THE OUTLOOK FOR WATER REVISITED[1 2]

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Soon after Resources for the Future (RFF) was established and Irving Fox, later vice president, became director of the water resources program, I began, with their support, research on water uses in New Mexico, the United States (U.S.), and Chile. Of these the most complex was the U.S. study. RFF joined with a newly created Select Committee of the U.S. Senate to accomplish their joint objectives. In exchange for giving the committee a preliminary version of the RFF report, I was able to participate with Theodore M. Schad, the committee's staff director, in formulating requests for information addressed to federal and state agencies. The responses were published as committee prints numbers 1 - 31. (Select Committee on National Water Resources, U.S. Senate, 86th Congress, 2nd Session, 1960). The RFF preliminary version was Committee Print (C.P.) 32, *Water Supply and Demand* (C.P. 32 in what follows). Resources for the Future's publication, *The Outlook for Water* (The Johns Hopkins Press) co-authored with Gilbert W. Bonem, appeared in 1971. Bonem prepared the data for computer processing, enabling more extensive study of changes in key variables. The ten-year delay in final publication resulted from an error discovered by Howard Cook, Corps of Engineers, in extending flow-storage relationships from 50 percent of the mean annual flow to 100 percent. The error lay in inadequate weight given to inter-annual variation of stream flows in western regions. Irving Fox commissioned George Löf and Clayton Hardison to prepare a new set of flow-storage measurements for all water resource regions, which were published independently as *Storage Requirements for Water in the United States* (*Water Resources Research*, vol. 2, #3, 1966). In redoing the final version, the base year was changed from 1954 to 1960 and projections extended to 2020. Both C.P. 32 and *The Outlook for Water* were the product of many people. Appreciation of their contributions cannot be overstated.

The model used in C.P. 32 and *Outlook* was designed to meet RFF's objective of providing a national assessment of water resources and the Select Committee's objective of ascertaining, "the extent and character of water resource activities, both governmental and nongovernmental, that will be required to take care of needs for water for all purposes between now and 1980" (Forward, Senate Report #29, 87th Congress 1st session, January 30, 1961).

The conterminous forty-eight states were divided into twenty-two water resources regions. For each region, base year and projected year estimates of population and production were made. These were joined with current and projected water use coefficients to yield water withdrawal, water losses (evapotranspiration plus incorporation into product plus discharge into saline waters), and waste loadings. Waste loadings were the basis for estimating the cost of waste treatment as a function of the amount of bio-chemical oxygen demand (BOD) removed before discharge of the waste water into the region's streams. From the amount of BOD removed, and the average character of each region's streams (natural reaeration, etc.), the amount of clean water dilution required to assure an instream dissolved content of 2mg/l, 4mg/l, or 6mg/l was estimated. Dilution flows also took into account nitrogen and phosphorous discharged with waste water and heating from discharge of cooling water. It was assumed that toxic materials not amenable to treatment would be excluded from waste water. The amount of water "required" by each region was defined as the sum of losses plus waste dilution flows. All measures of treatment, treatment costs, and dilution flows were based on a study by George W. Reid and Associates that was included in *Outlook.*

The "supply" of water was defined as the minimum flow available, in streams of the region, as determined by the amount of regulatory storage in place. Evaporation from new reservoir surface area was deducted from each increment of dependable flow. The costs of increments of storage yielded a schedule of the costs of flow.

The "cost of water" was, therefore, the cost of flow, consisting of the flow needed to meet losses and instream dilution requirements, plus the cost of treatment associated with a designated requirement for waste dilution flow. Cost of flow and cost of treatment were substitutable within the hydrologic limits of the region after accounting for water loss. Within the hydrologic limits of the region, three alternative programs were stipulated: (1) maximum flow and minimum treatment,

(2) minimum flow and maximum treatment, (3) minimum total cost of treatment plus flow.

I have dwelt at length on the model, because, if we were to address a comparable research project today, the model might be irrelevant. Today's hostility to dams would diminish, if not eliminate, the provision of waste dilution as a part of the solution. Also, certain uses of water that received scant attention in 1960 would now be more prominent, especially in the west.

