure 2** shows the drop in deaths per 100,000 population from typhoid fever after filtration was begun in the water systems of the cities shown. The drop in the Ohio River Valley cities

TABLE 1

Conversion factors used in this article

Unit	Equivalent
Volume:	
1 U.S. gallon	3.785 liters
1 cubic meter (m^3)	264.2 U.S. gallons 1,000 liters
1 liter	0.2642 U.S. gallons
1 acre-foot	3.259×10^5 U.S. gallons 1,234 cubic meters
Flow rate:	
1 U.S. gallon per minute (gpm)	0.0631 liters/second (l/s) 5.42 cubic meters/day
1 million U.S. gallons per day (mgd)	43.7 l/s 3,785 m^3/day
1 cubic foot per second (cfs)	449 gpm 28.3 l/s
1 cubic meter per second (m^3/s)	22.8 mgd 35.3 cfs

TABLE 2

U.S. water usage standards

(million m^3/year)

	Per person	Per 1,000 households	Per urban residential km^2 public use*
Public use: municipal*		0.54	0.86
Residential: single	0.0001	0.32	0.50116
Residential: multi	0.00008		
Public use**	0.000039	0.124	0.195
Schools	0.00009	0.068	0.113
Hospitals/bed	0.0008	0.018	0.031
Factories: sanitary	0.00002	0.0035	0.0058
Manufacturing/employee	0.005	0.879	1.465
Agriculture: irrigation/km^2	0.69	2.7	4.5
Commercial/hectare	0.0016	0.012	0.02
Electrical generation/kwh	0.00015	3.6	6
Total		7.78	12.8

*The sum of residential, public use, schools, hospitals and commercial.
**For street cleaning, fire department services, and so forth.

TABLE 3

International standards for drinking water

Tentative limits for toxic substances in drinking water:

Substance	Upper limit of concentration (mg/l)
Arsenic (as As)	0.05
Cadmium (as Cd)	0.01
Cyanide (as CN)	0.05
Lead (as Pb)	0.1
Mercury (total as Hg)	0.001
Selenium (as Se)	0.01

There are also recommended control limits for fluorides (as F), depending on the maximum daily air temperature.

Additional limits of substances affecting acceptability of drinking water:

Substance or characteristic	Highest desirable level	Maximum permissible level	Undesirable effects that may be produced
Calcium (as Ca)	75 mg/l	200 mg/l	Scale formation
Total solids	500 mg/l	1,500 mg/l	Gastrointestinal irritation
Chloride (as Cl)	200 mg/l	600 mg/l	Corrosion in hot water systems
Copper (as Cu)	0.05 mg/l	1.5 mg/l	Corrosion
Iron (as Fe)	0.1 mg/l	1.0 mg/l	Deposits; growth of iron bacteria
Manganese (as Mn)	0.05 mg/l	.5 mg/l	Deposits in pipes; turbidity
Zinc (as Zn)	5.0 mg/l	15 mg/l	Sand-like deposits; opalescence
Magnesium (as Mg)	Not more than 30 mg/l if there are 250 mg/l of sulfate; if there is less sulfate, up to 150 mg/l Mg may be allowed	150mg/l	Gastrointestinal irritation in the presence of sulfate
Sulfate (as SO_4)	200 mg/l	400 mg/l	Gastrointestinal irritation when Mg or sodium are present

There are other characteristics for which limits are set—for example, mineral oil or pH. There are also limits for microbiological contaminants, etc.

Source: World Health Organization, 1971.

(Pittsburgh, Cincinnati, and Columbus) was dramatic.

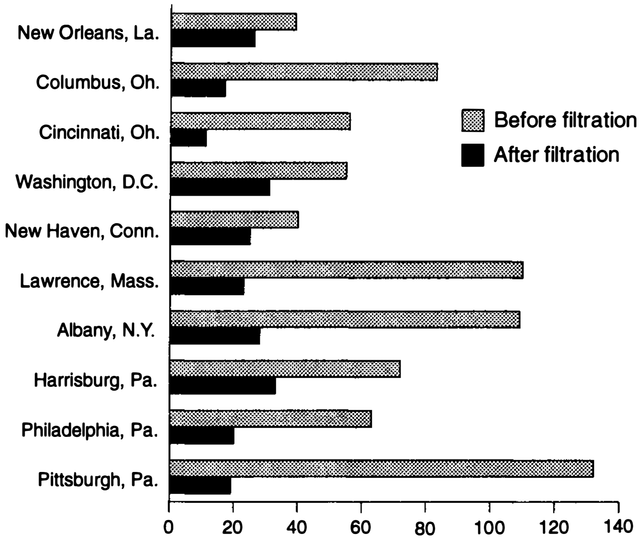
Distribution

As shown in Figure 1, the elements involved in delivering water to its destination for use, are commonly a reservoir or holding tank, the pipes for delivery, elevated tanks, and booster stations. A key consideration is the pressure, which, for adequate domestic service, should not be below 45 pounds per square inch in the main conduit at the house connection. The costs to move water vary much more according to the volume to be moved, than to the altitude to which it must be moved. It is therefore much cheaper to move large volumes of water than small quantities, even up steep slopes. **Figure 3** shows how the costs of conveying water vary with volume carried and gradient, as figured by engineers in 1970 cents per cubic meter. Today, the cost in a

FIGURE 2

Typhoid mortality drops when water is filtrated

(deaths per 100,000 population, 5-year average)

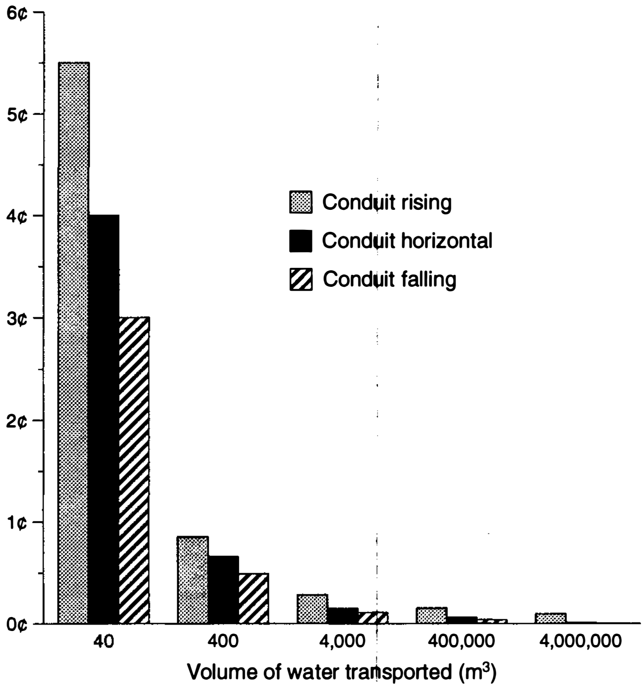


Source: George A. Johnson, "The Typhoid Toll," *Journal of American Water Works Association,* 3(2), 1916.

FIGURE 3

Water is far cheaper to transport in high volume

(cents per m^3 of water)



Source: Colin Clark, *The Economics of Irrigation,* London: Pergamon Press, 1970.

place such as California, is roughly figured to be about $120 per acre-foot (1,234 cubic meters) for a 20-mile pipeline and an 800-foot lift.

Sewage treatment

Standard modern treatment involves holding the effluent or other contaminated waste in pools, stirring it to aid oxygenation, and allowing suspended matter to sink to sludge at the bottom. The water may get more filtration through sand, and a final disinfection with chlorine, ultraviolet radiation, or some other means, before it is discharged.

The costs of each of these processes correspond to the steps needed to treat the water, and in general, sewage treatment is more expensive than purification.

Table 4 gives the average cost for these stages of treatment, as charged by a small, modern water district in northern Virginia, where the average annual rainfall is close to 100 cm (40 inches) and the water system uses 80% river run-off (from the lower Potomac River basin) and draws well water for the remaining 20%. The system can produce 800 million gallons of water a year (3.028 million cubic meters), and serves 19,000 people. The treated sewage water is then discharged back into the Potomac River.

On a daily basis, this water system provides about 2.1 million gallons (7,948 cubic meters) of safe water, or about 110 gallons a day per person.

A rough guide to costs for setting up a new wastewater treatment plant for handling secondary or advanced secondary effluent treatment would be about $10 per gallon handled, or $2,642 per cubic meter. If you figure on 100 gallons per person per day, this figure would be accurate, especially in the range of producing 6 million gallons per day, or enough for 60,000 people, for uses that are mostly domestic and municipal, and not industrial.

This example indicates that a rough guide for water purification costs is about $2.40 per 1,000 gallons, including present-day financing charges, and excluding costs of distribution and sewage treatment. Of this, 70¢ is for operations and maintenance. The distribution costs are about 40¢, counting 20¢ for water and 20¢ for sewer water. The sewage treatment costs $3.01, of which 85¢ is for operations and maintenance.

Local water treatment costs in similar U.S. regions run in about the same range as the Virginia example, as shown in **Table 5.** Therefore, the rough figures of $2.40 per 1,000 gallons for purification, and $3.00 per 1,000 gallons for sewage treatment, can be taken as benchmarks for looking at costs to provide safe water in widely varying locations and conditions.

TABLE 4

Average water treatment costs for the Leesburg, Virginia municipal and sewer system, 1992

($ per 1,000 gallons)

Process	Total cost[1]	Operations and maintenance only
Supply	Minimal for river	n.a.
Purification	$2.47	$0.70
Distribution		
Water	.20	
Sewage	.20	
Sewage treatment	3.01	0.85
Total	$5.88	

1. The total cost includes capitalization, administration, employee benefits, financing charges, etc.

Source: Office of the Leesburg Municipal and Sewer System, Leesburg, Virginia.

TABLE 5

Costs of residential water for selected states, 1984

($ per 1,000 gallons)

State	Average cost from water utilities
Vermont	$2.50
Connecticut	2.42
Pennsylvania	2.29
Illinois	1.97
Kansas	1.94
Virginia	1.75
Louisiana	1.51
Colorado	1.27
California	1.04
North Dakota	.96
Utah	.58

Source: American Water Works Association, *1984 Water Utility Operating Data.*

The water resource base

We begin with the water resource base, in order to answer the question: What is the quantity and quality of the water source, relative to current and future needs? For simplicity, our "benchmark" water system shown was chosen from the rain-fed Piedmont region of the eastern United States, where the drinking water source is river water, available at next to no cost (as long as the flow level is maintained, and the water not polluted). In many locations, such plentiful and cheap water is not available.

Where the freshwater base is not adequate, there are three ways to intervene to expand the resource base, and the costs will vary accordingly: 1) Make waterworks improvements in the freshwater patterns of run-off (rivers, lakes) or underground water, etc. 2) Make new fresh water through desalting seawater or brackish water. 3) Treat wastewater to transform it into fresh water, and use it over again.

The first approach involves geographic engineering (dams, tunnels, canals, and reservoirs) within the watershed of the river and its tributaries (i.e., the river basin), or else altering the water flow between river basins, a procedure called interbasin transfer. There are many locations where continental-scale interbasin transfers are now needed, as successors to past water improvements, and the costs are very low on a per-cubic-meter basis.

The second approach, desalting briny water, can involve many types of distillation, whose main cost is electricity: The higher the salt content, the more electricity is needed. Nuclear power plants, coupled with modern desalination methods, therefore provide the lowest costs of any desalting method. Built on a large enough water volume scale, the costs are in the range of the Virginia $2.40 per 1,000 gallons benchmark cost.

Finally, there are modern, high-energy ways to treat sewage, even toxic waste water, that will provide acceptable fresh water in the cost range near the $2.40-3.00 per 1,000 gallons benchmark cost.

