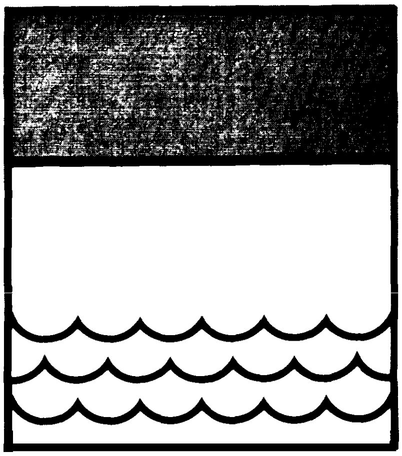

Technologies Affecting Surface Water Storage and Delivery

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Chapter VII

Technologies Affecting Surface Water Storage and Delivery

In the Western States, where demand for water often exceeds supply, additional surface water can be made available by: 1) increasing the total amount of water in storage, or 2) conserving existing water supplies. Conservation methods, which can often be applied relatively easily, hold promise for short-term changes in water use, Methods that increase the amount of water in storage require significantly larger investments of time and money and may take generations to implement.

This chapter considers a variety of technologies that affect surface water storage and delivery. Methods that increase the total amount of water in storage include desalination, interbasin transfers, and new water projects. Several commonly discussed water-conservation technologies are also discussed including flexible irrigation delivery systems, seepage and evaporation control, and vegetation management.

This chapter focuses on those technologies that have potential for sustaining supplies of surface water. The effects of widespread adoption of these practices by agricultural producers, however, are difficult to judge, and quantitative analyses are lacking. Debate continues regarding their technological potential, their economics of use, and the legal and social implications of their application.

THE WATER SETTING

Natural streamflow and precipitation seldom meet agricultural demands for irrigation, household, and stock water in U.S. arid and semiarid regions. Therefore, Native Americans and settlers devised various ways to manage their water supplies early in U.S. history. Some of these methods were relatively simple and involved collecting precipitation and runoff for use when other water sources failed (see discussion of runoff agriculture in ch. VI). Later, more elaborate systems of reservoirs and canals were built to store runoff, sustain downstream flow during dry periods, and convey water to irrigation users. Also, multipurpose reservoirs were built to control floods, maintain fish and wildlife habitat, and supply electrical power and recreation.

These and other developments have altered the hydrologic cycle. Series of large reservoirs now regulate the amount and timing of surface water flow for much of the length of several Western river systems. Natural runoff has been reduced by 100 million to 150 million acre-ft annually (ch, III). Smaller scale developments also have affected surface water quality, Some methods for restoring riparian vegetation decrease sedimentation and increase water storage, Changes in ground water use have also affected surface waters. Ground water pumping from the Ogallala aquifer has lowered water tables and decreased surface water flow in Nebraska and western Kansas.

THE TECHNOLOGIES

Technologies That Augment Water Supplies

Storage Facilities

INTRODUCTION

Three Federal agencies have authority over the extensive system of Western water-storage facilities. The U.S. Army Corps of Engineers and the Department of the Interior's Bureau of Reclamation are charged with developing, managing, and conserving water resources. Both agencies' missions include supplying water for municipalities, industry, irrigation, recreation, hydroelectric power, and fish and wildlife. In addition, the Corps, builds and operates projects for flood control, hurricane protection, and navigation. The Bureau of Reclamation, initially authorized to provide irrigation water, operates only in the 17 Western States,

In addition to these groups, the Soil Conservation Service of the U.S. Department of Agriculture encourages development of small watershed projects for soil and water conservation and flood control. The U.S. Geological Survey maintains a large collection of data on hundreds of lakes, reservoirs, and other surface waters, Finally, State governments have built storage facilities. For example, California designed, financed, built, and operates one of the world's largest multiple-purpose reservoirs at Oroville Dam.

A complex system of both large and small reservoirs exists as a result of these water-development projects. The reservoir storage capacity in the Western river basins is about 79 percent of the U.S. total (table 41). These storage facilities include a few very large dams and reservoirs that contribute much of the total storage capacity, a sizable number of medium-sized reservoirs, and even more farm and ranch ponds (table 42).

These reservoirs are managed to permit more convenient and efficient use of available water

Box L.—Dams and the Western Spirit

Stored water: to some it makes the desert bloom; to others it is sacrilege. Our feelings about dams reflect our most fundamental values:

> Hoover Dam, show piece of the Boulder Canyon project, the several million tons of concrete that made the Southwest plausible, the *fait accompli* that was to convey, in the innocent time of its construction, the notion that mankind's brightest promise lay in American engineering. Of course the dam derives some of its emotional effect from precisely that aspect, that sense of being a monument to a faith since misplaced , . . .—Joan Didion, 1970
>
> Growing upon a farm that had been homesteaded by his grandfather in the eighteen-seventies, [Bureau of Reclamation Commissioner] Dominy often enough saw talent and energy going to waste under clear skies . . . . When Dominy was eighteen years old, a big thing to do on a Sunday was to get into the Ford. . . and go out and see the new dam. Eventually he came to feel that there would be, in a sense, no West at all were it not for reclamation.—John McPhee, 1971

SOURCES: Excerpted from: Joan Didion. "At the Dam," The *White Album (New* York: Simon & Schuster, Inc., 1979), 1970, p. 199. John McPhee, Encounters With the *Archdruid [New York:* Farrar, Straus & Giraux, inc., 1971), pp. 158-159.

Photo credit: USDA-Soil Conservation Service

The American Falls Dam and reservoir stores 1,700,000 acre-ft of water. It was constructed in 1925 near Pocatello, Idaho

Table 41.— Reservoirs in the Western River Basins With at Least 5,000 Acre-ft of Storage Capacity

Region	Number of reservoirs	Natural flow	Storage capacity (000 acre-ft/yr)	Evaporation losses (000 acre-ft/yr)	Other losses
Rio Grande	23	2,670	3,958	816	53
Arkansas-White-Red	14	1,440	1,321	113	48
Missouri	105	23,880	26,005	1,108	57
Upper Colorado	40	15,130	33,083	766	209
Lower Colorado	27	2,650	35,883	1,369	—
Great Basin	48	8,350	4,237	1,645	204
California/South Pacific	221	75,890	36,931	1,323	4,148
Columbia/North Pacific	201	248,350	42,734	4,577	4,896
Texas-Gulf	0	10	0	12	—

SOURCE U S Department of the Interior, *Critical Water Problems Facing the Eleven Western States* (Washington, D C U S Government Printing Office, April 1975) pp 43, 45-46, tables 11-28-30

Table 42.—Features of U.S. Reservoirs

Reservoir size (1,000 acre-ft)	Number	Storage capacity (1 ,000 acre-ft)	Part of total U.S. storage (percent)
More than 10,000	5	117,000	25
2,000 to 10,000	26	74,000	16
5 to 2,000	1,600	168,000	37
0.05 to 5	47,500	91,000	20
Less than 0.05	1,843,000	10,000	2
Total	1,892,131	460,000	100

SOURCE U S Water Resources Council, The *Nation's Wafer Resources 1975-2000* (Washington, D C U S. Government Printing Office, 1978), vol 2, pt IV, table IV-3

supplies by downstream users. They may be used in conjunction with other surface or ground water facilities such as pumps, pipelines, wells, and canals. Both large and small facilities may have multiple uses. For example, farmers and ranchers sometimes store water for frost control, fire protection, domestic use, spraying fertilizers or pesticides, or recreation.

Onfarm irrigation reservoirs are used to:

1. store runoff for use during dry periods,
2. store water during periods of low demand or at times when irrigation is not possible,
3. store water overnight,
4. regulate flows or otherwise match elements of an irrigation system,
5. store irrigation runoff, called "tailwater," and
6. control water levels in adjacent areas.

Ranches often have small stock-watering reservoir systems developed from natural or artificial impoundments. These may be used to increase stocking rates by: 1) lengthening the grazing season, 2) spreading use more evenly over the range, or 3) opening new land to grazing.

ASSESSMENT

Construction technologies for large and small reservoirs are well developed. Recent advances include the use of rolled concrete and soil cement and improved methods for placing cutoff walls. Modern dams are safer and more durable than their early 1900 counterparts. Technologies to manage reservoirs are advancing rapidly. New means exist to gage and time water flows and to monitor water movement throughout even the largest river systems. In order to assess the future of surface-water storage facilities, therefore, it is necessary to look beyond available technology.

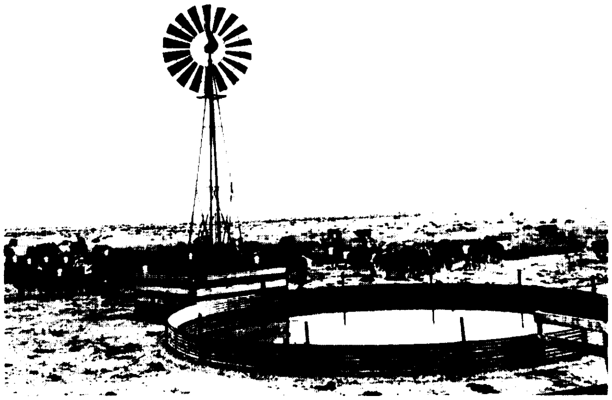


Photo credit. USDA Soil Conservation Service

This 33-ft-diameter stock-water tank supplies ground water for two herds of cattle near Sterling, Colo.

The Federal Government is a major reservoir owner as a result of past investments. For example, the Federal Government owns over 2,000 dams, ranging in size from small diversions to huge multipurpose projects such as the Central Valley Project in California. In addition, 50-percent Federal cost-sharing spurred farm- and ranch-pond construction; by 1964, one-fourth of all U.S. farms and ranches had privately owned ponds, pits, reservoirs, or earthen tanks. Over 2 million such structures were built, but they were not heavily concentrated in the West (15).