In *Outlook*, water use was projected along low, medium, and high paths, reflecting corresponding growth paths of population, gross product, and economic sectors. Actual paths of population and gross product between 1960 and 2000 conform reasonably well with low growth assumptions. In comparing projected with experienced water use figures, we'll use 1980 low and 2000 low. Projected and actual withdrawals and losses for all withdrawal uses are as follows:

Withdrawal Uses, United States*

(BGD)

	Withdrawals		Losses	
	Outlook	USGS	*Outlook*	USGS
1960	250	270	104	61
1980L	335	440	115	100
1995	----	402	----	100
2000L	391	----	124	----

*Estimated Use of Water in the United States in 1995 United States Geological Survey (USGS) Circular 1200 (1998).

In *Outlook*, water use figures were based upon coefficients that reflected reasonably efficient practices whereas USGS figures measure actual practice. There is some evidence of convergence, although the effects of actual availability of water, as in the case of irrigated agriculture, will affect the USGS actual use figures for any particular year. Comparison of projected with actual uses for specific sectors allows the following conclusions:

1. Agriculture: Projected and realized losses conform closely, but this agreement conceals a shift in the industry that was not anticipated: Irrigated acreage in the seventeen western states plateaued about 1975 but has continued to grow in the eastern half of the country, probably contributing to the pollution of surface waters from non-point sources.

2. Steam-electric power, manufacturing and mining: Actual withdrawals reveal an increase in re-circulation of fresh water, implying a reduction in volume but possibly increased waste concentration in water discharged.

3. Municipal (domestic and commercial): USGS's estimated withdrawals are considerably lower than projected figures, indicating that demand-side management is effective.

4. Water Quality: There was no 1960 measurement of water quality except indirectly by stipulating levels of treatment and quantities of dilution flow to assure instream levels of dissolved oxygen.

Information available today about the status of fresh water quality is in three forms: verbal description of the capability of surface waters to perform the services demanded of them, reports by USGS and Environmental Protection Agency (EPA) on chemical quality of rivers and lakes, and rates of violation against a stipulated standard.

In its *National Water Quality Inventory* (Report to Congress, 1995), EPA indicated that 57 percent of the rivers and streams were "good," i.e. supporting all functions demanded of them; 7 percent were "good" but under threat of deterioration; 22 percent were "fair," that is, "partially supporting;" and 14 percent were poor, that is "not supporting." (For lakes, 63 percent were classified as "good.") Time series dealing with particular pollutants indicate a decline in toxic releases to surface water over the period 1988-93, and steady reductions in reported violations of national standards over the years 1975-1995 for dissolved oxygen, dissolved cadmium and dissolved lead, but relatively steady levels for fecal coliform bacteria and total phosphorus (pp. 331, 299). According to a recent press report (Wall Street Journal, September 27, 1999), EPA is just now planning to prohibit discharge of mercury, PCB's, and other toxic materials into the Great Lakes and surrounding wetlands over the next ten years.

Of specific relevance to *Outlook*'s model of treatment and dilution, is the fact that the EPA makes occasional reference to the harmful effects of low flows (p. ES-15), and the beneficial effects of maintaining base flows (p. 82), but avoids the topic of low flow augmentation as an instrument of protecting water quality.

Reservoir capacity grew from 163 million acre-feet in 1947 to 359 million acre-feet in 1963. (*Inventory of Reservoirs*, USGS Water Supply Papers, #1360 and #1383). The most recent figure is 450 million acre-feet provided by Walter Langbein (*Dams, Reservoirs and Withdrawals for Water Supply*, USGS Open File Report, #82-256 [1982]). The same capacity is reported in the *Annual Report* of the Council on Environmental Quality (1996, p. 37).

Langbein concluded that the curve describing the historical growth of total reservoir capacity would be asymptotic to 1.2 billion acre-feet because of the limited number of sites remaining for reservoir construction. His estimate of 450 million acre-feet in place meant, therefore, a maximum additional capacity of 750 million acre-feet. This figure is much lower than Löf and Hardison's estimate of maximum capacity (2 percent chance of deficiency) of 3.5 billion acre-feet or that in *Outlook*, after adjusting for size distribution and reservoir evaporation, of 2.9 billion acre-feet. Langbein explained the flattening of the storage curve after 1960 in part by the preference for nonstructural means over dams, commenting that "one function of storage reservoirs has been judged unacceptable – that of augmentation of low flows to improve water quality." Langbein does conclude, however, that at some time in the future, nonstructural means of meeting water needs "will become less effective than reservoirs. If so, the flattening (of the curve) would be seen as merely an inflection along a generally upward trend in capacity, albeit at a rate slower than formerly" (1982, p. 8).