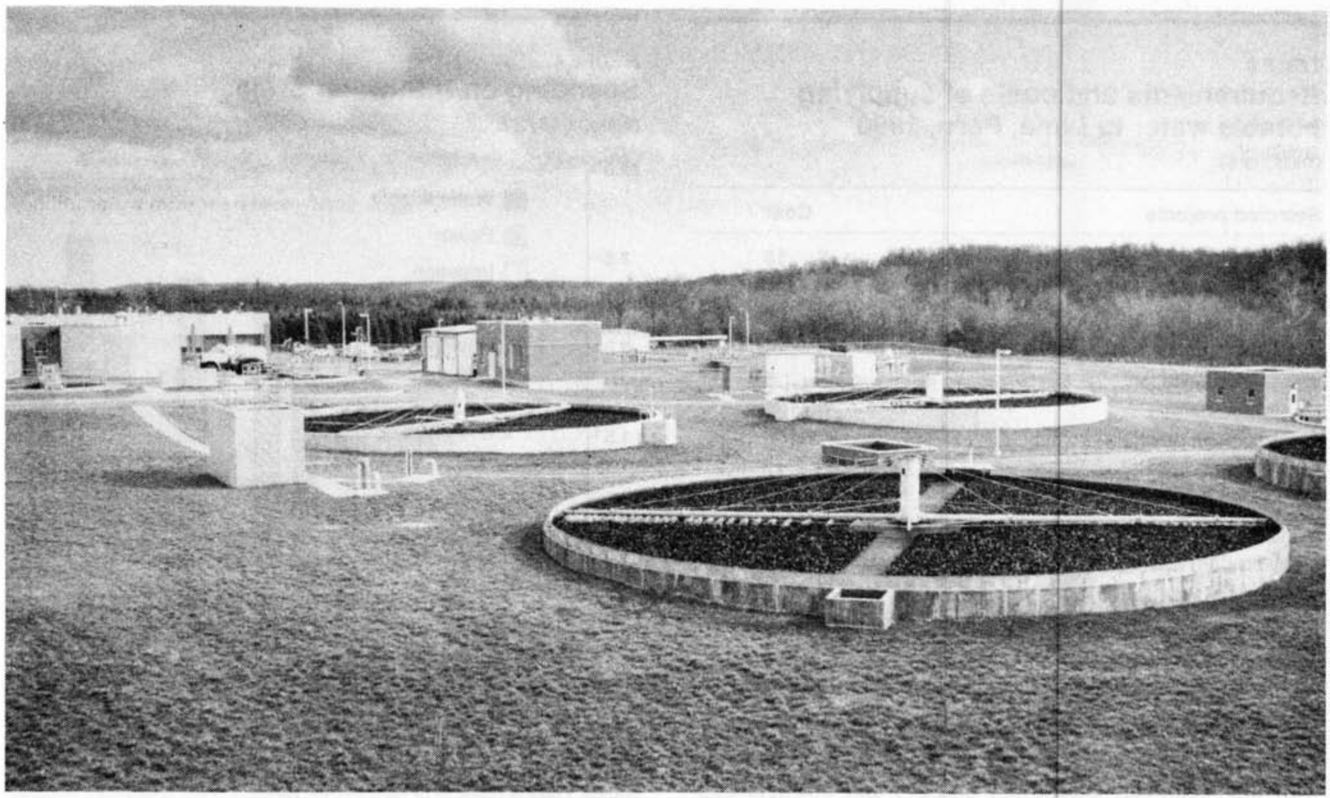
These three means of mobilizing expanded water resources are discussed in detail below, with references, diagrams, and costs. Some form of one or more of these approaches to supplying new sources of water can be adapted to any water-short region of the world. In most cases, the engineering concepts have existed for years.

The alternative to making waterworks improvements is tragically clear. Cholera, hepatitis, typhoid fever, and other waterborne illnesses are coming back with a vengeance. Droughts are causing sweeping famine, such as this year in Africa, instead of merely "one bad season" for crops. Needless flood damage occurs. And commerce and travel is made expensive for lack of cheap water transit.

Even worse, the superstition is gaining ground that waterworks "harm nature." In October, Hollywood released a propaganda film to promote this backward, immoral point of view. Called "A River Runs Through It," the movie gives a romantic picture of how land should be with no people or no technology. Look briefly at the powers behind this.

Who says the cost is too high?

Over the past 25 years, a nexus of international agencies and private central banks, including the International Monetary Fund (IMF), the World Bank, and the Federal Reserve



The municipal sewage treatment facility in Leesburg, Virginia, serving a population of 19,000, is this study's "benchmark" for the cost of maintaining a flow of pure water—in this case, from the Potomac River. After treatment, the sewage is returned to the river. The cost of treating 1,000 gallons of effluent is about $3.00.

Bank, has functioned to obstruct needed water resources development.

The rationalization they use for their opposition is the lie that both large-scale water diversion and nuclear-powered desalination are too expensive. They argue that waterworks developments are threats to the environment. Instead, the Federal Reserve has argued, "the market" must allocate scarce water resources to the highest bidder. Under the IMF model, localities and nations have been forced to make usurious payments—debt service, financing, and fees to select financial entities, and have been prevented from mobilizing for water and other basic economic requirements.

For example, in Lima, Peru, a series of needed water treatment improvements—designed on the basis of the standard processes outlined above—were repeatedly stalled or canceled through IMF and World Bank intervention over the 1980s. **Table 6** gives the facilities which as of 1990 had been proposed by city officials. These were especially urgent because the city is located in a coastal desert, with next to no stopgap water supplies as an alternative to central water systems.

In January 1991, cholera broke out in Lima. It has now spread throughout the Western Hemisphere, reaching the Rio Grande River system in the spring of 1992. This is the direct result of IMF opposition to waterworks.[3]

In the United States, the Federal Reserve has likewise intervened in recent decades to stop needed water development. **Figure 4** shows the rise in national spending on water projects from 1900 to 1970. Spending varied over time for different uses of water. In the earliest period, improved navigation was the goal; then water for irrigation and water for power became important. In the 1960s, new water supplies for general use were added.

Since 1970, the argument is repeatedly made that "the era of water projects is over." The Fed's western district governors have stated their opposition repeatedly. Among their clearest statements of this point of view is a book containing the proceedings of a 1979 symposium sponsored by the Federal Reserve Bank of Kansas City, on the topic of "Western Water Resources: Coming Problems and the Policy Alternatives."[4] The speaker, Theodore M. Schad, on "Means to Augment Supply," argued that where water resources are scarce, "the most economic way to bring supply and demand into balance is by reducing demand." He argued that "our institutions can be updated to meet the new conditions" of inadequate water for such uses as irrigation.

At the same conference, the idea of large-scale interbasin transfers, such as the North American Water and Power Alliance (see below), was singled out for special attack. Canadian engineer Keith Henry asserted, "I do suggest that the

TABLE 6

Requirements and costs of supplying potable water to Lima, Peru, 1990

(millions $)

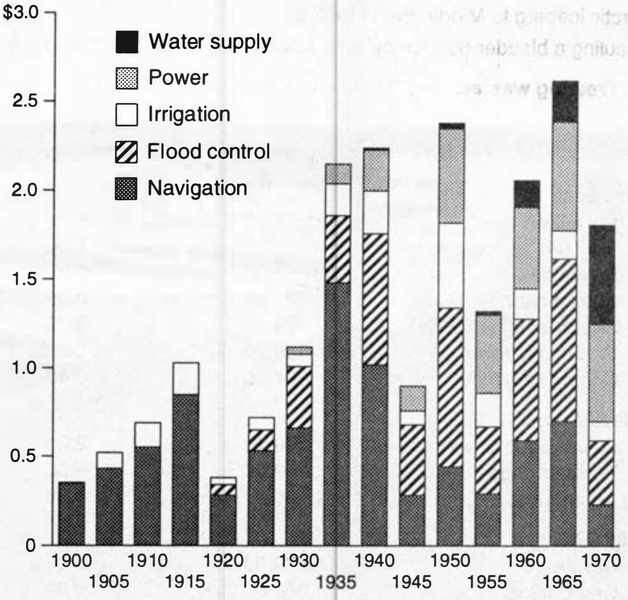
Selected projects	Cost
Expansion of La Atarjea water treatment plant	$ 15
Yuracmayo Reservoir	25
Wells—Argentine-Peruvian Protocol (60 wells under construction)	14
Wells—rehabilitation	5
Mantaro Aqueduct	131
Completion of whole project	169
Reduction of water loss	17
Peruvian-Italian Protocol	10
Mantaro-Sheque water project (hydro dam and aqueduct)	1,800
Total estimated cost	**$2,285**
Allocated as of April 1991	**$ 14**

Source: "Auschwitz Below the Border," *EIR Special Report*, May 1991.

FIGURE 4

Spending on U.S. water projects, 1900-70

(billions 1972 $)



Source: Federal Reserve of Kansas City, *Western Water Resources*, Boulder, Colo.: Westview Press, 1980.

colossal concepts such as Nawapa will not be practicable with the technical, economic, energy, and political constraints under which we presently live, and even smaller schemes are going to present great difficulties."

The Federal Reserve has collaborated with a phalanx of water "experts" at such think-tanks as Resources for the Future to rewrite state and federal laws governing water, and their anti-improvements policy has prevailed up through the present. The same staff has gone back and forth between the Federal Reserve and other policymaking positions, to carry out their campaign. For example, Emery Castle, past president of Resources for the Future, was a Fed staff researcher in Kansas City. Most recently, Gus Speth, a founder of the Washington, D.C.-based World Resources Institute—part of the Federal Reserve policy group—was appointed by President-elect Bill Clinton to head his transition "cluster" group on resources and the environment.

California has been a target state, because, with or without drought, its water budget has been exceeded for several years, because of the Federal Reserve's anti-development policy. In October 1992, a new federal water law gave permission to deregulate California's Central Valley Project—the largest federal water program in the country, and to create a "water market."

This is an example of the new institutions the Federal Reserve has demanded. In early 1991, the senior economist of the San Francisco Federal Reserve, Ronald Schmidt, wrote, "Over the longer term, deregulated water markets could offer an automatic mechanism to solve the [water] allocation problem in the least-cost way. As supplies shrink, prices would rise. And those who can most easily reduce their consumption will do so. Once water users face the true cost of water—that is, the price others would be willing to pay for it—they have financial incentives to put water to its most valuable use."

High-cost, primitive 'alternative' systems

The World Bank, Federal Reserve, and related agencies have collaborated in producing many surveys and databanks on costs of "alternative" water treatment methods, in an effort to justify their ban on water development. They argue that primitive "alternatives" are cheaper. But **Table 7** gives a summary of this type of thinking, and the figures show how this argument is a lie.

Sources: How about towing icebergs to water-short areas? Since you see only the proverbial "tip of the iceberg," you could easily underestimate the significant towing costs for the ice mass beneath the waterline. Furthermore, the water channel has to be deep and wide enough to accommodate an iceberg, and many channels are not. Finally, the ice melt rate is so slow, that crushers, conveyer belts, and heat exchangers would be required to organize any decent flow. Therefore, the cost per cubic meter of iceberg water soars.

So, how about hauling water in giant plastic bags or bladders? This can be done, but the towing and handling costs also drive up the price. It may work for a remote tropical island, or an oil rig, but not for a large, economically active population.

TABLE 7

Costs of primitive water systems

I. Providing water

Arctic iceberg to Middle East (1992 $)	$ 3.75 per cubic meter ($14.25 per 1,000 gallons)
Hauling a bladder 500 km by sea, 1,000 cubic meters per bladder (1970 $)	$15.00 per cubic meter

II. Treating wastewater: World Bank estimates for different sanitation systems, given in costs per 6-person household

	Total investment cost	Monthly operational cost	Monthly water cost	Total monthly cost[1]	Percent[2] of income of average low-income household
Low-cost:					
Pour-flush toilet	$ 70.70	$0.20	$0.30	$ 2.00	2
Vacuum truck cartage	107.30	1.60	n.a.	3.80	4
Pit latrine	123.00	n.a.	n.a.	2.60	3
Bucket cartage	192.20	2.30	n.a.	5.00	6
Septic tank	204.50	0.40	0.50	5.20	6
Communal toilet	355.20	0.30	0.60	8.30	9
Composting toilet	397.70	0.40	n.a.	8.70	10
Medium-cost:					
Sewer aqua privy	570.40	2.00	0.90	10.00	11
Truck cartage	709.90	5.00	n.a.	13.80	15
Aqua privy	1,100.40	0.30	n.a.	13.80	16
High-Cost:					
Sewerage	1,478.60	5.10	5.70	41.70	46
Septic tanks	1,645.00	5.00	5.90	46.20	51

III. Distribution: World bank estimates for prices charged by water vendors
(factors are for mid-1970s-80s)

City	Multiples of price[3] charged by public water utility
Lima, Peru	17
Karachi, Pakistan	28-83
Lagos, Nigeria	4-10

Notes
1. Assuming that the investment cost is financed by loans at 8% over 5 years for low-cost systems, over 10 years for medium-cost, and over 10 years for high-cost.
2. Assuming that average annual per capita income is $180, with 6 persons per household.
3. The price estimates are by *EIR,* based on 1992 water costs.

Sources: World Bank Studies in Water Supply and Sanitation, *Appropriate Sanitation Alternatives: A Technical and Economic Appraisal,* Baltimore: Johns Hopkins University Press, 1982; World Bank Urban Development Division, "Urban Strategy Paper," draft, Washington, D.C.: May 1989.