The Federal Government has an investment of more than $26 billion in completed water-resource projects and annual construction and rehabilitation costs for the federally owned

Box M.—Managing the Columbia River: CROHMS

The Columbia River Operation Hydromet Management System (CROHMS) is an example of the integrated management of a river and its reservoirs to produce a more efficient use of the region's water. It is based on new and advanced technology: a central computer with access to hydrological data gathered throughout the Columbia River Basin, data processors and displays, and mathematical models of river and reservoir behavior. Taken together, these components simplify decisionmaking on reservoir management at 80 dams used for hydroelectric power generation, flood control, irrigation water supplies, and recreation.

A number of independent data-collection systems forward information to CROHMS, where data is processed and made available to all potential users. Cooperating Federal agencies include the Bonneville Power Administration, the U.S. Army Corps of Engineers, the Bureau of Reclamation, the National Weather Service, the Geological Survey, and the Soil Conservation Service (SCS). The Province of British Columbia also participates. Several U.S. agencies collect and provide data from remote weather stations such as SCS Snotel and Bonneville's Hydromet. The computer software is another important aspect of CROHMS. These programs are still under development at the center in Portland, Oreg., but they will eventually include a complex data-management system, methods for data validation, and various mathematical models for forecasting streamflows and reservoir regulation. Eventually, automation will virtually eliminate the cumbersome manual tasks of preparing data for the computer.

CROHMS represents an attempt to forecast and regulate the flow of a major river system by computerized data collection, analysis, and modeling. If successful, this approach should improve the efficiency with which the water in a river basin can be managed. This, in turn, should make more equitable the allocation of water among potentially competing users.

SOURCE: Speer, et al., "CROHMS–An Example of Successful Interagency Coordination in Data Collection," *47th Annual Meeting, Western Snow Conference* **(Reno, Nev.,** 1979), **pp.** 102-107.

projects are high. In fiscal years 1981 and 1982, combined appropriations for the Army Corps of Engineers and the Bureau of Reclamation for these purposes totaled $1.7 billion and $1.9 billion, respectively. Only a portion of the Corps' budget was spent in the West, but the entire Bureau of Reclamation budget is related to Western water developments. Long-term U.S. Treasury borrowing finances these projects almost totally (39).

The benefits of these expenditures have been sizable, The larger projects made it possible to plan, build, and finance works on the scale required for main-stem Western rivers. Sometimes these have provided irrigation water, higher farm incomes, flood control, municipal water supplies, reservoir recreation, and power generation, For example, irrigation has made agricultural land use more productive on a per-acre basis.

There have also been substantial costs in addition to those noted above, Scenic and productive lands have been inundated, capital and labor have been diverted, families and towns have been displaced, fish and wildlife habitat has been altered, and towns have faced "boom town" social problems.

In the past, these large, federally funded water projects were approved on an ad hoc basis and met with little opposition (7). This situation no longer exists. Project selection, authorization, and construction now receive increased attention (see ch. V).

Barriers to new large-scale developments are physical, economic, and environmental. The physical sites most suitable for large-scale storage facilities have been used. The remaining sites may be less favorable for large dam construction and more distant from major population centers, thus decreasing their value for recreation, an important benefit for multiple-purpose projects.

The economic costs of large projects have escalated, making conservation, improved management, and other nonstructural methods more attractive for making more water available. In addition, the economic costs and benefits of existing projects have been called into question. The analytical techniques used by project sponsors to determine costs, associated benefits, and interest and payback rates from users sometimes have been criticized as inaccurate and misleading (8,38).

Also, today it is clear that large reservoir construction may result in major environmental effects and hazards (tables 43 and 44). Development around Lake Powell, for example, has increased air pollution, noise pollution, and litter (19). The majority of dams and reservoirs in many States became operational in the early part of the 1900's. Because previous water planners focused on project construction, not operation and maintenance, many expenditures to ensure the safety and efficient management of old facilities have been postponed. The total cost of these repairs could reach several billion dollars (39).

Because of these constraints, many experts expect that the Federal role in building and operating new large-scale water projects will decline sharply. New storage facilities are likely to be smaller, and their construction may depend entirely on private or non-Federal public investment or innovative cooperative arrangements between private and public developers or among Federal, State, and local governments. State bonds, revenue-sharing, property taxes, user charges, and joint ventures may become alternative means of raising funds. In Wyoming, for example, when the State Engineer declared a reservoir unsafe if more than one-half full, private investors agreed to renovate the reservoir in return for the first new 5,000 acre-ft of storage (l).

It is not clear to what extent farmers and ranchers will be able to take advantage of arrangements such as these. If Bureau of Reclamation irrigation projects that are based on irrigators' ability to pay contribute only about 19 percent of all costs, it is unlikely that private financing at higher levels will be profitable (17,28), The hydrologic effects are also not well known. The trend to construction of a larger number of smaller reservoirs may reduce the amount of water stored throughout the region.

Table 43.—Changes in the Colorado River, Grand Canyon National Park, as a Result of Glen Canyon Dam

Feature	Pre-dam	Post-dam
Appearance of water	Red	Green
Average annual sediment load	140 million tons	20 million tons
Annual variation in water discharge	High, seasonal	Low, daily
Annual water temperatures	32-85’ F	42-48” F
Light penetration.	1-2 inches	River bottom

SOURCE S W Carothers and R Dolan, Dam Changes on the Colorado River, " *Natural History, vol* 91, 1981, pp 75-83

Table 44.—The Effects of Glen Canyon Dam on Animal and Plant Life in the Colorado River, Grand Canyon National Park

	Results	
Alteration	Increases	Decreases
Water discharge	Streamside plants, animals	Wetland breeding habitat
Light penetration	Mats of green algae	
Water temperature	Exotic fish (19 species)	Native fish (8 species)
Overall changes	Complex terrestrial food webs	Complex aquatic food webs

SOURCE S W Carothers and R Dolan, “Dam Changes on the Colorado River, " *Natural History, vol 91, 1981,* pp. 75-83

With higher surface to volume ratios, these reservoirs might lose larger percentages of their water by evaporation and seepage.

Desalination

INTRODUCTION

As municipalities, industries, and irrigated agriculture continue to grow, demand for freshwater is expected to increase in the arid and semiarid regions of the West. Desalination is one technique that can supplement freshwater supplies by removing salt from ocean water or by improving the quality of salt-degraded water. In some cases, complete desalination may not be necessary. Salt-tolerant plants (ch. IX) and corrosion-resistant hardware may allow brackish water to be used. In addition, saltwater or desalination wastes may have direct uses. For example, some solar-powered greenhouses use saline water for heating and cooling. Moreover, seafood aquiculture depends on saltwater (ch, XI), and salt-gradient solar ponds can supply economical electricity and heat (12).

Of the many desalting techniques that exist, there are four general methods: 1) distillation, 2) membrane processes, 3) crystallization, and 4) chemical processes (table 45). General desalting operations are similar (fig. 38). Water is delivered and mechanically screened to remove suspended solids and debris. Subsequent processing results in two products: a disposable brine stream and a product stream which may be treated further, depending on its intended use.

Desalting plants exist throughout the world and are located in arid, semiarid, and humid climates. They range in capacity from a fraction of an acre-foot to hundreds of acre-feet per day. In the United States, a reported 637 plants produce 760 acre-ft/day or approximately 15 percent of the worldwide output (table 46). One-half of these plants are located in California, Florida, Texas, and Arizona.

One of the largest U.S. facilities will be the Bureau of Reclamation's Yuma (Ariz.) desalting plant, Scheduled to be operational by the end of 1987, it will produce 0.1 million acre-ft of water per year using a membrane process (18). The plant will treat Colorado River water before it passes to Mexico, as required by treaty.

Table 45.—Methods of Converting Saline Water to Freshwater

Distillation processes:
Examples:
  Multistage flash distillation
  Vertical tube distillation
  Multieffect multistage distillation
  Solar humidification
Attributes:
  Most widely used
  Energy intensive and costly
  Results in "ultrapure" water
  Favored for seawater

Membrane processes:
Examples:
  Reverse osmosis
  Electrodialysis
  Transport depletion
  Piezodialysis
Attributes:
  Favored for brackish water
  Require pretreatment to remove pollutants
  Potentially energy efficient
  Increasingly popular

Crystallization processes:
Examples:
  Vacuum freezing-vapor compression
  Secondary refrigerant freezing
  Eutetic freezing
  Hydrate formation
Attributes:
  Experimental stage
  Minimize corrosion
  Potentially energy efficient
  High recovery without major pretreatment

Chemical processes:
Example:
  Ion exchange
Attributes:
  Less costly "ultrapure" water
  Useful for low-salinity water

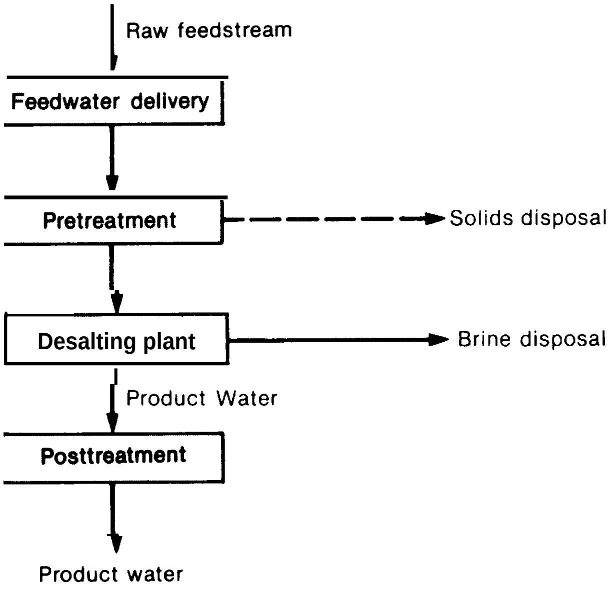
SOURCES U S Department of Interior, The ABC of Desalting (Washington, DC. U S. Government Printing Office, 1977), p 2, U S General Accounting Office, "Desalting Water Probably Will Not Solve the Nation's Water Problems But Can Help" (Washington, D C General Accounting Office, CED-79-60, 1979)

ASSESSMENT

Desalination by many methods is technically feasible, at least for small amounts of water. It has proven to be a reliable way to meet specialized water needs but requires further development before it can produce low-cost freshwater.