We can compare the additional amount of storage projected in *Outlook* to meet a dissolved oxygen standard of 4mg/l with the 91 million acre-feet added since 1963. For the United States, by year and program, the figures are as follows (million acre-feet):

	Min. Flow	Min. Treatment	Min. Cost
1960	4	546	24
1980L	6	1421	42
2000L	29	1615	101

These figures support the present national choice, with establishment of EPA and clean water legislation, of treatment rather than dilution to assure water quality. As time goes on, however, without substantial technological changes in production and urban living or acceptance of lower water quality, we shall be pressing upon physical limits, as indicated by the following additional storage requirements, by programs for the year 2020 (million acre-feet):

	Min. Flow	Min. Treatment	Min. Cost
2020L	110	1801	2112
2020M	195	2026	376
2020H	813	2493	839

Minimum treatment programs go far beyond Langbein's maximum of 1.2 billion acre-feet total storage, although within the limits of maximum stream control in *Outlook* (and Löf and Hardison). But even with maximum treatment (minimum flow), we can expect to push against the Langbein asymptote sometime within the next century.

Today, the major water problem in the east is water quality; in the west it is quantity. The bitterness of feelings over water is indicated by the rise in litigation and in on-going problems with Mexico. Additionally, demands for water that in 1960 were below the horizon have risen to prominence. How these conflicts will be resolved will depend upon technological and institutional responses.

In the Middle Rio Grande, two generic demands for water threaten the disruption of established water rights:

habitat for the silvery minnow and preservation of the bosque. These demands are on top of the recent realization that ground water sources, used by municipalities along the river, will be exhausted in the foreseeable future.

The Middle Rio Grande's depletable supply under interstate compact is about 350,000 acre-feet per year. If the Fish and Wildlife Service's claim for a live stream to maintain the silvery minnow is upheld, it is estimated to require 150,000 acre-feet per year. Riparian vegetation, the bosque, in the Middle Rio Grande is estimated to consume about 130,000 acre-feet per year, and had been considered a potential source of additional water if eradicated.

A new required use of water jeopardizes all existing water rights. If the Fish and Wildlife Service complies with state water law, its newly acquired right would be junior to those already granted, and the plight of the silvery minnow would scarcely be improved. A solution that conforms to existing water rights and provides reasonable assurance of the minnow's survival, is the purchase of existing water rights that possess the requisite seniority. Protection of the silvery minnow would be accomplished in the context of the market for water and its cost would be clearly visible. A comparable arrangement could be used by those who wish to save the bosque.

It is true that prior appropriation laws may encourage waste of water because nonuse can lead to loss of a water right. However, as shortages have become more acute, the efficiency of the market in water rights has improved, stimulating an increase in transfers of water from lower valued to higher valued uses. As this process continues, the social cost of preserving environmental resources will increase, as will the urgency for finding a mechanism that yields solutions acceptable to all parties without frequent litigation. If new environmental demands are met by acquisition of existing water rights under state law, the results will be generally acceptable. Vigorous protagonists of environmental demands might focus efforts on changing water law to include instream flow as a "beneficial use" entitled to a durable water right. New law might also be required to create "environmental districts" analogous to existing irrigation districts that would be empowered to buy, receive, and administer water for environmental purposes. Funding of such districts could be public, private, or both.

In the face of new demands for water, two technological responses already employed, may possibly be expanded. The first is substitution of ground storage for surface storage. In southern New Mexico, as elsewhere in the Southwest, reservoir evaporation is about 9 feet per year, an amount equal to 15-20 percent of annual river flow through the Middle Rio Grande basin. Another possible technological solution would be cheap desalinization of ocean water. If southern California could meet its own needs for urban and agricultural uses, it could relinquish use of Colorado River water for the benefit of interior states, ameliorating the southwest's water problem until well into the 21st century.

ENDNOTES

[1] *The Outlook for Water* was published in 1971 and marked a substantial advance in large-scale water planning techniques. Relationships developed in that study are still used by investigators today.

[2] Many thanks to Ann Conner and Dixie Prowell for editing and typing. (NW).