Sewage treatment: The World Bank argues for primitive sewage treatment, on the basis of how expensive modern sanitation methods are when costs are borne as a percentage of a low per capita income. The World Bank figures in this case are $180 per person per year. But their argument falls apart if you presume that per capita incomes should in fact be higher, and that people need sanitation to be productive. Moreover, from a scientific standpoint, the primitive methods listed would simply not work to protect the population if they live in any kind of concentrated density.

Distribution: Water street vendors, who bring it to you in multi-gallons cans, are part of what the World Bank and IMF like to call the "informal economy"—their polite name for the coolie-labor impoverishment they are enforcing. The costs of water per 1,000 gallons in this system is exorbitant.

Improving the natural endowment

If you look at the Earth as a planetary engineer does, you see that it is well endowed with water. However, the forms of water are not always useful: It is too salty, frozen, or scanty, and regionally, there is great variation in freshwater supplies.

Run-off

Table 8 shows what a tiny fraction of the Earth's water exists as freshwater run-off. Over 97% of the world's water is in the oceans. And of the 2.8% that is fresh water, only a fraction of 1% is available as stream run-off, lakes, and groundwater.

TABLE 8

Estimated world water supply and budget

Water item	000 km^3 volume	% of water total
Water in land areas:		
Fresh water lakes	125.00	0.0090%
Saline lakes and inland seas	104.00	0.0080%
Rivers (average instantaneous volume)	1.25	0.0001%
Soil and vadose water	67.00	0.0050%
Ground water to depth of 4,000 m (about 13,100 ft.)	8,350.00	0.6100%
Icecaps and glaciers	29,200.00	2.1400%
Total in land area (rounded)	37,800.00	2.8000%
Atmosphere	13.00	0.0010%
World ocean	1,320,000.00	97.3000%
Total, all items (rounded)	1,360,000.00	100%
Annual evaporation:		
From world ocean	350.00	0.0250%
from land areas	70.00	0.0050%
Total Annual precipitation[1]:	420.00	0.0310%
On world ocean	320.00	0.0240%
On land areas	100.00	0.0070%
Total	420.00	0.0310%
Annual runoff to oceans from rivers and icecaps	38.00	0.0030%
Groundwater outflow to oceans[2]	1.60	0.0001%
Total	39.60	0.0031%

Notes:
1. Evaporation (420,000 km^3) is a measure of total water participating annually in the hydrologic cycle.
2. Arbitrarily set equal to about 5% of surface runoff.

Source: Nace, U.S. Geological Survey, 1967

Historically, lakes, river and stream flow are the handiest, cheapest form of fresh water. The relative quantities of freshwater run-off on each continent are shown in **Table 9.** This flow is carried by a practically uncountable number of rivers and streams. The United States alone has an estimated 3.25 million miles of river channel. **Figure 5** shows some of the prominent rivers of each continent, with an outline for the borders of the river system watershed, or "basin."

In the course of human history, as patterns of human settlement evolved, existing surface water sources were used up in many locations, and societies intervened with "man-made" rivers and lakes to channel freshwater flow where needed. The oldest known dam is said to have been built between 2700 and 2500 B.C. at Helwan, Egypt, where a dry *wadi* was dammed to trap seasonal water. The most famous man-made rivers are the aqueducts of ancient Rome, dating from 312 B.C. to A.D. 226, and the Grand Canal of China.

However, it is only since the Golden Renaissance of the fifteenth century that water technology has leapt ahead. In the Netherlands, for example, water engineering has for centuries succeeded in holding back seawater with dykes, allowing for freshwater storage inland, and capturing more land for productive use. Dutch waterworks appear in many Rembrandt drawings and paintings. The Italian Renaissance master Leonardo da Vinci studied and depicted water flows and engineering.

In the twentieth century, advanced construction techniques came into being, using concrete, heavy equipment and explosives, and entire river basins were improved by dams, channels, and other waterworks. The 1930s was the era of the great dams in the United States, when, for example, the Boulder Dam was built, creating the largest man-made

TABLE 9

Worldwide stable runoff, by continent

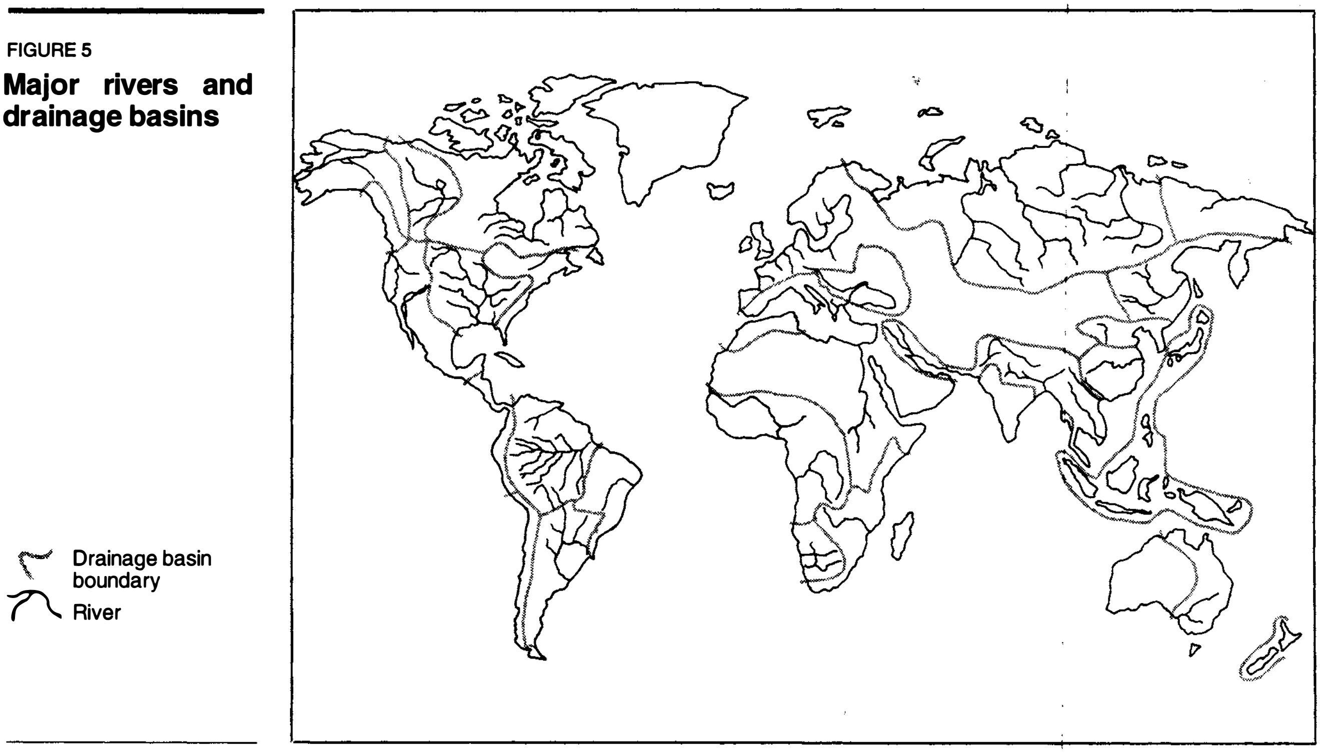
	Stable runoff (km^3)[1]					
	Of underground origin	Regulated by lakes	Regulated by water reservoirs	Total	Total river runoff[2]	Total stable runoff as % of total runoff
Europe	1,065	60	200	1,325	3,110	43
Asia	3,410	35	560	4,005	13,190	30
Africa	1,465	40	400	1,905	4,225	45
North America	1,740	150	490	2,380	5,960	40
South America	3,740		160	3,900	10,380	38
Australia[3]	465		30	495	1,965	25
Total[4]	11,885	285	1,840	14,010	38,830	36

Notes
1. Excluding flood flows.
2. Including flood flows.
3. Including Tasmania, New Guinea, and New Zealand.
4. Except polar zones.

Source: Lvovitch, M.I., *Eos*, Vol. 54, No.1, Jan. 1973, © American Geophysical Union

FIGURE 5

Major rivers and drainage basins



lake in the country, Lake Mead. The Colorado River basin is the textbook example of river basin development. The Tennessee Valley Authority developed the multi-state region of the Tennessee River system.

Hydrologists have estimated the amount of run-off flow that has now been organized for man's use, on each continent, as shown in **Table 10,** which gives withdrawals as a percentage of river run-off, and withdrawals per capita by continent and by selected country. What stands out is that in South America and Africa, relatively little of the river run-off is withdrawn for man's needs: 3% in Africa and 1% in South America. The withdrawals vary greatly from country to country, depending on their river flows and economic activity. In Egypt, 97% of the river run-off is used; in Israel, 88%. In Saudi Arabia, 106% is used; the Saudis add water to run-off through desalination. In contrast, 1% of the run-off is withdrawn for use in Canada, and 2% in Sweden.

In particular, interbasin transfers of water have been organized to direct flow from one basin into another, where it is needed more for direct human consumption, and for improving the environment. The earliest dated interbasin transfer in the United States, for example, was in Massachusetts.

In the post-World War II period, nuclear scientists conducted successful experiments with peaceful nuclear explosives (PNEs) for use in geographic engineering, especially for continental-scale water projects, as well as for waterway channels—for example, a new, wider Panama Canal, or a canal cut through the Isthmus of Kra in Thailand. Called "Project Plowshare" for turning the destructive power of the atomic bomb into constructive uses, the programs were eventually canceled under pressure from anti-development powers.

Groundwater

In addition to surface water run-off, underground water is a vital water resource. Tables 8 and 9 indicate volumes of groundwater by continent. Some groundwater is considered "fossil" water—trapped in long past times, and not being replenished by any new flow. Other groundwater—whether large aquifers, or flow adjacent to a river bed—is considered renewable, because it receives an inflow, which can potentially replenish what flows out or is pumped out. Estimates for locations and volumes of groundwater are being revised frequently, as new resources are identified by satellite, using special sensing techniques that can "see" underground to about 20 feet below the Earth's surface.

Over the centuries, water pumping technology has allowed greater use of groundwater. The famous Archimedes screw—an auger that can lift water up through a pipe—is reckoned to have come into use around 250 B.C. Centuries ago, the system of buckets on a chain around a sprocket came into use, with the further advance of treadmill power. In the twentieth century, high-powered drills, tough drill bits, and electrified water pumps have enabled groundwater to be pumped up at record volumes from record depths.

In recent decades, water levels in some aquifers have dropped significantly because of overdraft—the drawing out

TABLE 10

Annual withdrawals of river run-off

Location	Run-off (km^3)	With-drawals (km^3)	Percent of water resources	Withdrawals per capita (m^3)
World	40,673	3,296	8%	660
Africa	4,184	144	3%	244
Egypt	58.3	56.4	97%	1,202
Congo	271.77	0.04	1%	20
North America	6,945	697	10%	1,692
United States	2,478	467	19%	2,162
Mexico	357.4	54.2	15%	901
Canada	2,901	36.15	1%	1,501
South America	10,377	133	1%	476
Venezuela	1,317	4.1	<1%	387
Brazil	6,950	35.04	1%	212
Peru	40	6.1	15%	294
Asia	10,485	1,531	15%	526
Israel	2.15	1.9	88%	447
Saudi Arabia	2.2	2.33	106%	321
China	2,800	460	16%	462
India	2,085	380	18%	612
Japan	551.43	107.8	20%	923
Europe	2,321	359	15%	726
Belgium	9.25	9.03	72%	917
Sweden	197.11	3.98	2%	479
Germany	195	41.4	26%	650
Former U.S.S.R.	4,634	353	8%	1,330
Oceania	2,011	23	1%	907
Australia	343	17.8	5%	1,306
New Zealand	397	0.03	<1%	379

Source: *World Resources, 1990-1991*, New York: Oxford University Press, 1990.

of more water than was being replenished by inflow. Where this occurs in an aquifer near the seacoast, salt water intrusion frequently becomes a problem, as, for example, in California, Florida, and on Long Island, New York. Inland problems can include ground slumping, as the water table lowers from groundwater overdrafts, for example, in Houston.