High costs are the major current limitation to use of desalination, although brine-disposal

Figure 38.—General Scheme of a Desalting Plant



SOURCE: Catalytic, Inc., *Desalting Handbook for Planners* (Washington, D.C.: U.S. Department of the Interior, OWRT TT/80 3, September 1979), p. 3.2, fig. 3.1

Table 46.—Desalting Plants, by Location

Region	Number of plants	Plant capacity (acre-ft/day)
United States	637	760
U.S. Territories	34	78
North America (outside U. S.)	58	51
Central America and Caribbean	66	123
South America	41	30
Great Britain and Ireland	63	51
Europe	256	380
Africa	244	438
Arabian Peninsula and Iran	599	3,485
Asia and India	172	292
Australia and the Pacific	19	9
U.S.S.R.	18	202
All regions	2,207	5,899

SOURCE Techno-Economic Services, *Desalting Plants Inventory Report No 7* (Honolulu, Hawaii Techno-Economic Services and Ipswich, Massachusetts Water Supply Improvement Association, May 1981), p 9, table 1

problems also could be troublesome. Costs and conversion rates for the various desalting processes vary widely. They include capital costs based on the process type, plant capacity, feedwater type and salinity, pretreatment required, product salinity, site-related costs for land, and operating, maintenance, and replacement costs.

These considerations limit production of desalted water to municipalities and industries and exclude most agricultural uses (5). For example, desalted municipal water costs about $1,300/acre-ft for seawater and $325/acre-ft for brackish water. Municipal water from conventional sources costs about $13/acre-ft (37). Some irrigators pay $0.27 to $9.82/acre-ft of water (39).

Use of expensive desalted water for irrigation would seem feasible where high-value, high-yield crops could be grown under a year-long or nearly year-long growing season, or where no other water was available. Under such conditions, farmers could take advantage of the year-round water production from a capital-intensive desalting plant. Precise farm delivery and crop application would be required because of the high water costs. Where desalination is required because of agricultural salt buildup (e. g., the Yuma plant), agriculture cannot carry desalination costs alone.

Interbasin Transfers

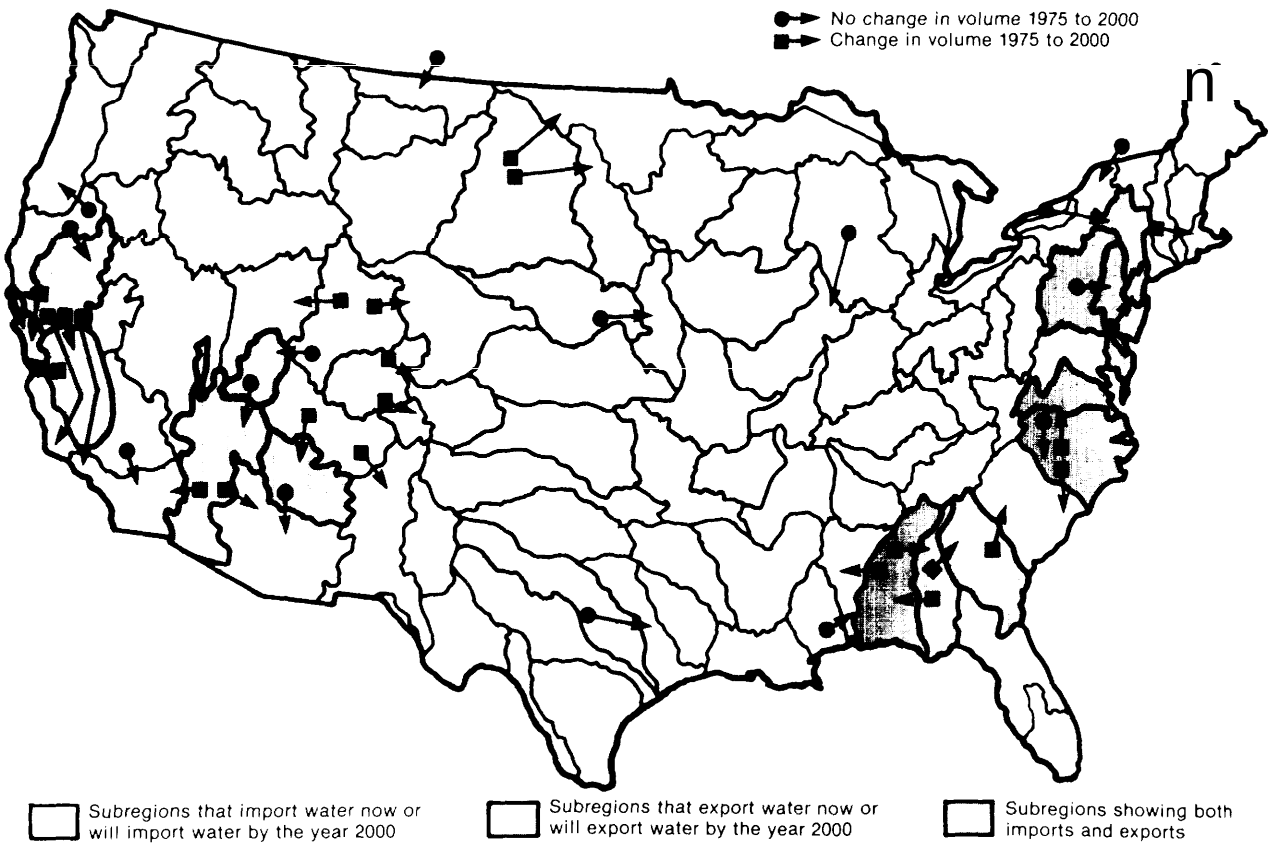
INTRODUCTION

Water transfers from one river basin to another for irrigation, municipal and industrial use, hydroelectric power, and other purposes have existed throughout the world for centuries. In the Western United States, regional transfers of water from the Colorado River Basin to other basins—e.g., the Colorado-Big Thompson Project—have been in operation for many years (fig. 39). Current attention focuses on proposals to transfer water from areas of supposed surplus (e. g., Alaska, the Missouri River) to Western stream systems for irrigation use.

ASSESSMENT

Results of the recently completed Six-State High Plains-Ogallala Regional Resources study, authorized by Congress in 1976, highlight the complexity of the interbasin transfer issue. As part of the overall study, Congress directed the U.S. Army Corps of Engineers to investigate the potential for augmenting water supplies in

Figure 39.—Water Imports and Exports



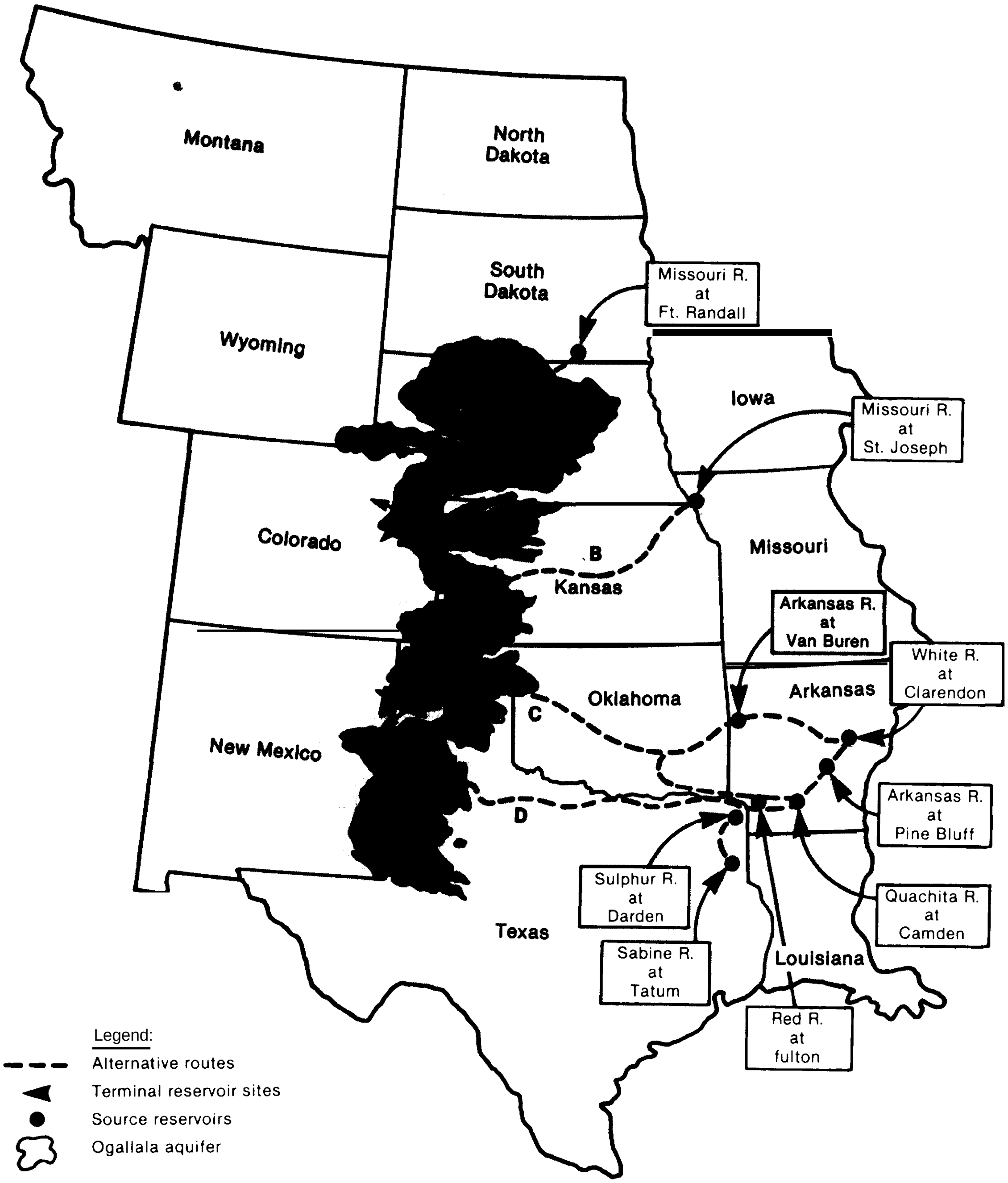
Water transfers occur throughout the United States, both within water resource regions and between regions. This illustration shows where water imports and exports occurred in 1975 and are projected for 2000. The estimates of future increases or decreases in transfers are based on authorized and/or funded projects only.

SOURCE: U.S. Water Resources Council, *The Nation's Water Resources 1975-2000* (Washington, D.C.: U.S. Government Printing Office, 1978), vol. 2, pt. IV, p. 15, fig. IV-6

the region through interbasin transfers from “adjacent areas. ” The Corps examined four plans in detail. Two proposed to divert water from either Fort Randall, S. Dak., or St. Joseph, Mo., on the Missouri River and convey it to eastern Colorado or Dodge City, Kans. Two other proposals considered tapping water at Various points along the Arkansas, White, Ouachita, and Red Rivers in Arkansas and the Sulphur and Sabine Rivers in Texas and transferring this water to storage points in Texas (fig. 40).

The Corps concluded that construction of canal systems capable of transporting 9 million acre-ft of water was feasible from an engineering standpoint. However, there were numerous economic, physical, and environmental barriers to implementation (z). First, the cost of irrigation water obtained from an interbasin transfer was prohibitively expensive and ranged from $226 to $434/acre-ft (1977 dollars), exclusive of costs beyond the terminal reservoir. Furthermore, with the high energy requirements needed for operation, water costs were projected to escalate significantly as energy costs increased, Second, no surplus water existed in the basin of origin, given present and future needs of the source basin. Third, construction of any of the routes would result in major environmental impacts. These projected effects included altered flow regime of the source streams, inundation of large areas of productive land for source and terminal stor-

Figure 40.– Interstate Water Transfer Routes Assessed by the U.S. Army Corps of Engineers



SOURCE: High Plains Associates, *Six State High Plains Ogallala Aquifer Regional Resources Study* (summary, July 1982), p. 71, fig. VI-5. Original source: U.S. Army Corps of Engineers, "Water Transfer Elements of High Plains-Ogallala Aquifer Study" (review draft, January 1982), fig. 5.

age, conversion of large amounts of agricultural land to other uses, and disruption of wildlife migratory patterns.

Other considerations and possible limitations to interbasin transfer, though not identified by the High Plains study, include:

- treaty requirements and restrictions—e. g., the Mexican Water Treaty;
- commitments under the Wild and Scenic Rivers System;
- Federal and State statutory prohibitions against interbasin transfers, particularly interstate;
- vested rights to the waters of the source stream;
- allocations under interstate compacts;
- uncertainties concerning Federal reserved water rights and Indian water rights;
- lack of comprehensive, multipurpose, up-to-date regional planning encompassing both the source river basin and prospective affected area;
- lack of State water plans in many States;
- lack of generally accepted projections of future consumptive water demands in the source basins and receiving States; and,
- public opposition in the source basins to water transfer.

In the present and foreseeable future, political, financial, legal, and institutional considerations probably will preclude the use of extensive interbasin transfers of water to sustain irrigated agriculture in arid and semiarid regions of the West. Major changes in Federal and State laws and policies; provisions of large amounts of Federal and State funds; comprehensive, multipurpose, regional planning for water and other resources; and major changes in public perceptions and attitudes would be necessary before such transfers could be implemented. For example, the Colorado River Basin Project Act of 1968 (Public Law 90-537) prohibited planning by Federal agencies or with Federal funds for water diversions from the Columbia River Basin for use outside that basin. The initial 10-year moratorium has since been extended for another 10 years by the Reclamation Safety of Dams Act of 1978 (Public Law 95-578).

Technologies That Conserve Existing Water Supplies

Flexible Delivery Systems

INTRODUCTION

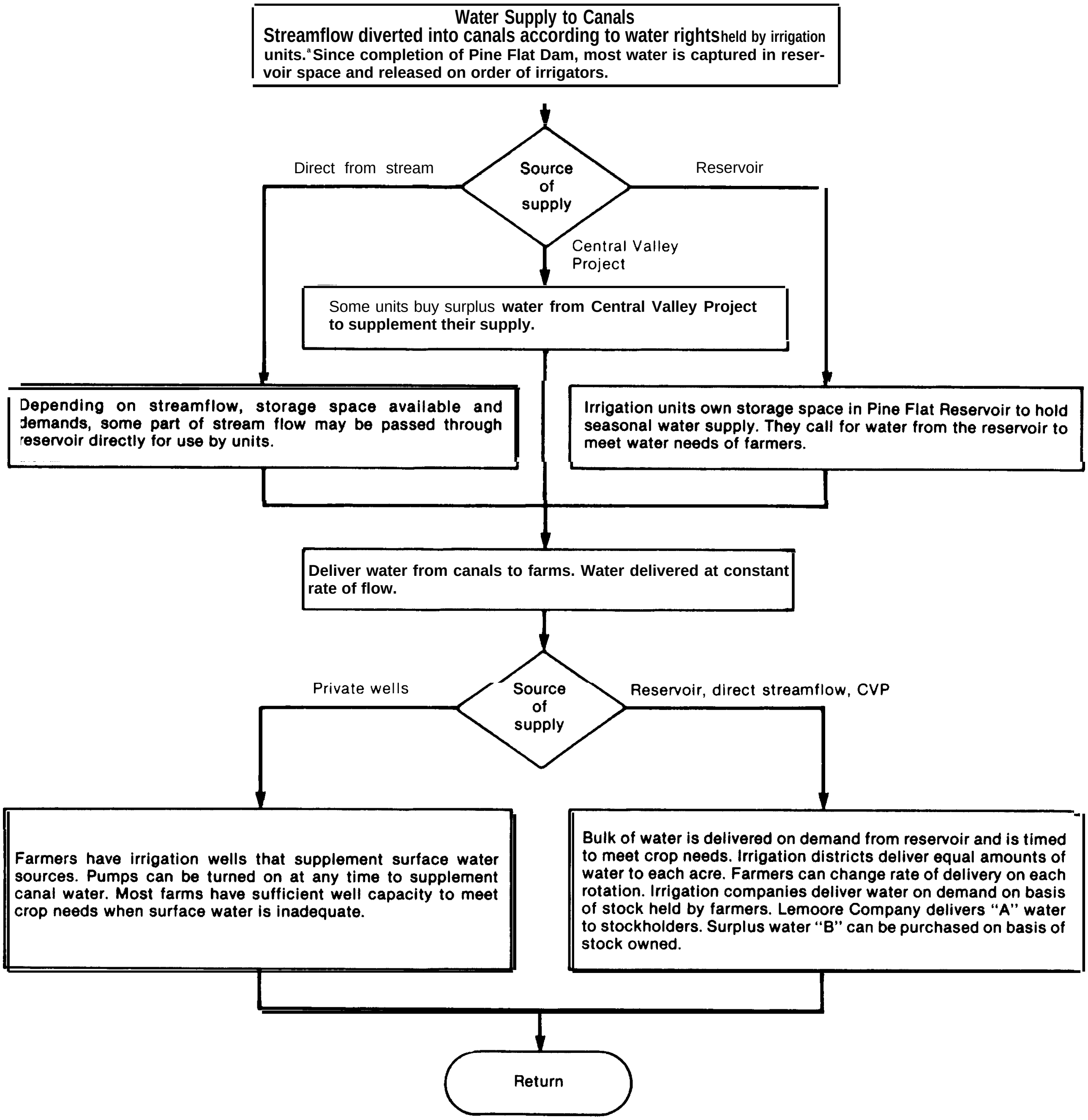
An adequate water supply is a critical aspect of surface water management. Timely water delivery is a second key element. Onfarm and off-farm irrigation systems that use surface water have two major features: a physical system of storage and conveyance and a managing organization to oversee distribution. Physical components generally include one or more storage reservoirs, diversion works to channel water into the conveyance system, a conveyance system with structures for flow control, and a distribution system that brings water to the individual user. Throughout the system, control gates or pumps regulate water levels and control the quantity of water being discharged through or into a particular structure.

The Federal Government builds and operates many reservoirs and major conveyance systems in the Western States, but many non-Federal public and private systems also exist, If Federal water is to be used for irrigation, it is sold to irrigation districts and/or canal companies. The exact arrangements for water distribution to individuals vary considerably from place to place, They include procedures that allot water based on crops, farm location, shares owned in the irrigation system, time of settlement, and other factors (fig. 41),

Operations of surface water systems are complex. Where sufficient supplies of water exist and conveyance systems are capable of transporting variable flows, a water system can be operated to meet all users' potential demands. However, in most arid and semiarid regions, systems that respond to unregulated demand are not feasible because water supply or system capacity is limited. Here, systems that are designed around supply have been more common.

The amount and timing of surface water flow in a supply-type system is controlled upstream. Federal or local project operators release water

Figure 41.—Irrigation Water Distribution Procedure, Kings River, Calif.