North American Water and Power Alliance

FIGURE 6

United States: annual precipitation

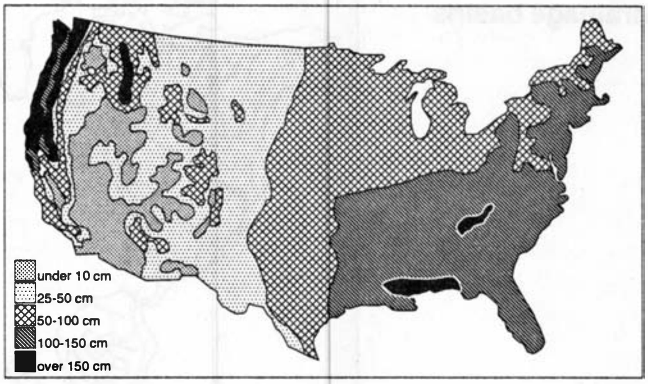


Figure 6 gives the pattern of average annual precipitation in the United States, from which it can be seen that for the most part, rainfall in the eastern states is ample for rain-fed agriculture and stream run-off, and groundwater replenishment; whereas as you go west, the rainfall declines markedly, with the exception of the Northwest. In the 17 arid western states are located most of the large dams built this century for river basin management to provide maximum use of run-off in the region—for example, the dams on the upper Missouri system, the Colorado River system. About three-quarters of the run-off in the dry states comes from snow melt from the Rocky Mountain chain.

Although some work remains to be done on these river management systems, the limits are being reached overall on how much more water can be gained. As the best barrier sites for dams were utilized, the potential for gain diminished. (See Table 9 for a world overview of amount of river run-off made stable by dams and basin management.) In the United States, the average reservoir capacity producer per cubic yard of dam declined from 10.4 acre-feet in the 1920s and earlier, down to 2.1 in the 1930s, 0.52 in the 1940s, and 0.29 in the 1960s, according to the U.S. Geological Survey.[5]

This limitation was foreseen 40 years ago, and in the 1960s, various larger-scale water projects were considered in Congress and by western states engineers, especially in Texas, California, and Colorado. The most ambitious plan put forward was the North American Water and Power Alliance (Nawapa), which, had it been implemented, would have prevented the California water shortages which are now being blamed on the drought.[6]

Figure 7 gives a schematic route of Nawapa, superimposed on a topographical map of North America. The idea is to divert to the south, water that now flows northward, unutilized, into the Arctic Ocean. The northwestern region of North America receives about one-quarter of all the rain and snow that hits the continent. The Nawapa scheme would divert up to 15% of this flow, beginning with channelling it into a natural wonder reservoir: the 500-mile-long Rocky Mountain Trench in British Columbia. The trench is a 10-mile-wide geological formation that could hold almost 500 million acre-feet of water.

Construction time for the entire Nawapa design is estimated to be 20 years, after the first 5-8 years of engineering reconnaissance and other preparations. This timetable is based on traditional construction methods, not the time-sav-

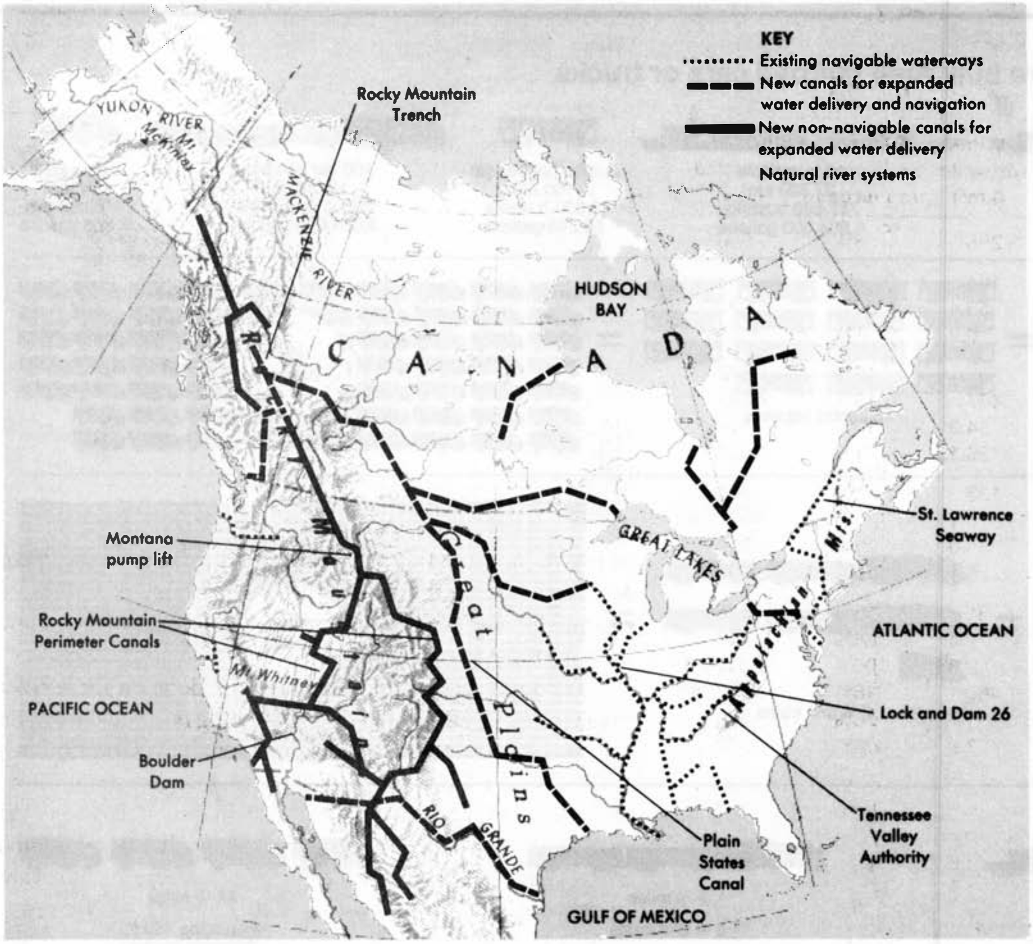


FIGURE 7
The North American Water and Power Alliance

Source: As elaborated by the Fusion Energy Foundation, 1982.

ing nuclear methods that could also be applied.

Ultimately, the plan could provide an addition of 135 billion gallons a day to the United States, and additional supplies to Canada and Mexico. For the U.S., this would be a 25% increase to the existing, readily available national water supply of 515 billion gallons daily.

The project would best proceed in stages. Under the original projection, after Year 8 of construction, it would be possible to produce and sell 5 million kilowatts of electricity. After year 9, some 23 million kW would become available, and the first flow of 15 million acre-feet per year of water would begin. In 12 years, there could be 31 million kW of electricity, and 39 million acre-feet of water.

The benefits of Nawapa go beyond water for direct consumption. The transport benefit is also enormous. Water is the cheapest method of moving goods. **Figure 8** gives the comparisons of tons that can be moved by three freight modes: barge, train, and truck.

As of 1990, the United States had about 11,000 miles of mainline inland waterways. Nawapa would increase this by a huge factor in the United States, and would open up new lands for settlement in Canada. Nawapa would bring new north-south water routes through the High Plains of the prairie provinces and states, where at present such travel is costly. This could open up population densities on the scale of southeastern Pennsylvania or Rhineland Germany.

The added water from Nawapa can be the means to stabilize and maintain the Great Lakes, which are otherwise being degraded from decades of pollution from depressed economic activities and from "natural" lacustrine aging.

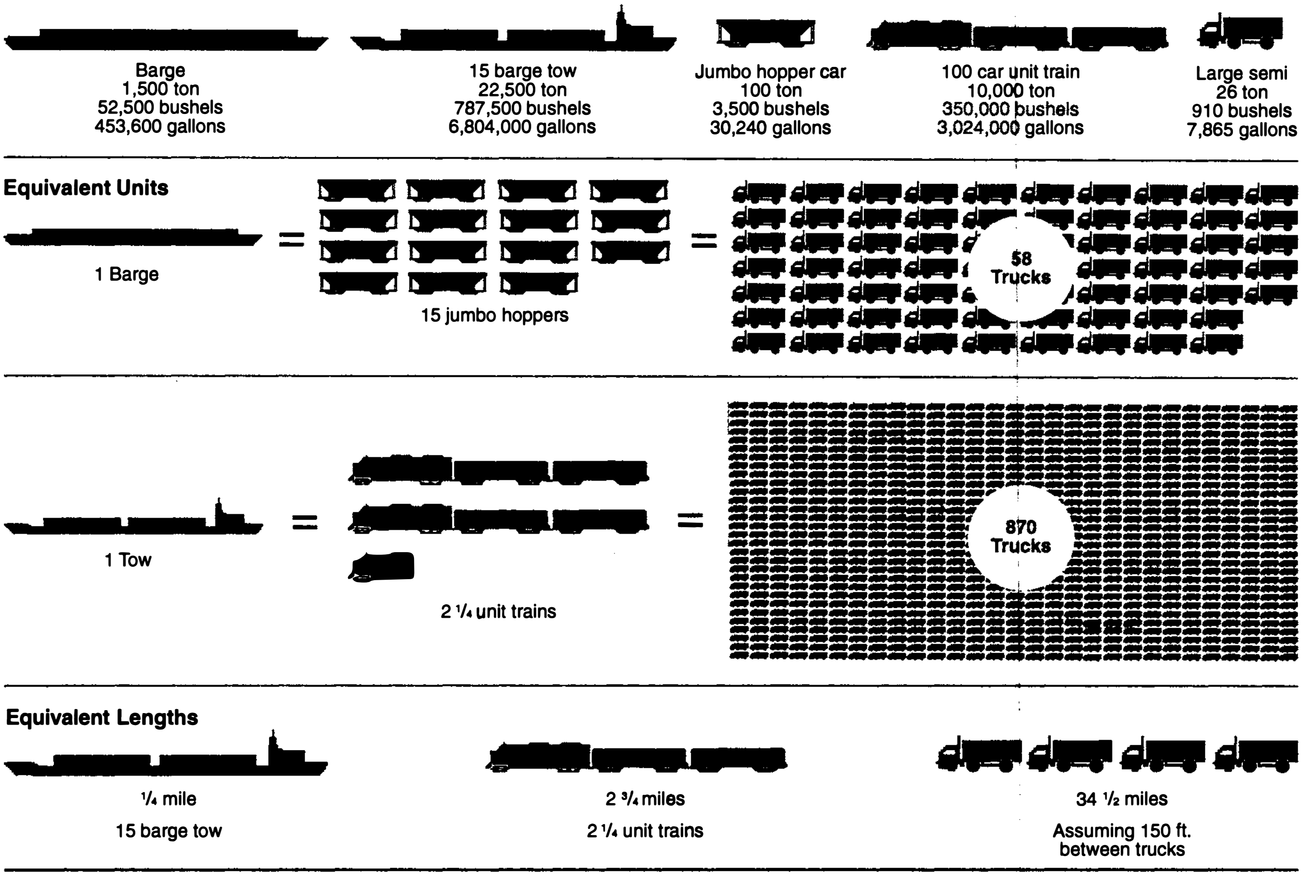
The cost of Nawapa was figured at $100 billion in the 1960s, which today would be $300 billion, or $10 billion a year for 30 years, depending on the pace of construction. Each phase completed would have significant positive effects on the entire economy as the project proceeds.[7]

China's great water projects

Figure 9 gives the precipitation pattern for China, showing the striking change from the monsoonal rain belt in the southeast, to the extreme arid void in the far northwest. The river run-off patterns reflect this: The Yellow River and other streams in the north have far less flow than the Yangtze and others to the south. However, there is another striking feature of China's run-off. The Yellow River carries a heavier load

FIGURE 8

Barges carry far more bulk than railroad cars or trucks



Source: Iowa Department of Transportation.

of silt than any other river in the world. It flows through China's famous "loess" belt, a huge area where crusty, wind-blown soil deposits exist, contributing to heavy sedimentation in the run-off. (See **Table 11.**)

While the water endowment of China overall, as shown in Table 10, may appear ample, the problem is that there is an acute water shortage in much of northern China. So the challenge is to shift water, or improve the Yellow River system to aid the target regions, while not harming the south. A comprehensive approach to this was given earlier this century by Sun Yat Sen.[8]

Figure 10 gives a schematic picture of priority water projects today. Engineers have identified three channel routes which could be built in the headwater region of the Yangtze, and which could divert some of its ample waters northward into the headwaters of the Yellow River. In addition to its augmented flow, the Yellow River could be improved by side channel drainage lakes, where sediment could collect, leaving the main channel to flow cleaner and faster.

Figure 10 also identifies the route of improvements in the centuries-old Grand Canal running between the lower Yangtze and the lower Yellow River. Engineers have also devised central canal routes to take Yangtze Basin water northward toward Beijing. Work also needs to be done to keep the Yangtze levees in place. Reinforced levees, plus headwater diversion and flood safety provisions in communities, would minimize the damage now sustained when the Yangtze floods periodically.