Water Supply to Canals

Streamflow diverted into canals according to water rights held by irrigation units.[a] Since completion of Pine Flat Dam, most water is captured in reservoir space and released on order of irrigators.

Some units buy surplus water from Central Valley Project to supplement their supply.

Depending on streamflow, storage space available and demands, some part of stream flow may be passed through reservoir directly for use by units.

Irrigation units own storage space in Pine Flat Reservoir to hold seasonal water supply. They call for water from the reservoir to meet water needs of farmers.

Deliver water from canals to farms. Water delivered at constant rate of flow.

Farmers have irrigation wells that supplement surface water sources. Pumps can be turned on at any time to supplement canal water. Most farms have sufficient well capacity to meet crop needs when surface water is inadequate.

Bulk of water is delivered on demand from reservoir and is timed to meet crop needs. Irrigation districts deliver equal amounts of water to each acre. Farmers can change rate of delivery on each rotation. Irrigation companies deliver water on demand on basis of stock held by farmers. Lemoore Company delivers "A" water to stockholders. Surplus water "B" can be purchased on basis of stock owned.

[a] Units are irrigation companies and districts.

SOURCE: Raymond L. Anderson and Arthur Maass, "A Simulation of Irrigation Systems," U.S. Department of Agriculture Technical Bulletin No. 1431, (Washington, D.C. 1978), p. 71

from an upstream source based on "water orders" that anticipate downstream needs, The water then moves into a main canal (managed by Federal or local organizations), through a system of smaller canals, and is delivered to the farm. If farmers or districts decide not to use the water, it continues to move through the system and is spilled at the lower end of the canal.

Districts have formal rules and regulations for water distribution. Often, delivery schedules are developed in advance and are fixed for time and length. Adjustment in timing, duration, or quantity of water application is limited. For example, if several users are allowed to shut off water, flow along the entire canal system changes, and canal banks may overtop. while these rules allow close control of water in the system and enable officials to maintain accurate records of water deliveries, the amount and timing of water deliveries facilitate water distribution rather than accommodate crop needs. This situation limits the amount of water conservation that is possible. A variety of technologies for providing improved flexibility in water delivery are being examined,

Automated Upstream Control.—Stabilization of water levels in a conveyance system is difficult with conventional, manually operated check gates. In recent years, many irrigation districts have installed automated gates that maintain a constant water level regardless of

Box N.—Water Delivery: Pulling It Down and Putting Some Over the Hill

I suppose it was partly the memory of that [raft trip] that led me to visit, one summer morning in Sacramento, the Operations Control Center for the California State Water Project. Actually so much Water is moved around California by so many different agencies that maybe only the movers themselves know on any given day whose water is where . . . , They collect this water up in the granite keeps of the Sierra Nevada and they store roughly a trillion gallons of it behind the Oroville Dam and every morning, down at the Project's headquarters in Sacramento, they decide how much of their water they want to move the next day. They make this morning decision according to supply and demand, which is simple in theory but rather more complicated in practice. In theory each of the Project's five field divisions . . . places a call to headquarters before 9 a.m. and tells the dispatchers how much water is needed by its local water contractors, who have in turn based their morning estimates on orders from growers and other big users. A schedule is made. The gates open and close according to schedule. The water flows south and the deliveries are made.

In practice, this requires prodigious coordination, precision, and the best efforts of several human minds and that of a Univac 418. In practice it might be necessary to hold large flows of water for power production, or to flush out encroaching salinity in the Sacramento-San Joaquin Delta, the most ecologically sensitive point on the system. In practice a sudden rain might obviate the need for a delivery when that delivery is already on its way. In practice what is being delivered here is an enormous volume of water, not quarts of milk or spools of thread, and it takes 2 days to move such a delivery down through Oroville into the Delta, which is the great pooling place for California water and has been for some years alive with electronic sensors and telemetering equipment and men blocking channels and diverting flows and shoveling fish away from the pumps. It takes perhaps another 6 days to move this same water down the California Aqueduct from the Delta to the Tehachapi and put it over the hill to Southern California. "Putting some over the hill" is what they say around the Project Operations Control Center when they want to indicate that they are pumping Aqueduct water from the floor of the San Joaquin Valley up and over the Tehachapi Mountains. "pulling it down" is what they say when they want to indicate that they are lowering a water level somewhere in the system. They can put some over the hill by remote control from this room in Sacramento with its Univac and its big board and its flashing lights . . . [and] with its locked doors and its ringing alarms and its constant printouts of data from sensors out there in the water itself. . . . I stayed as long as I could and watched the system work on the big board with the lighted checkpoints. The Delta salinity report was coming in on one of the teletypes behind me. The Delta tidal report was coming in on another. The earthquake board, which has been desensitized to sound its alarm (a beeping tone for Southern California, a high-pitched tone for the north) only for those earthquakes which register at least 3.0 on the Richter Scale, was silent. I had no further business in this room and yet I wanted to stay the day . . . ,

SOURCE: Excerpted from: Joan Didion, "Holy Water," *The White Album [New* York Simon & Schuster, Inc , 1979], 1977, pp 60-62, 66.

water flow. These gates do not change the basic operation of the system. For example, if water demand increases upstream, downstream gates automatically close to maintain a constant water level and users on the downstream end may not receive enough water. Conversely, a decrease in upstream demand automatically opens downstream gates to allow extra flow to pass. However, if supply exceeds demand, water may spill at the lower end of the canal system,

Downstream Control Systems.—Downstream control of irrigation water ("demand delivery") is a second category of canal control. Downstream control compares to water delivery in municipal systems where water is available any time an individual turns on the tap and at any flow rate, up to the limits of the piping system or regulation. A downstream controlled system automatically responds to the opening and closing of farm gate turnouts. If an irrigator opens a turnout gate in these systems, a water wave is transmitted upstream to a gate, which in turn opens to release extra water. An opposite reaction occurs when the turnout is shut off.

Downstream control has been achieved in parts of irrigation projects in the United States, and complete systems have been constructed in Morocco and Tunisia. Two types of downstream control have been used. In one type, a series of level-top canals are connected by controls that respond to changes in downstream water levels, If water is discharged from the downstream end of a pool, for example, the water surface drops at that end and the resulting wave causes the upstream canal gate to open wider. A second, more rapid response, downstream control relies on multiple-sensing devices to take continuous readings throughout a canal system. Data are relayed to a computer in the central office and gates are adjusted on the upstream end.

Regulating Reservoirs Along Irrigation Canals.—An alternative to upstream or downstream control is to use one or more regulating reservoirs along the irrigation canal to buffer imprecise upstream deliveries and to allow a demand schedule to be implemented in a largely upstream-controlled system. Irrigation water can be stored until it is needed, and response time to irrigator demand can be shortened.

Combination Control.—It is not necessary to have downstream control structures throughout the canal system to deliver water to farm turnouts on a demand schedule. Upstream control structures on the upper one-half or two-thirds of a system and a regulating reservoir below this point can be an economical alternative. Demand scheduling can then be implemented on the lower end of the conveyance system.

Centralized Scheduling Services.-The U.S. Bureau of Reclamation has been experimenting with an extension of downstream control that predicts water requirements in individual fields based on weather and crop data. Water requirements for the aggregate system can then be predicted and the complete operation can be prescheduled,

Onfarm Reservoirs.—Where irrigation districts deliver water on a fixed schedule, farmers may build onfarm reservoirs at the turnout point to store water until it is needed.

ASSESSMENT

Flexible delivery schedules are relatively new in concept, design, and implementation. For example, level-top and newer rapid-response downstream control methods remain experimental, design refinements are still required, and as yet, capital and labor costs remain high (31).

The main advantage of these delivery schedules is the choice they provide in duration, frequency, and quantity of water delivered to ensure that the crop receives water when needed but not in excess of the amount required. For example, automated upstream control provides irrigators with limited flexibility in operation of turnout flows (discharge openings). Downstream control allows an irrigator to have water when it is needed and simplifies canal company operations, since farmers determine delivery schedules. Combined methods of control have advantages of several control methods and generally reduce the risk of spillage and under-irrigation (4).

Advocates of these control methods note many benefits for individual irrigators. These include: higher crop production per unit of water applied; higher crop production per acre; less surface runoff, erosion, and sedimentation; less deep percolation and attendant loss of fertilizers and pesticides; less seepage; less ground water use; and reduced pumping requirements. With better control, any excess water may remain in the system with the result that instream flow may increase. Because less polluted water is returned to the stream, water quality may improve and deposition of suspended sediment in reservoirs and streams may decrease (20,40).

Delivery arrangements based on considerations of technical efficiency alone may not be easy to implement. Some factors that restrict implementation include (24):

Economic limitations.' Some irrigation systems are old and rehabilitation to achieve more flexibility is prohibitively expensive. Others, such as onfarm reservoirs, are expensive to build and maintain and take land out of crop production.

Training and education needs of engineers, managers, and designers: The expertise required for some onfarm measurements of soil moisture or water application, for example, may be beyond that which most irrigators have or want. Some irrigation districts do not have the capability for automated water forecasting and management.

Institutional considerations: Water rights doctrines in the Western States are based primarily on the appropriation doctrine with a water right tied to specific lands. Many decreed rights may be far in excess of irrigation requirements, using current or improved technology, but irrigators who use less water on their farms and ranches may not get the economic benefit of that water, since it becomes available to the next junior user. For example, farmers and ranchers may have little incentive to use downstream controls that could reduce the amount of water applied to fields unless economic losses—e. g., those from fertilizer leaching–can be demonstrated.

Accuracy of water measurement in canals and soil is an important requirement in flexible delivery systems. For instance, extensive field measurements are needed to calibrate the computer programs that predict crop water requirements for centralized scheduling services. Downstream control systems must be monitored to ensure that requests do not exceed the capacity of the system. Modern electronic measurement devices are available for accurate accounting of water in all parts of the system, but ensuring that farmers and managers have access to this equipment and to backup information is difficult.

Responsibility for maintaining water records is shifting in some areas. For example, Federal efforts in providing centralized scheduling services have been criticized as understaffed and unresponsive to individual requirements. Private agricultural consultants in some areas are replacing Bureau of Reclamation irrigation scheduling services, but this transition is not without friction (23).

Seepage Control

INTRODUCTION

Seepage occurs through the sides and bottoms of reservoirs and canals. Its extent depends largely on geology, soils, and topography. Many technologies used to make soils impervious for water harvesting (ch. VI) also can be used for seepage control. These include: 1) compacted earth, 2) rigid surfaces, 3) buried and exposed membranes, and 4) soil sealants. Each area must be evaluated individually before a control method is chosen. Soil characteristics, operating capacity and flow velocity of the irrigation canals, structural stability required, water quality, and safety and maintenance needs must all be analyzed.

Assessment

Water "losses" from seepage can be large enough in some areas to prevent reservoirs from filling (4). However, estimates of the problem's magnitude vary widely and are difficult to make. For example, Morrison and Johns (25)

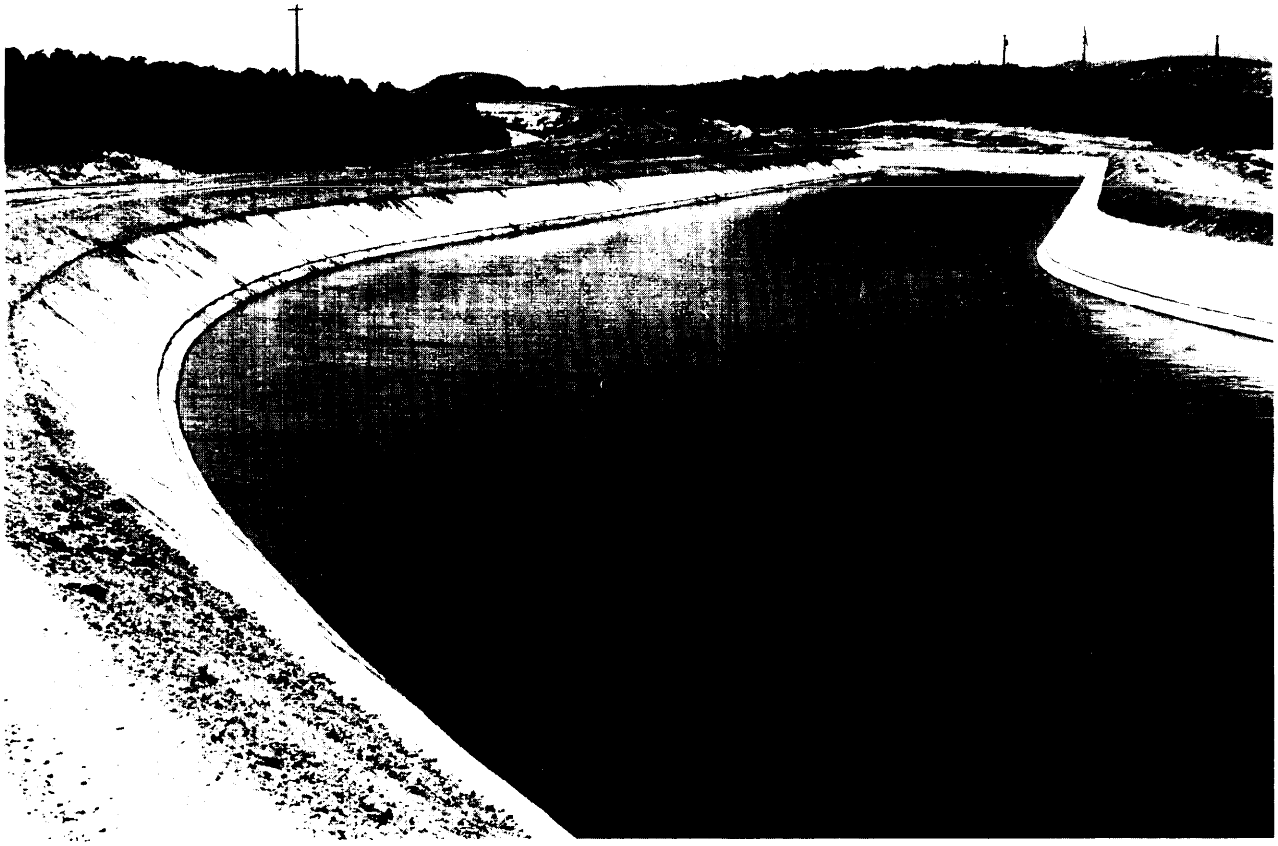


Photo credit: DOI-Bureau of Reclamation

This canal is lined to prevent seepage. It is part of the Central Valley Project Friant-Kern Canal stretching 150 miles from Fresno to Bakersfield, Calif.

suggest that eliminating seepage from irrigation systems could affect 1.5 million acre-ft of water. According to another author, consumption and conveyance water losses, including seepage and water use by riparian vegetation, account for about 5 percent of usable reservoir storage in the West (4). An earlier compilation of data by the Bureau of Reclamation showed that losses were considerably higher for many rivers (table 47).

Seepage control only "saves" water on a local basis, though, and its effects vary widely in different locations. Water lost to seepage is not lost to downstream users, to organisms in artificial or natural wetlands and streams, nor to the hydrologic system. For example, seepage from leaky irrigation systems in some areas provides ground water recharge. Depending on conditions, uncontrolled seepage may also result in soil salinization, waterlogging, or erosion of neighboring soils.

Seepage control currently is easier and less expensive than evaporation control (26). Both processes are expensive, however, and high cost is the primary limitation to use. As the relationship between standing water from inefficient irrigation and wildlife populations is explored, other limitations may be identified. In California, for example, applications of irrigation water in excess of plant needs and seepage from canals have contributed to increases in waterfowl populations. As water

Table 47.—Major Seepage Losses From Western Rivers, 1975

Basin	Acre-ft of annual seepage	Percent of total water diverted
Missouri River:		
Buford, Trenton, ND	6,149	35
Mirage Flats, NE	6,821	46
Buffalo Rapids, MT	42,478	55
Lower Yellowstone, MT, NE	57,985	21
North Platte, WY, NE	542,380	43
Milk River, MT	151,967	59
Columbia River:		
Crescent Lake, OR	32,830	49
Arnold, OR	8,590	38
Missoula Valley, MT	710	24
Umatilla, OR	60,335	30
Minidoka Palisades, ID, WY	1,457,949	24
Boise, ID, OR	784,655	35
Columbia, Basin, WA	676,320	23
Yakima, WA	520,832	24
Sacramento River:		
Orlando, CA	45,066	37
Colorado River:		
Salt River, AZ	526,177	39
Grand Valley, CO	59,661	18
Rio Grande River:		
Rio Grande, NM, TX	273,301	39
Middle Rio Grande, NM	121,360	24
Klamath River:		
Klamath, CA, OR	265,473	28
Total	5,641,039	

SOURCE U S General Accounting Office, "More and Better Uses Could be Made of Billions of Gallons of Water by Improving Irrigation Delivery Systems," (Washington, D C GAO 77117 Sept 2, 1977). p 15 Original source U S Bureau of Reclamation Annual Report, 1975

conservation becomes more common, waterfowl are decreasing (35). It is not yet clear how these tradeoffs will be judged and managed (table 48).

Of the various types of seepage control, compacted earth linings often are available locally and at low cost. But these linings require specific soil conditions; when these conditions are not present, treated canals may continue to leak.

Rigid surface linings—e.g., concrete, asphalt, and soil-cement—are chosen when structural stability is important, such as when soils are unstable or near municipal areas. Concrete is most resistant to erosion, which is important when canals carry water at high velocities. Concrete-lined structures are susceptible to frost and chemical damage, though, and preventive features increase costs. Concrete linings may be either poured or applied under pneumatic pressure ("shotcrete"). The latter is limited to small canals and mild climates.

Asphalt and asphalt concrete also are effective linings. Asphalt concrete is durable, watertight, and erosion-resistant but requires careful compaction by large machinery. Therefore, it is used only in those large reservoirs and canals where cost is not prohibitive. Asphalt blown onto soil, then covered with more soil to prevent mechanical damage, is suitable for smaller structures and is less costly, but also less durable. Asphalt may also be mixed with other materials, such as rubber or fiberglass.