These projects would go far toward improving the pattern of water flow in China, without detracting from existing water use patterns. In the southern Yangtze Basin, and southward, water is put to intensive use in agriculture, with two crops a year. This must not be disrupted, lest the food supply for millions of people be jeopardized. With the canal approach, three new north-south corridors of potential high-technology development are opened up without disruption to present agricultural water use patterns.

This approach is discussed for India and China by civil engineer Ramtanu Maitra, who heads the New Delhi-based policy group Fusion Asia. "Water management is a challenging proposition," he wrote in a recent article.[9] "Simple formulas will simply end in failure. It is for this reason that

FIGURE 9

Annual precipitation in eastern China

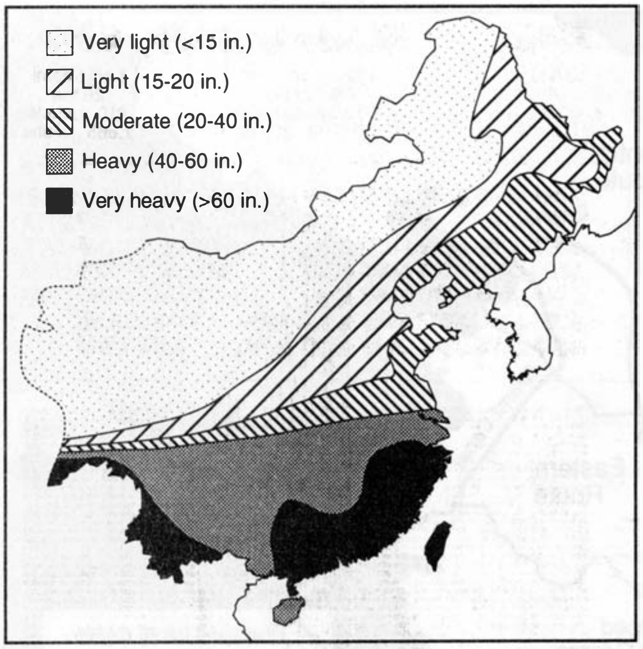


TABLE 11

Yellow River carries largest sediment load

River	Annual sediment load (million metric tons per year)	Mean water discharge (m³/second)	Catchment area (km²)
Huang He (Yellow)	1,640	1,370	752,000
Ganga	1,450	11,800	955,000
Amazon	850	172,000	6,100,000
Chiang Jiang (Yangtze)	480	29,200	1,807,000

Source: Frits van der Ledeen, *Water Resources of the World,* Port Washington, New York: Water Information Center, 1975.

a dam system, a canal, or a reservoir by itself is always inadequate. The minimum water-management unit is an entire river basin, which requires a combination of infrastructure. The water balance of adjacent river basins must be taken into consideration, with the purpose of using water supplies to create a balanced situation throughout the entire region."

The freshwater run-off in China could never be enough to provide the volumes of water needed in the arid north to turn it into a widely irrigated region; the water is not there, no matter how the rivers are managed. Northwestern China is a desert void. However, with advanced agriculture methods such as hydroponics, which yield up to 100 times the biomass per cubic meter of water as open-field farming, new limited supplies of water could be put to effective use. What this requires is cheap energy—namely, nuclear power.

A series of nuclear-powered desalination plants in the population concentrations in the lower Yellow River basin could supply both urban needs—now at the crisis stage in Beijing, Tianjin, and other cities—and could also provide water for hydroponic farming.[10]

Cost estimates for these projects will be in the range of the Nawapa continental-scale project described above.

Figure 10 also shows the location for the proposed giant "Three Gorges Dam" on the Yangzte River. The problems with this proposal—a pet project of the World Bank—do not lie with questions about its construction feasibility. Although it would be the world's highest dam, the engineering studies show that it can be built. The problems are that it could be disruptive to downriver economic activities, while its hydropower potential—the main argument in its favor—is inferior to a nuclear power program. As of 1992, the first phase of moving people out of the way of the future lake and construction site has begun.

Water basin development for India

Figure 11 shows the wide variation in water resources on the Indian subcontinent. The Indo-Gangetic plain stands out, where the run-off from the Himalayas, plus the monsoonal rainfall in the basin, add up to a large annual river run-off. However, most of the Indian subcontinent—the Deccan shield—is dry. The major rivers are shown in **Figure 12,** and Table 10 gives the water run-off for the country.

The goal of bringing water to the drylands has been promoted for decades. The leading idea has been to run a link canal north to south, through the intervening river basins, to create a Ganga-Cauvery waterway, although this has not been initiated. The Rajasthan Canal in the northwest desert has opened up large new farmlands.

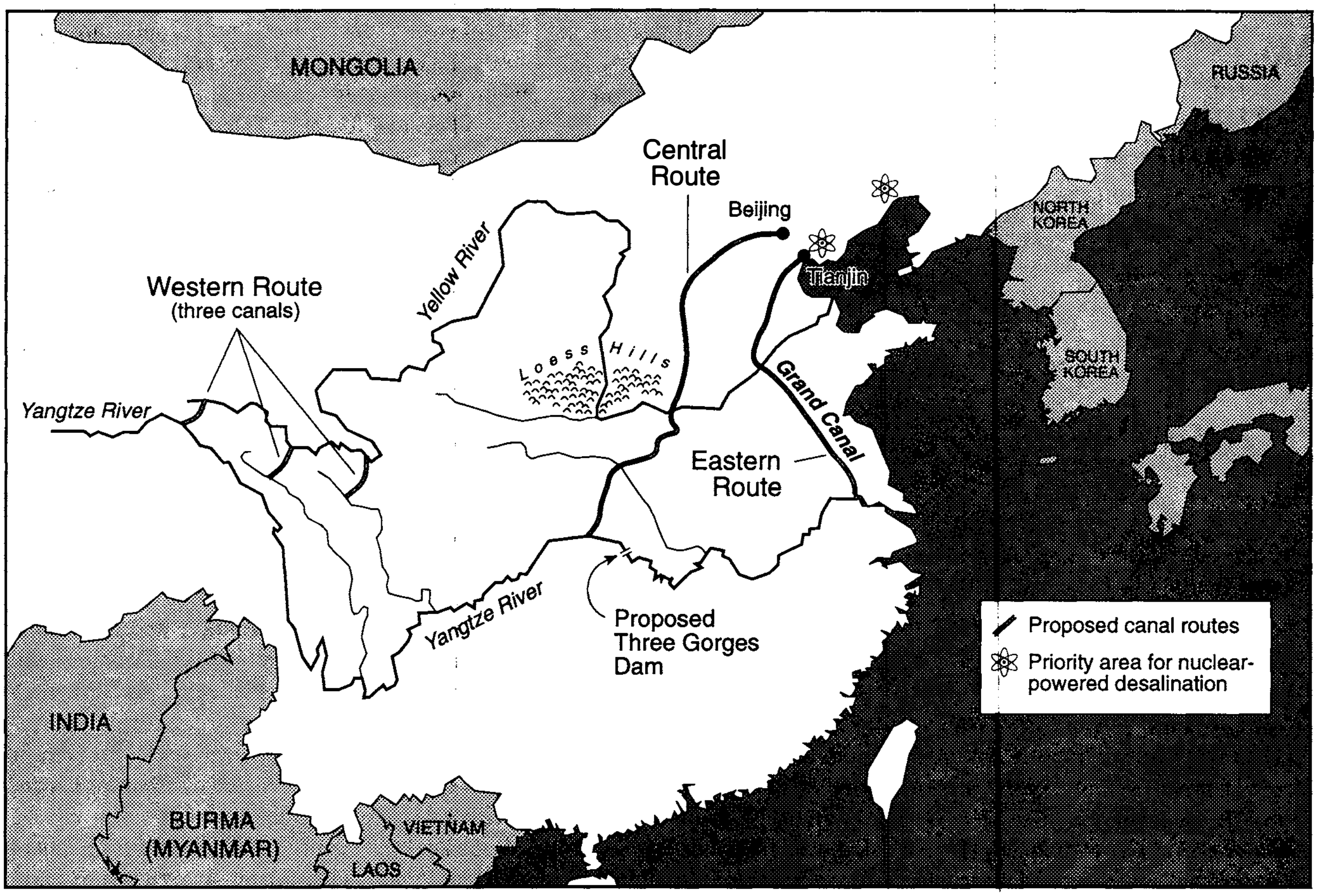
The newest project is the Narmada Valley Development Project.[11] The inset map in Figure 12 gives the outline for this program, the largest ever undertaken in India. The Narmada is India's fifth largest in size, and the largest among the east-west-flowing rivers. It represents an enormous untapped potential resource, because without the project, river water utilization is barely 4%, as huge amounts of fresh water drain into the Gulf of Khambhat in the Arabian Sea unused each day.

The design encompasses construction of 30 major dams, 135 medium-sized dams, and more than 75,000 kilometers of canals. The total project area is 96,350 square kilometers. The centerpiece of the project is the Sardar Sarovar Dam, whose site is at Vadgam in the state of Gujarat. This dam will provide an irrigation potential of 1.9 million hectares and an installed capacity of 1,500 megawatts of electrical power, plus flood control and opportunity for aquaculture and recreation.

The project is conceived to be built in stages, but when

FIGURE 10

Route alternatives for proposed interbasin transfer in China



completed by the turn of the century, it is expected to provide irrigation water to 5.2 million hectares of arable land, generate 3,500 megawatts of electrical power at peak load, and make water available to at least 10.8 million rural people who do not now have access to an adequate amount of water.

The original estimated cost was about $15 billion—a figure likely to be too conservative, but still cheap at the price. The Sardar Sarovar Dam cost is estimated at $5 billion.

Nuclear-powered desalination

Several types of processes are available today that will remove dissolved minerals (salts) from seawater or brackish water and will render the water fit for its intended use, whether pure (for drinking water and sensitive processing) or less pure (for agriculture and manufacturing use). Broadly, the processes fall under two categories: distillation and membrane use.

The costs involved vary greatly, but they mostly depend on the condition of the water source and the cost of energy required to do the job. Therefore, the cheapest way to produce large volumes of water at desired purities is from nuclear-powered, large-scale advanced desalination.

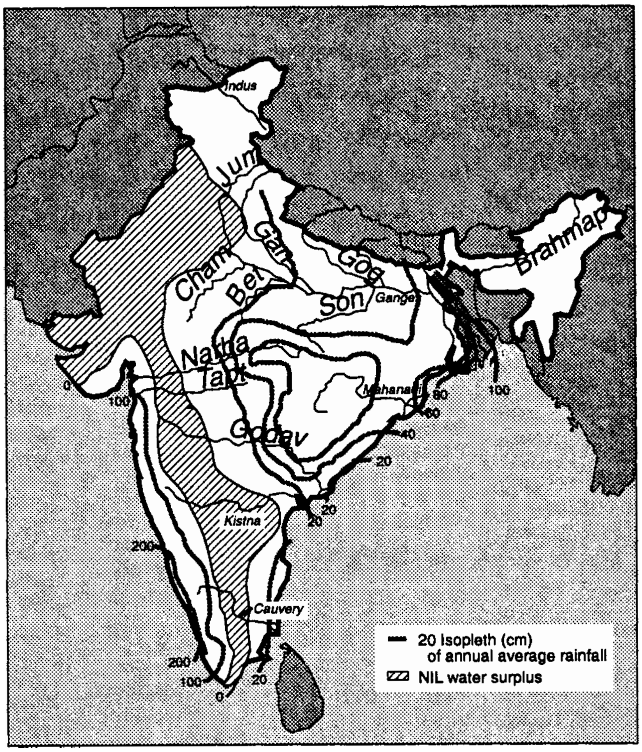
The desalination methods are here described briefly, and specifics are then given for two of the proposed large-scale nuclear-powered water plants.[12]

Distillation processes

- **Multi-stage flash (MSF).** By this method, seawater is first heated, then passed to another vessel (called a "stage"), where the water will immediately start boiling—a process called a "flash," because of the ambient pressure there. A small percentage of the water will convert into vapor, which is condensed as fresh water on heat exchanger tubes. Multiple stages of this process are operated at successively reduced pressure. The heat exchanger tubes that run through each flash vessel in turn warm up the feed water. In this way, the thermal energy requirement is lessened in order to heat the incoming seawater in what is called the "brine heater."

FIGURE 11

India: wide variation in water resources



- **Multi-effect distillation (MED).** This also occurs in a series of vessels (effects or stages) in which there is successively reduced pressure. Pure water is produced in a number of ways: by flash evaporation, as in MSF; and by boiling and directing the steam produced in one vessel as the heat source for the next one. Bundles of evaporator tubes are sprayed with seawater in a thin film, which promotes rapid boiling and evaporation. The fresh water product is recovered from the condensation of steam or water vapor inside the tubes.
- **Vapor compression (VC).** Various types of compressors—mechanical or steam jet-type thermo units—are used to provide the heat for evaporating the seawater feed. Different configurations are used for the heat exchangers.