A rigid surface lining can also be made of a water, soil, and cement mixture. This mixture, called soil-cement, has high durability and low permeability if mixed and applied properly, It can be made only with relatively fine-grained soils and requires careful compaction (6),

Many different types of membranes have been used to line canals, sometimes only experimentally. These include synthetic rubber, prefabricated asphalt sheets, fiberglass-reinforced polyester, and other types of plastics. Thin membranes placed on the inside surface of a canal are exposed to weathering, vandalism, erosion, animals, and weeds. Such liners require careful ditch preparation to remove sharp objects and to ensure that the liners lie flat. Asphalt or plastic liners are usually covered by about a foot of earth, Asphalt linings have been in place for over 20 years; plastic linings have been used for almost 30 years, but detailed analysis of their performance covers a shorter period of time. Both are relatively low cost and effective, Rubber has been used less because it costs about three times as much as plastic (25),

A wide variety of soil sealants has also been used to eliminate canal and reservoir seepage, These agents may physically plug soil pores, form a distinct impermeable membrane, or chemically react with soil constituents, Soil sealants must be nontoxic to humans, animals, and crops; withstand a broad range of water quality; and resist breakdown by animals, equipment, erosion, and water pressure, Var-

Table 48.—Tradeoffs Between Agricultural and Wildlife Practices: California's Sacramento Basin

	Opportunity	Agricultural viewpoint		Fish-wildlife-recreation viewpoint		
Practice	for water saving	Positive	Negative	Positive	Negative	Comments
Increase ground water pumpage	Possibly very large	Farmers gain operating independence and dry-year flexibility	High initial cost; big energy user	Reduces diversions from river	**May increase percolation**	One of two true means of saving water in basins
Increase reservoir storage	Moderately large	Increased dry-year supply	None	Decreases peak flows; increases dry-year summer flows; enhances reservoir-type fisheries	Would flood out native lands	Opportunity for true in-basin water savings
Reduce water applied to rice	Large, possible several hundred thousand acre-feet	Should produce a large net saving in applied water use; save energy and fertility	Would increase irrigation management costs; increase TDS of drainage water	Would tend to reduce diversions from the Sacramento River, leaving more water for in-channel use	Would decrease drain flows, hence diminish riparian vegetation and fish flows, increase TDS and water temperatures	No savings would result unless storage provided
Level all rice paddies, form rectangles	Included above	Would decrease applied water use by an estimated 5°/0; increase yield, reduce water management and harvest costs, increase net profit	Would take land out of production for one crop year; require capital outlay	Included above	Elimination of berms would reduce wildlife habitat	Now catching on rapidly in rice-growing areas
Drain wet mountain meadows; improve water management	Small	Would reduce water use; increase forage production	Would require annual maintenance cost; high original investment	None	Would reduce wetland habitat reduce late summer downstream flows	As time goes on, practice will be employed through the incentive to increase forage production
District practices; canal lining (reduce seepage); increased use of relift pumps, control ditch bank vegetation, clear channels	Large, could reduce district demands	These practices will decrease water demands on a district basis; could increase yields and decrease fertilizer needs	Would require more energy, capital, and manpower, increase the unit cost of water, leave drain water users with no available supply	None	Would reduce wetland habitat, reduce fish flows, raise water temperatures, increase TDS, concentrate pesticides, and increase channel velocities in some areas	Must develop incentives for districts to take action; must persuade people that water-saving practices are necessary

SOURCE State of California, *Water Conservation In California,* Department of Water Resources Bulletin No 198 (Sacramento, Calif May 1976), p 70 ious sodium salts meet these conditions and a sodium-treated reservoir will have a lifespan of many years (11). Soil sealants of other types, such as bentonite clays, have given variable results with differing soil types.

Evaporation Control

INTRODUCTION

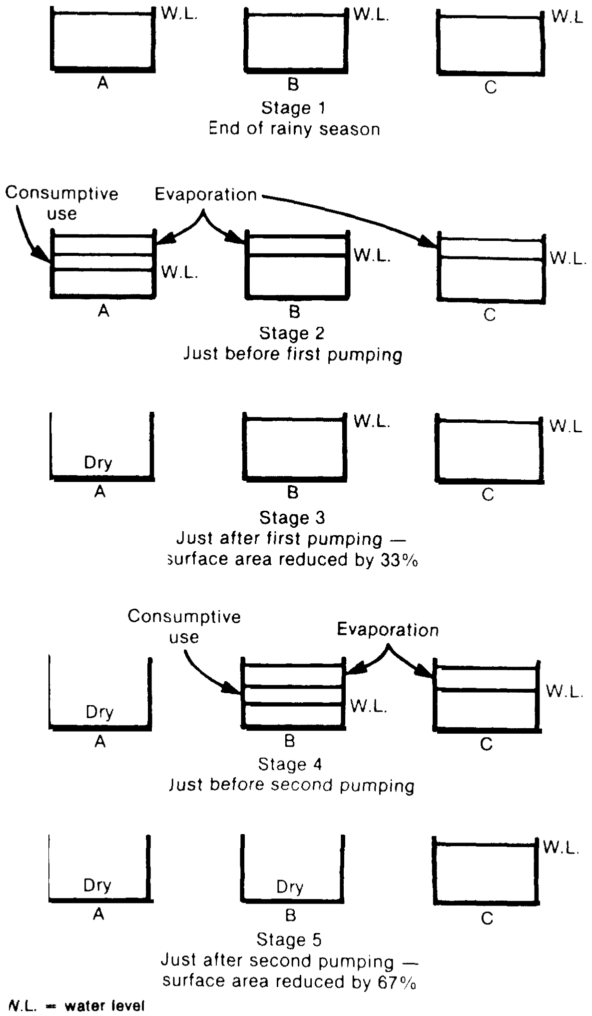
The process of evaporation requires a source of energy to vaporize water and a mechanism to transfer water vapor from the liquid's surface to the air, The climate in arid and semiarid lands provides both factors in abundance, and evaporation is high. Solar energy drives evaporation while low atmospheric humidity and frequent high winds accelerate the transfer of water vapor into the air.

Since conserving collected water is one of the most economical methods of maintaining an adequate water supply, a great deal of research has sought effective evaporation control technologies, These technologies increase water supplies, in effect, by increasing reservoir capacity without new construction. They alter the processes that contribute to evaporation by: 1) lessening the amount of energy that reaches the water surface to drive evaporation, and 2) altering the ease with which vaporized water moves into the air.

Four methods of controlling evaporation have received attention: 1) surface-area reduction, 2) reflective coatings, 3) surface films, and 4) mechanical covers. Surface-area reduction can be achieved by selecting proper sites, by diking to eliminate shallow areas of each reservoir, by deepening existing reservoirs, or by compartmentalizing them. Deepening reservoirs reduces evaporation both by exposing less water surface to warm, dry air and by lowering the temperature of the deeper water (and thus increasing the amount of energy needed to evaporate that water). "Compartmented" reservoirs actually consist of several separate reservoirs of varying depths (fig. 42). Water is used from the shallower reservoir until the remaining water equals the storage capacity of the other compartments. water from the first container is pumped to fill the others at that time, This process is repeated as other reservoirs are drawn down, It ensures that most reservoirs will have the lowest possible ratio of surface to volume water and thus the lowest evaporation.

Figure 42.— A Compartmented Reservoir in Operation

Water is used from and pumped between separate reser. voirs so that the evaporative surface is as small as possible



SOURCE: C. Brent Cluff, "Surface Storage for Water Harvesting Agrisystems," *Rainfall Collection for Agriculture in Arid and Semiarid Regions*, G. R. Dutt, C. F. Hutchinson, and M. Anaya Garduno (eds.) (Slough, U.K.: Commonwealth Agricultural Bureaux, 1981), p. 27, fig. 1.

Reflective coatings are designed to reduce the amount of incident solar radiation reaching the water. They also may provide a barrier to vapor. Surface films, which do act as barriers, received considerable attention during the 1950's and 1960's, Single-molecule films of long-chain alcohols were applied, sometimes by airplane. More substantial floating covers also have been developed. These mechanical covers include polystyrene sheets, lightweight concrete slabs, wax blocks, and rubber sheets.

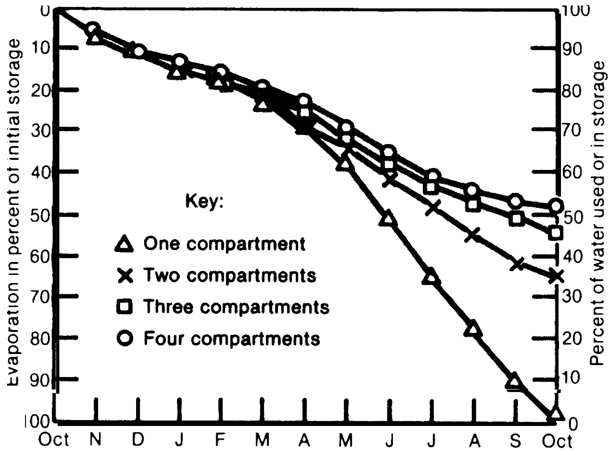
Assessment

Average evaporation from reservoirs throughout the West is approximately 6 percent. In some regions, though, reservoir evaporation may reach about 40 percent of usable storage (4). Small reservoirs, stock tanks, and farm ponds with large surface areas exposed to arid conditions may lose more water to evaporation than is used productively (26). Compartmented reservoirs can reduce evaporation substantially (fig. 43), Measurements made under idealized conditions in Arizona suggest that savings of 35 to 50 percent are possible, but these amounts vary in different climates (6).

Evaporation reductions achieved using different methods have been variable and often disappointing. For example, reflective coatings have reduced evaporation by about 50 percent for 1 month, but the materials used, such as perlite, eventually become waterlogged. Once coatings are wetted, evaporation savings drop to about 10 percent, making such technology impractical. Reflective coatings and surface films are unstable if the water surface is not still. Long-term field studies show that monomolecular layers of alcohols reduce evaporation only about 10 to 20 percent (4,14). These controls are most economical for large reservoirs or in highly regulated river systems where evaporation losses are large and increasing salinity levels must be controlled.

Figure 43.—Evaporation From Compartmented Reservoirs

Reservoirs with several compartments have the potential for reducing evaporation. The amount of water "saved" can be substantial, as illustrated in this idealized graph for Tucson, Ariz.



SOURCE C Brent Cluff, "Surface Water Storage for Water-Harvesting Agrisystems," *Rainfall Collection for Agriculture in Arid and Semiarid Regions*. G. R. Dutt, C. F. Hutchinson, and M. Anaya Garduno (eds.) (Slough, U.K.: Commonwealth Agricultural Bureaux, 1981), p. 28, fig. 2

Mechanical covers are often simple and cost-effective and have the highest potential for use on small reservoirs, stock tanks, and ponds, Materials of various kinds have achieved reductions in evaporation of 80 to 90 percent. Only minor problems have been reported, such as damage by birds and weathering (14). Some elaborate types of covers are specially treated to retard weathering, but this makes them too expensive to use for conventional agriculture. They may be cost-effective when used in conjunction with water-harvesting methods, compartmented reservoirs, or less-than-full irrigation.