Membrane processes

- **Electrodialysis (ED).** In this process, salts are removed from the brine by use of the principle that most mineral salts dissolved in water will dissociate into their ions in the presence of an electric current, so the salts can be segregated out by two special membranes that allow the passage of either only positively (cation) or only negatively (anion) charged ions. The configuration for this usually involves a "stack" of alternate layers of the two membranes, with water passages between them, and the electrodes at the top and bottom. There are both ED and EDR (electrodialysis reversal) systems.
- **Reverse osmosis (RO).** This process does not use heating or phase change (liquid to vapor) for separating out the salts. RO uses pressure to force pure water through a special membrane, leaving the salts behind. There are three commercial configurations for applying this principle: spiral wound, hollow fiber, and flat plate. The first two configurations are most commonly used. The pressures required vary with the level of salt concentration, and with the type of membrane in use.

Systems compared

The RO system is relatively new, coming into use in the 1970s for brackish water, and for seawater in the 1980s. Its wider use has come about because of advances in membrane technology.

The MSF and MED plants are widely applied where steam is available from an adjacent electricity plant. MSF plants have been in use since the 1950s, and tend to be built in units producing from 4,000 to 30,000 cubic meters per day (1 to 8 million gallons per day). The MED plants are commonly smaller.

VC units usualy use electrical energy, and tend to be smaller yet, and not linked to a power plant. They are used for industrial applications, offshore drilling rigs, and such specialty locations as resorts.

ED and EDR are extensively used for brackish water, or for improving the purity of local water to meet high standards. The process is used to treat low salt water (in the range of 1,000-5,000 milligrams per liter,) and the amount of energy required varies directly with the salt content. Installations can be made large by having multiple plant modules. They tend to be built for industrial, municipal, and hotel use.

Table 12 shows the output size for which each method of desalination is commonly used because of its power and other requirements.

Over 65% of the world's installed capacity is located on the Arabian Peninsula in the oil-rich desert countries of Saudi Arabia, United Arab Emirates, Qatar, Oman, and Kuwait. The largest desalination plant in operation today is at Al Jubail, Saudi Arabia, which produces 288 million gallons per day. The plant at Doha West, Kuwait produces 115 mgd; the Abu Dhabi plant in U.A.E. produces 91 mgd.

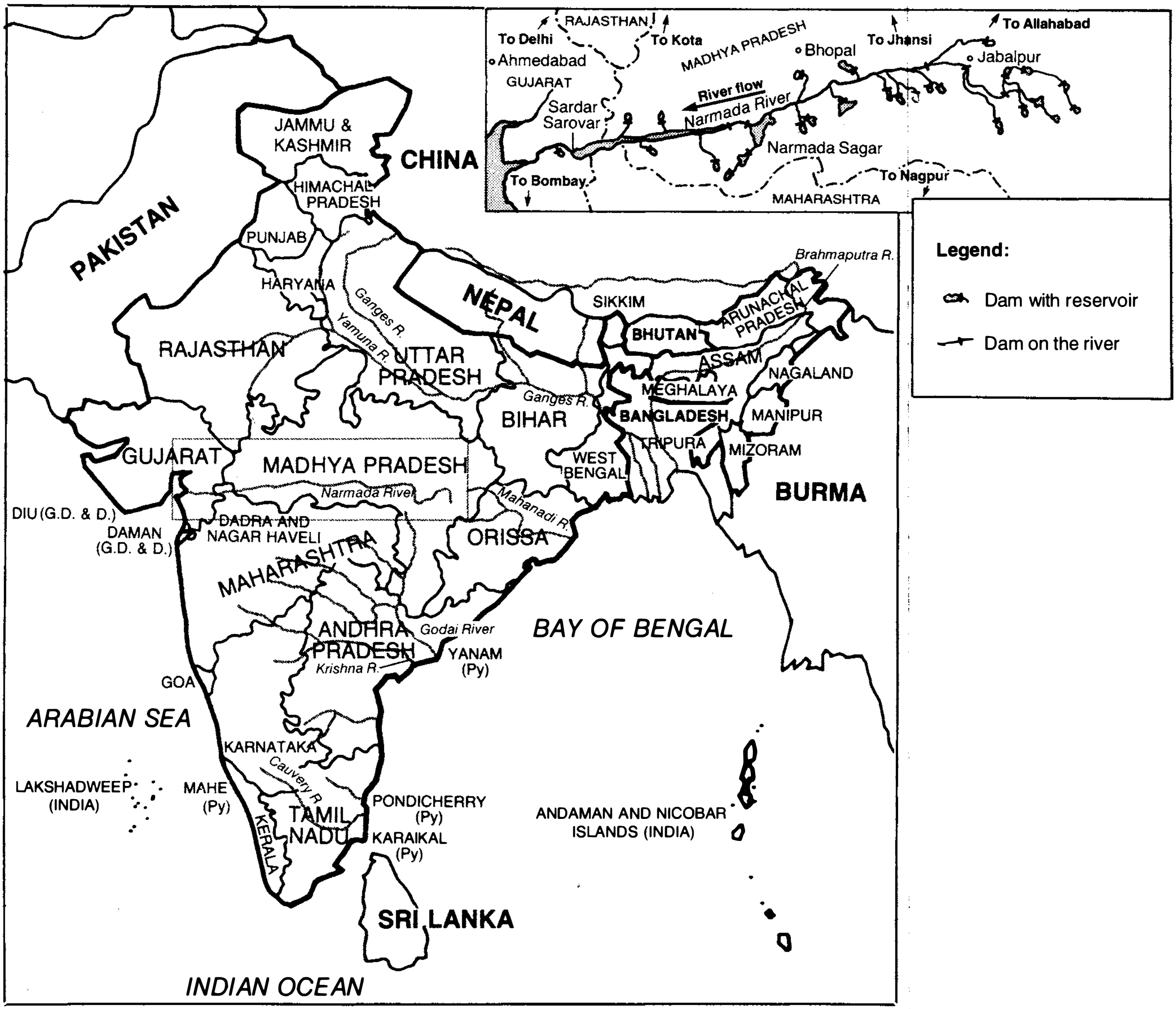
However, nuclear power is not used in any of these plants, which instead rely on oil and natural gas. Because of the worldwide anti-nuclear policy, there are very few desalination facilities around the globe, and most of them are small and high-cost. The common uses are for resort hotels, oil rigs, industry use, etc.

Proposed nuclear desalination projects

In 1988, the U.S. Department of Energy and the Metropolitan Water District (MWD) of California jointly commis-

FIGURE 12

Narmada Valley Development Project in India's river systems



sioned a study to see if nuclear-powered desalination would be beneficial for southern California, in providing both water and electricity. The final report was prepared by General Atomics, Bechtel National, Inc., and Gas-Cooled Reactor Associates in December of that year, and the specifications showed that such a facility could be built by the turn of century, providing 106 million gallons (401,000 cubic meters) of fresh water daily and 466 MWe of net power (**Table 13**). The costs would be about 50¢ per cubic meter for water, and 5¢ per kWh for electric[13] (**Table 14**).

Subsequently, the MWD officials decided against the undertaking, not because of fault with the designs, but because of anti-nuclear pressure and the economic depression. The details indicate that the plans are feasible and provide inexpensive power and water.

The California MWD proposal

A modular high-temperature gas-cooled reactor (MHTGR) can be coupled to a low-temperature multi-effect distillation (LT-MED) desalination facility to yield power and water in the quantities desired. The principle is to use the cheap reject heat from the power plant to distill the seawater. The concept involves coupling the MHTGR to a high-temperature turbine-steam system, from which the turbine exhaust heat is then delivered to the desalination process, at a relatively low temperature of 165°F.

TABLE 12

Common sizes in use and energy requirements for desalination processes

Process	Plant size commonly in use (daily volume)	Energy required
Multi-stage flash	4,000-30,000 m^3 (1-8 million gal.)	
Multi-effect distillation	2,000-10,000 m^3 (0.5-2.5 million gal.)	
Reverse osmosis		3.5-9.0 kWh/1,000 liters (13.25-34 kWh/1,000 gal.)
Electrodialysis and electrodialysis reversal	50-4,000 m^3 (15,000-1 million gal.)	
Vapor compression	20-2,000 m^3 (5,000-500,000 gal.)	

Source: International Desalination Association.

TABLE 13

Major design parameters of the MHTGR desalting plant

Reactor thermal power (MWt)	1,400
Gross generator output (MWe)	546
Net electrical output (MWe)	466
Fresh water production (mgd)	106
Thermal power to water plant (million Btu/hr.)	2,980
Water plant performance ratio	12.4
Maximum brine temperature (°F)	147
Intake seawater flow (gpm)	333,500
Product water, total dissolved solids (parts per million)	<30
Plant life (years)	40

Source: S. Goaln, R. Schleicher, G. Snyder, M. LaBar, and C. Snyder, "Introduction to Nuclear Desalting: A New Perspective," *Fusion Technology,* Vol. 20, December 1991.

The LT-MED uses a horizontal tube configuration in which each bundle of tubes is close-packed, with a tube plate at one end and a collector at the other. The multi-stages of evaporation and heat recovery take place in 16 of these bundles of tubes, grouped together as a "train" of 16 effects. There are eight identical 13.3 mgd seawater desalting trains in the proposed water production plant. Besides the effect bundles, each train has a flash chamber and a heat rejection effect, all of which are contained within an epoxy-lined steel vessel measuring approximately 28 feet in diameter and 512 feet in length.

The nuclear plant consists of four 350 MWt reactor modules, and the electricity plant consists of two turbine-steam trains. Each reactor module is a helium-cooled, graphite-moderated nuclear core. The low-enriched uranium fuel is in the form of ceramic-coated particles embedded in the graphite core structure. The core is enclosed in a high-strength steel pressure vessel which is connected to a single steam generator pressure vessel. A motor-driven circulator stirs the helium coolant through the core and steam generator. There is an independent shutdown heat removal system, to remove decay heat for reactor maintenance and refueling conditions.

From these four reactor modules, the high-pressure, superheated steam is fed to a common header and delivered to the area where it is converted to electric power, and from which reject heat is supplied to the desalting plant.

TABLE 14

Major costs of the MHTGR desalting plant

	First	Replica	Nth of a kind
Annualized capital cost (millions $/yr.)	$143.3	$132.6	$125.9
Annualized fuel cost (millions $/yr.)	$ 55.7	$ 50.0	$ 41.0
Annualized O&M cost (millions $/yr.)	$ 47.7	$ 44.4	$ 41.1
Annualized decommissioning cost (millions $/yr.)	$ 2.3	$ 2.3	$ 2.3
Total plant annual cost (millions $/yr.)	$249.2	$229.3	$210.3
Levelized power values (cents/kWh)	5.79¢	5.27¢	4.77¢
Power sales revenue (millions $/yr.)	$188.8	$171.8	$155.6
Required water sales revenue (millions $/yr.)	$ 60.4	$ 57.6	$ 54.7
Levelized water cost without blending ($/acre-foot)	$604	$576	$547
Levelized water cost with blending ($/acre-foot)	$452	$433	$414

Source: S. Goaln, R. Schleicher, G. Snyder, M. LaBar, and C. Snyder, "Introduction to Nuclear Desalting: A New Perspective," *Fusion Technology,* Vol. 20, December 1991.

The advanced liquid metal reactor proposal

Another design for a nuclear-powered desalination plant has been done by General Electric, under Department of Energy sponsorship.[14] The nuclear plant, called an advanced liquid metal reactor (ALMR), uses liquid sodium as the coolant, which permits operation at atmospheric pressure, with large margins to boiling, greater than 400°C (700°F).

The GE design couples the reactor with a proposed reverse osmosis desalting system, which is a relatively heavy user of electricity. The power plant's waste heat helps raise

TABLE 15

Major design data for the ALMR reverse osmosis desalination plant

Reactors per power block	3
Number of power blocks	1 / 2 / 3
New electrical output	465 / 930 / 1,395 MWe
Turbine throttle conditions	955 pounds/in^2
Reactor thermal power	471 MWt
Primary sodium temperature	
Core inlet	338°C (640°F)
Core Outlet	485°C (905°F)
Fuel type	
Reference	U-Pu-Zr metal
Alternative	U-Pu oxide

Source: C.E. Boardman and C.R. Snyder, "Advanced Liquid Metal Reactor (ALMR) Desalinization/Electric Plant," *Fusion Technology,* Vol. 20, December 1991.

the seawater feed temperature. The design proposal figures on a 100 mgd capacity (see **Tables 15** and **16**).

Desalination costs compared

Figure 13 gives the cost per cubic meter of desalted seawater provided by the reverse osmosis method, in plants ranging from very small, up to over 100 million gallons per day. Using nuclear power, and installing large-scale operations give the lowest cost per unit of water provided.

For comparison, note the horizontal line drawn at $2.40, which is the cost of providing 1,000 gallons of water in the benchmark water treatment plant on the Potomac River in Virginia. By this measure, the costs of large-scale, nuclear-powered desalinated water are reasonable. Additional comparisons are given in **Table 17,** in terms of the electricity needed per cubic meter, and the varying costs of producing the safe water, depending on the electricity costs.

The low costs of modern technology give us the power to create new "run-off"—new man-made rivers and reservoirs of man-made water. **Table 18** compares the flow and volume of water from large-scale nuclear-powered desalination plants, with that of selected rivers and municipal water districts. A giant desalination plant would produce more flow than several natural rivers in Texas—for example, the Nueces or the Pecos rivers combined. Just the one desalination plant proposed for southern California could provide all the water for a town the size of Atlanta in the 1970s.

And besides creating water anew, used water can be cleaned up for safe recycling by modern means.

High-energy electron wastewater treatment

Radiation can be applied to contaminated water in a way to render it safe and clean. Ultraviolet radiation is commonly

TABLE 16

Major annual operation costs of the ALMR reverse osmosis desalination plant

	Cost (millions $)	Cost per 1,000 gallons
Capital charge	$18.9	$0.69
Operation and maintenance	3.3	0.12
Membrane replacement	7.22	0.26
Chemical cost	4.9	0.18
Electricity cost	25.4	0.93
Total annual cost	59.8	
Cost of water		2.18 ($704/acre-foot)

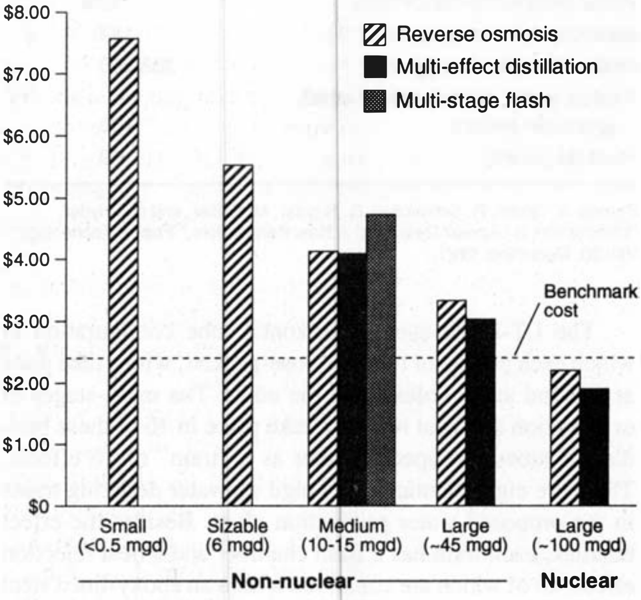
Basis of calculations:
International Desalination Association computer cost program
1990 constant dollars
6% fixed charge rate
48-month construction period
90% availability
75% on-stream
80°F feedwater temperature
35,000 TDS seawater
0.043 $/kWh ALMR power cost

Source: C.E. Boardman and C.R. Snyder, "Advanced Liquid Metal Reactor (ALMR) Desalinization/Electric Plant," *Fusion Technology,* Vol. 20, December 1991.

FIGURE 13

Comparison of seawater desalination costs, by scale and type of process

($ per 1,000 gallons)



Source: International Desalination Association, "A Brief Background on Desalination and Its Processes," *Desalination and Water Reuse Quarterly,* Vol. 2, No. 1, 1992.

TABLE 17

Typical electricity amounts and costs for modern water treatment processes

Process	Amount (kwh/m^3)	Cost (\$/m^3) Island	Florida	Nuclear
I. Desalinating Water				
Seawater, state-of-art reverse osmosis, with 1 GW power input	3	\$0.36 0.12/kwh	\$0.21 0.07/kwh	\$0.15 0.05/kwh
Brackish water, Florida, reverse osmosis or electrodialysis reversal, 45,000 m^3/day (12 mgd)	0.05	0.006	0.0035	0.0025
II. Electron beam treatment of wastewater and sewage	2.6	—	0.18	0.13

Source: International Desalination Association, *Advances in Nuclear Science and Technology,* Vol. 22, New York: Plenum Press, 1991.

in use to disinfect water, and a less-known method promises to be even cheaper and more adaptable: high-energy electron beam radiation.[15]

The electrochemical principle involved is that irradiation of the water results in the formation of the aqueous electron e^-, hydrogen radical, H^+, and the hydroxyl radical, OH^-. These reactive transient species initiate chemical reactions capable of destroying organic compounds in the water, in most cases reducing them to carbon dioxide, water, and salt. The reaction by-products are non-toxic.

The process involves generating electrons by an electric current, accelerating them through an evacuated space under high voltage, and then aiming at the water target. Since the electrons are rapidly attenuated—for example, at an acceleration voltage of 1-2 million volts, they would travel only 3-4 meters in the air—the process is very safe. They travel only fractions of a centimeter if they hit water. Therefore, the engineering problem becomes how to design an effective treatment system.

A full-scale beam treatment plant is now in operation, for purposes of research and testing, in Miami, Florida, at the Virginia Key Wastewater Treatment Plant. **Figure 14** shows how the plant is organized.

The wastewater influent comes in via a pipe and is directed over a weir, where it falls in a thin sheet (about 4 millimeters thick), and as it falls it is zapped by the electron beam. The beam originates from a 1.5-million-volt insulated core transformer (ICT) electron accelerator. The accelerated electrons are propelled in a concentrated beam down a high-vacuum tube toward a scanner, which scans the beam to a rectangular shape and directs it to cover the veil of water as it passes over the weir.

TABLE 18

Comparison of large desalination plant output with selected rivers and municipal systems

I. Discharge

Source	Flow (m^3/sec.)
Reverse osmosis desalination plant, corresponding to power at 1 GW input, and 3 kWh/m^3	92
Pecos River, Texas	8.24
Nueces, Texas	21.9
Santee, South Carolina	67
Red River of the North, North Dakota	68.5
St. Johns, Florida	92.2
Grand River, Michigan	95.2
Rio Grande River	100
Congo River	39,200
Amazon River	175,000

II. Volume

Source	Quantity (mgd)	Population served
Proposed MHTGR multi-effect distillation California plant (401,210 m^3/day output)	106	(Depends on use)
Memphis, Tennessee[1]	90	623,530
Indianapolis, Indiana	91	680,000
Atlanta, Georgia	104	700,000
Honolulu, Hawaii	110	535,000
San Diego, California	110	723,000
Los Angeles, California[2]	118	535,000

1. Urban data are for 1970.
2. Southern California Water County District.

Sources: American Water Works Association, *EIR, Water Resources of the World.*

It is at this point, where the electrons penetrate the waste stream, that the treatment occurs. The system shown treats 120 gallons per minute of sludge, which is 172,800 gallons a day, or 238,710 cubic meters a year, but it can easily be scaled up.

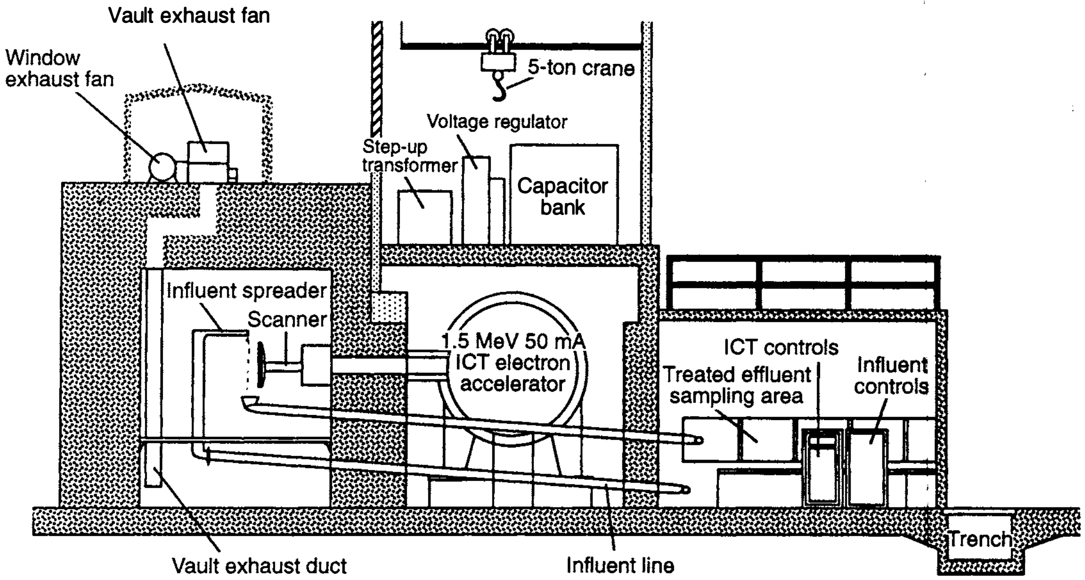
The results from this test plant show what can be done for treatment anywhere in the world. Treatment causes the removal of up to 99% of most toxic organic compounds, including chloroform, carbon tetrachloride, benzene, toluene, dieldrin, phenol, and many others.

Costs of electron beam-treated wastewater

The Miami, Florida test facility was built in 1982 at a cost of \$2 million, and its estimated cost of water treatment is about \$2.50 per 1,000 gallons of treated water. In comparison, the current estimated costs of treating water with ultraviolet light and ozone is about \$2.60 per 1,000 gallons (at a flow rate of 600 gallons per minute). For comparison, see

FIGURE 14

Side view of the Electron Beam Wastewater Treatment Facility, Miami, Florida



Source: Drinking Water Research Center, Florida International University, Miami, Florida.

Table 4, which lists the costs of sewage treatment at the conventional Virginia sewage treatment plant at $3.00 per 1,000 gallons.

The exact cost of using electron beam treatment can vary widely, from a low of 25¢ per 1,000 gallons to $500 per 1,000 (including capital costs), depending on the flow rate and on what compounds are in the wastewater, and what dose of radiation is required. Table 17 shows various costs of detoxifying a cubic meter of wastewater based on the costs of electricity for 2.6 kWh per cubic meter.

For reference, **Table 19** gives the estimated current costs of the permanent 1.5 million electron volt facility at Miami.

TABLE 19

Costs of electron beam wastewater treatment system, Miami, Florida

Capital costs:	
Installed beam	$1,850,000
Support facility (shielding, delivery system, etc.)	500,000
Total	2,350,000
Amortization:	
10 years @ 15%	$466,000/year
20 years @ 15%	$374,000/year
Hourly operating costs:	
Operator	$20.00
Power (150 KW @ $0.07/kWh)	$10.50
Water (2,000 gph @ $1.25/1,000 gallons)	$ 2.50
Maintenance	$ 8.00
Total hourly operating cost	$41.00

Note
The estimated capital requirements represent an approximate 5% annual inflation of the total price actually paid for the Miami facility. No indirect costs are included, such as overhead or supervision.

Source: International Desalination Association, *Advances in Nuclear Science and Technology,* Vol. 22, New York: Plenum Press, 1991.

U.S. water infrastructure costs

Figure 15 shows the 18 major hydrologic regions of the country, and shows which locations currently have a water deficit, relative to today's population and economic activities in the region—even without taking into account greater needs in the future. With new water supplies from Nawapa, desalination, and high-energy-treated wastewater, water deficits can be easily closed. But additionally, there are repairs and replacements to be made in the existing national grid of water purification, distribution, and sewage treatment.

Water districts. Nationwide there are about 59,000 separate water districts, ranging in size from those serving 25 people—the minimum to be defined as a water district—up to multi-millions of customers in the Metropolitan Water District of southern California. In thousands of these districts, repairs and replacement facilities are overdue, as documented in the U.S. Conference of Mayors survey, released February 1992, called "Ready to Go." The two-volume re-

FIGURE 15

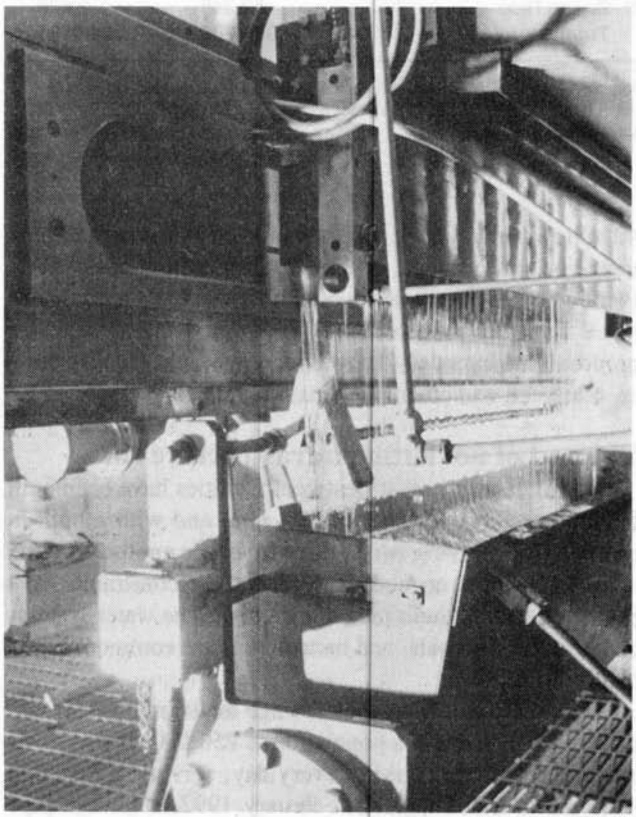
United States: 18 hydrologic regions, and areas of water supply problems

port reprints the descriptions of the backlog of local public works projects that need funding in the 535 cities responding to the survey. Hundreds of these projects are waterworks of all kinds—pipes, treatment plants, and reservoirs.[16]

If a conservative estimate is made that $1 million is required, on average, for each of 29,000 water districts for work on the supply, purification and distribution network; and that another $20 billion is needed for overhauling the largest population centers; then the total bill for this category of water treatment is about $50 billion.

Hydrologic basins. According to a survey done in the mid-1980s of the condition of water in the 21 hydrologic regions of continental United States, Alaska, and islands, an estimate was made that in order to meet water safety standards for the population in the year 2000, wastewater treatment infrastructure would require approximately $85.705 billion in spending.[17] The evaluation, called a "needs survey," was done by the Environmental Protection Agency (EPA). The continental U.S. was looked at in terms of the 18 hydrological regions, with a further breakdown into 314 sub-basins, whose dominant features were evaluated—lake shores, coastline segments, as well as rivers and streams. **Table 20** gives the list of estimated wastewater treatment costs by hydrological region. The highest costs are projected for the Mid-Atlantic region, where the highest population concentration is located, some 35 million people.

If these repair costs for local water treatment are tallied along with capitalization costs for new sources of water, then the overall infrastructure program cost adds up to about $200 billion. **Table 21** gives the breakdown. By contrast, the $20-



Wastewater can be very efficiently treated with electron beams, as in the experimental facility shown here in Miami, Florida. The water is "zapped" by high-energy electrons as it passes over the weir in a thin sheet. Treatment cost per 1,000 gallons is only about $2.50.

TABLE 20

U.S. wastewater treatment needs for the year 2000, by hydrologic region

Hydrologic region	Total needs (millions $)	Population (thousands)
1 New England	$ 6,526	11,417
2 Mid-Atlantic	14,935	35,328
3 South Atlantic	11,458	31,089
4 Great Lakes	7,850	19,975
5 Ohio	7,407	19,965
6 Tennessee	1,677	3,074
7 Upper Mississippi	5,229	21,479
8 Lower Mississippi	2,390	7,583
9 Souris-Red-Rainy	79	586
10 Missouri	2,214	11,446
11 Arkansas-White-Red	2,082	8,918
12 Texas Gulf	4,319	18,693
13 Rio Grande	409	2,470
14 Upper Colorado	131	1,026
15 Lower Colorado	1,050	5,703
16 Great Basin	931	2,977
17 Pacific Northwest	4,351	8,727
18 California	6,005	30,106
19 Alaska	343	631
20 Hawaii, Pacific, Virgin Islands	972	1,622
21 Puerto Rico	2,248	3,636
Total	**$85,705**	**246,451**

Source: "Assessment of Needed Publicly Owned Wastewater Treatment Facilities in the United States," Washington, D.C.: Environmental Protection Agency, 1985.

40 billion infrastructure program mooted by the new Clinton transition government, or the $20 billion program of Ross Perot's United We Stand, would not even meet a portion of the U.S. water infrastructure bill. Moreover, these lesser proposals are intended to cover not only water, but also power, transport, and other categories of projects.

The cost of not letting infrastructure rot

In this century, most treatment facilities have been built with an intended lifespan of 50 years, and with a built-in projection for serving two to three times the number of users served when first opened. However, these constraints have been exceeded in thousands of locations. The water systems plants are in disrepair, and breakdowns are common. Some highlights follow.

- *San Diego*. The city's sewage treatment system was built in 1963, to serve a population of 250,000. It now operates near or above capacity every day, serving 1.7 million residents of San Diego. In February 1992, a sewage pipe ruptured, and vast streams of effluent flowed along the beach and into the Pacific Ocean. The broken pipe was 9 feet in diameter, made up of sections 16 feet long, weighing 26-30 tons each.

TABLE 21

Cost of U.S. waterworks infrastructure requirements

(billions $)

Refurbish local water supply, treatment storage, and distribution	$ 50.0
Refurbish local wastewater treatment	85.705
Construct 10 nuclear desalination facilities	18.5
Construct 5 E-beam wastewater treatment plants	3.0
Nawapa	40.0
Other water projects	5.0
Total	**$200.705**

Sources: Environmental Protection Agency, U.S. Conference of Mayors, *EIR*.

- *New York City*. Most of the city's 14 treatment plants are overtaxed, and regularly over capacity and break down.
- *Pennsylvania*. In the mid-1980s, the aged municipal water systems of Scranton and McKeesport were struck by outbreaks of *giardia lamblia* parasite contamination. They had to be shut down, and water was provided by National Guard tank truck.

The role of the federal government in recent years, has been to chastise local water districts and demand compliance with water cleanup standards, under threat of legal sanctions. The federal Clean Water Act mandates sewage treatment, and the EPA's Water Enforcement Division monitors compliance. There are additional mandates, such as the Ocean Dumping Ban act, which authorizes federal spending of $14 million a year through 1995 for ocean monitoring, research and enforcement, but no water treatment. San Diego, Boston, and other cities are under court orders to clean up their water systems, but no mobilization of funding resources is forthcoming.

Clearing cholera from the Rio Grande Basin

The most glaring instance of water crisis in the United States is in the Lower Rio Grande River Basin—the border region between the United States and Mexico. The shortage of safe water is so severe that as of spring 1992, cholera has been in the basin. Hundreds of thousands of people are living in conditions where there is no sewage treatment, and no safe water. In El Paso County, for example, there is five times the national average rate of hepatitis A—a fecal contamination disease related to filthy water. Last year, the dysentery rate was 31 per 100,000—triple the national average.

This situation has come about directly as a result of evading the costs of infrastructure development, which was done in the name of keeping labor costs down for the purposes of "free trade."

In the 1970s, hydrologists forewarned of the dangers of

TABLE 22

Wastewater treatment needs in the Rio Grande Hydrological Region by the year 2000

Area	Expenditures needed for wastewater treatment (millions 1984 $)	Population served (thousands)
Rio Grande headwater	$ 22	102
Upper Rio Grande	173	985
Upper Pecos River	21	158
Lower Pecos River	20	72
Middle Rio Grande	83	630
Lower Rio Grande	88	472
San Luis Creek	—	3
Miscellaneous	2	48
Total	**$409**	**2,470**

Source: Environmental Protection Agency, 1985.

moving people into this basin without provision for water. Most of this region has a semi-arid climate, with low humidity and erratic rainfall. Average annual precipitation varies from 30 inches in the high mountains (in the headwater area in New Mexico), to only 8 inches in the middle valley area (falling mostly during rainstorms), to the humid area at the mouth of the Rio Grande. Water from stream flow and groundwater is used and reused, but there is no adequate treatment cycle.

Based on its 1975 surveys, the U.S. Geological Survey reports concluded: "Water quality is a serious problem in the lower Rio Grande Valley and precludes or inhibits expanded use of the valley under present conditions. . . . Flooding also affected all portions of the region, but is most severe in Texas. The El Paso area is particularly affected. In the lower valley, flooding problems are aggravated by inadequate drainage. . . . Texas also has a problem in providing satisfactory domestic water supplies under the 1974 Safe Drinking Water Act. Many communities will have to have improved systems, which they are unable to finance. In addition, 20% of the lower valley population is not served by a public water supply system. This situation is likely to be aggravated by the increasing population in that area."

The report concluded, "The primary problems in the region are associated with providing a water supply to accommodate an increase in population from 1,695,000 people in 1975 to 1,875,000 by 2000. [Numbers refer to the U.S. side only, and mostly to New Mexico—ed.] No additional water supply is currently available for the majority of this population increase."

Table 22 lists the costs for simply providing wastewater treatment facilities in the seven sub-basins of the river system, according to estimates by the EPA. This adds up to a total of $409 million.

In addition, nuclear desalination plants on the coast of the Gulf of Mexico could provide the added volumes of domestic use water lacking in the basin. Electron beam facilities on the river could clean wastewater for recycling back into the flow. The costs of these facilities are in the range of $3 billion combined.

Notes

1. Water usage standards are discussed in Chris White's "Build Infrastructure To Launch an Economic Recovery," *EIR*, May 29, 1992, pp. 16-33.

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3. "Auschwitz Below the Border," *EIR Special Report*, 1991.

4. Federal Reserve Bank of Kansas City, "Western Water Resources; Coming Problems and the Policy Alternatives. A Symposium Sponsored by the Federal Reserve Bank of Kansas City, Sept. 27-28, 1979 (Boulder, Colorado: Westview Press, Inc., 1980).

5. Marcia Merry and Chris White, "Create New Water Supplies Before Time Runs Out," *EIR*, June 21, 1991, pp. 24-37. See also, "Statistical Survey of World Land Use," *EIR*, June 29, 1990, pp. 66-73.

6. N.W. Snyder, "A North American Continental Water Transfer Plan," address presented in Pasadena, Sept. 22, 1988, at the Institute for Advancement of Engineering Symposium on Southern California's Future—An Engineering Challenge (Pasadena: The Ralph M. Parsons Corporation, 1988).

7. Lyndon H. LaRouche, Jr., "Won't You Please Let Your Grandchildren Have a Drink of Fresh Water?" (New York: National Democratic Policy Committee, 1982).

8. Ramtanu Maitra, "The Sun Yat Sen Program and China's Development Today," *EIR*, Sept. 1, 1989. See also, Dr. Sun Yat Sen, *The International Development of China* (New York: Putnam, 1929).

9. Ramtanu Maitra, "Water Management Is Necessary for Survival," *21st Century Science & Technology*, Winter 1992.

10. "Statecraft for the Development of a Modern China," an interview with Lyndon H. Larouche, Jr., *EIR*, April 24, 1992.

11. Susan and Ramtanu Maitra, "Narmada Project Proceeds Under the Gun," *EIR*, May 4, 1990.

12. International Desalination Association, "A Brief Background on Desalination and Its Processes," *Desalination and Water Reuse Quarterly*, Vol. 2, 1992 (Westport, Conn.: Green Global Publications, Inc.).

13. S. Golan, R. Schleicher, G. Snyder, M. LaBar, and C. Snyder, "Introduction to Nuclear Desalting: A New Perspective," *Fusion Technology*, Vol. 20, December 1991, pp. 631-35.

14. C.E. Boardman and C.R. Snyder, "Advanced Liquid Metal Reactor (ALMR) Desalinization/Electric Plant," *Fusion Technology*, Vol. 20, December 1991, pp. 636-40.

15. Charles N. Kurucz, Thomas D. Waite, William J. Cooper, and Michael Nickelsen, "High Energy Electron Beam Irradiation of Water, Wastewater and Sludge," in: *Advances in Nuclear Science and Technology*, Vol. 22, (New York: Plenum Press, 1991). See also Don Morse, "Accelerating Electrons," *Civil Engineering*, April 1989.

16. United States Conference of Mayors, "Ready To Go; A Survey of U.S.A. Public Works Projects to Fight the Recession Now," 2 vols., Washington, D.C.: The United States Conference of Mayors, February 1992).

17. Environmental Protection Agency, "Assessment of Needed Publicly Owned Wastewater Treatment Facilities in the United States; 1984 Needs Survey Report to Congress," (Washington, D.C.: EPA, February 1985, EPA 430/9-84-011).