Vegetation Management In and Near Surface Water

Riparian Vegetation

INTRODUCTION

Riparian zones constitute only a small fraction of Western lands. Their scarcity belies their critical role, however, in affecting and maintaining watershed stability, water quality, livestock grazing, wildlife habitat, and recreation (22). These areas also are significant for agriculture; they provide high-quality forage and drinking water for livestock and can decrease soil erosion when in good condition. They may, however, use water intended for irrigated crops, Riparian zones also constitute an important esthetic and wildlife resource (table 49). For example, although riparian zones

Table 49.—Southwestern Birds That Rely on Wetland and Riparian Habitats

	Distribution of bird species among habitats (percent)			
Location (no. species)	Wetlands and/or only riparian	Riparian preferred	Nonriparian	Suburban and agricultural
Blue-Point Cottonwoods (58)	45	29	24	2
Salt River Valley (86)	44	23	27	6
Central Arizona Mountains (102)	7	22	68	3
Flagstaff (125)	18	18	62	2
Grand Canyon (122)	16	14	68	2
Arizona (242)	30	22	46	2
Southwest Lowlands (166)	47	26	23	4

SOURCE Adapted from R Roy Johnson, "'The Lower Colorado River,'" *Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems* U S Department of Agriculture Forest Service General Technicai Report WO-12 (Washington, D C U S Government Printing Office, 1979), p 43, table 2

represent less than 1 percent of public arid lands, 75 percent of all sagebrush steppe wildlife in southwest Wyoming depends on these areas (33,34), and over half of the land designated Arizona State Natural Areas include riparian areas (3).

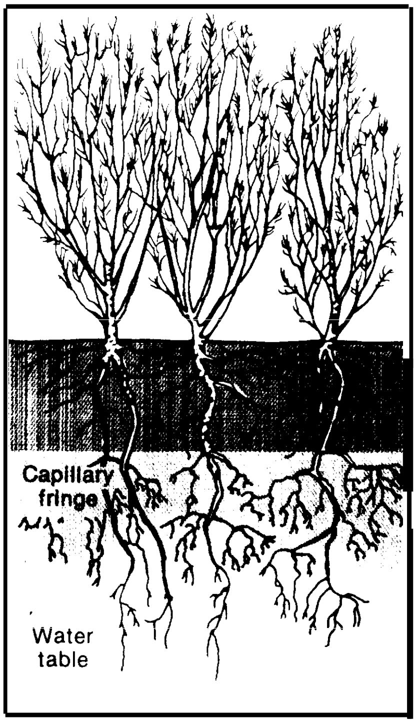
Riparian zones are identified by characteristic shrubs, trees, and grasses that are associated with abundant water. Plants that tap ground water, called "phreatophytes, " are common (fig. 44 and table 50). Plant species vary throughout the West as a result of climatic and management differences. The present vegetation sometimes is dominated by exotic species, such as saltcedar, which have invaded wide geographic areas and replaced native cottonwoods, willows, and mesquite.

Assessment

Knowledge of the hydrologic role of riparian vegetation has changed considerably in the past 30 years. Therefore, the approach to management also has changed. Early work indicated that phreatophytes "waste tremendous quantities of ground water each year, " cover about 16 million acres in the 17 Western States, and use as much as 25 million acre-ft of water annually (32), Such estimates often were based on limited studies, however, and extrapolation to the entire West is suspect.

Early workers assumed that most, if not all, of the water "saved" by removing riparian vegetation would remain in ground or surface waters and be available for direct human use. While some streamside plants use large amounts of water, removing the plants does not necessarily make this water available for other uses. One of the first long-term measures of water availability before and after clearing was completed in 1982. These Arizona results indicate that water "savings" depend on the vegetation that replaces phreatophytes, Annual average water "losses" are likely to increase by 60 percent, remain about the same, or decrease by 2 percent if three different irrigated

Figure 44.—Some Riparian Plants, Called Phreatophytes, Tap Ground Water



SOURCE: T. W. Robinson, *Phreatophytes*. U.S. Geological Survey Water-Supply Paper 1423 (Washington, D.C.: U.S. Government Printing Office, 1958), p. 10.

Table 50.—Widespread Phreatophytes of the Western United States

Common name	Scientific name
Baccharis	*Baccharis* spp.
Rabbitbrush	*Chrysothamnus* spp.
Saltgrass	*Distichlis* spp.
Wildrye	*Elymus* spp.
Velvet ash	*Fraxinus velutina* Torrey
Wirerush	*Juncus balticus* Willdenow
Sprangletop	*Leptocioa fascicularis* (Lamarck) A. Gray
Alfalfa	*Medicago sativa* Linnaeus
Reed	*Phragmites communis* Trinius
Engelmann spruce	*Picea engelmanni* Parry
Cottonwood, quaking aspen	*Populus* spp.
Mesquite	*Prosopis* spp.
Willow	*Salix* spp.
Elderberry	*Sambucus* spp.
Big greasewood	*Sarcobatus vermiculatus* (Hook) Torrey
Buffalo berry	*Shepherdia* spp.
Alkali sacaton	*Sporobolus airoides* Terry
Saltwort	*Sueda depressa* Watson
Saltcedar	*Tamarix* spp.

SOURCE T W. Robinson, Phreatophytes, US Geological Survey Water-Supply Paper 1423 (Washington, D C U.S Government Printing Office, 1958), pp 32-40, table 1, in part

forage grasses are substituted for saltcedar and mesquite, Without irrigation, more water probably would remain in ground and surface supplies, but no data verifies this (9).

Vegetation along rivers and canals also traps sediments, with both positive and negative results. In areas such as the Pacific Northwest, where soil erosion is severe, streamside plantings of phreatophytes and other plants supplement older structural control methods. In other areas, sediment is trapped upstream of reservoirs, extending their useful life. However, dense growth of phreatophytes can also block channels (fig. 45), When water flow is constricted, flooding can increase.

There is less emphasis placed on eradication of phreatophytes now that the results of past attempts appear questionable and multiple-use management is more common, In fact, phreatophytes such as mesquite and rubber rabbitbrush are potential new crops in the West (ch. IX). If they are developed, what is now considered to be a waste of agricultural water could become a beneficial use.

The technologies used to manage riparian vegetation are similar to those for brush management (chs. VI and IX) but are often constrained by the need to prevent water pollution. Chemical control and the use of fire are limited, and riparian vegetation is often mechanically cleared as a result. Dropping ground water levels quickly may be a practical method of control if a simultaneous use of the water ensures that the water table remains below plant roots. Antitranspirants, nondestructive chemical methods used to slow water use, have been applied to riparian vegetation. They are costly, their application is difficult, and their long-term effects on wildlife are unknown (10).

Aquatic Plants

INTRODUCTION

A number of organisms that live in and near water can affect water conveyances. Beaver and muskrat dams may block channels, and invertebrates may clog closed irrigation pipes, but aquatic plants present the greatest problems for irrigators (table 51). Such plants interfere with water movement both mechanically and biologically by slowing the movement of irrigation water, disrupting control devices, and causing leaks in canal linings. Some may lose water to the atmosphere at rates greater than an open water surface (16).

Technologies for controlling and managing aquatic plants include preventive, mechanical, biological, and chemical methods. Preventive measures are often overlooked, These include:

- encouraging growth of adapted plants compatible with irrigation,
- decreasing sources of seeds and other propagules,
- decreasing supplies of potential plant nutrients, and
- designing an irrigation system for quick establishment of cover plants.

Mechanical controls were common before the availability of pesticides. Weeds were hand cut, raked, dredged, or chained. Biological control methods are newer; these include the use of herbivorous fish, competitive plants, and in-

Box O.—Of Beavers and Willows: Restoring Riparian Habitats in Wyoming

Some riparian habitats have suffered from mismanagement. In southwestern Wyoming, for example, about 83 percent of these communities have been lost. This resulted in decreased forage, accelerated streambank erosion, lower water quality, declining water tables, and loss of fisheries habitat.

The Rock Springs District of the Bureau of Land Management is one of the groups attempting to reverse these conditions. Healthy willows appear to be key to this process. Some riparian areas have been restored, with the cooperation of ranchers, by 1 to 3 years' rest from grazing. Forage production increased by almost 2,000 pounds per acre in one study site where grazing management was tailored to willows.

In other areas, stream conditions require that more complex technology be used. Costs for improving these areas have ranged from $3,000 to $100,000 per site when structural methods were applied. A newer approach provides building materials at low cost to a different kind of engineer: beavers. As beavers use wood and old tires to build new dams, water storage increases and streams stabilize. This sets the stage for riparian recovery as willows and other plants colonize flooded areas.

private companies also have undertaken projects to restore riparian habitats. Timberline Reclamations, Inc., for example, has provided consulting services throughout the Western States, applying both engineering and biological approaches to natural resources. According to the company, the effects sometimes have been large: restoration of a creek in Montana which had been destroyed by grazing resulted in a substantial increase in property values based solely on the improved fishery.

These technologies appear to be very effective. They are too new, however, to have long-term records.

SOURCE: Excerpted from: Bruce H. Smith, "Riparian Willow Managament: Its Problems and Potentials Within the Scope of Multiple Use on Public Lands" (Lander, *Wyo.:* University of Wyoming, Shrub Ecology Workshop, June 5-6, 1990) and "Restoration of *Riparian* Habitats Within the BLM-Rock Springs District" (Salt Lake City, Utah: Native Plants, Inc., Wildlife Habitat Rehabilitation and Reclamation Symposium, Jan. 10-11, 1983). Timberline Reclamation, Inc., Bozeman, Mont., n.d.

sects and pathogens. Chemical methods include both water and ditchbank applications of pesticides.

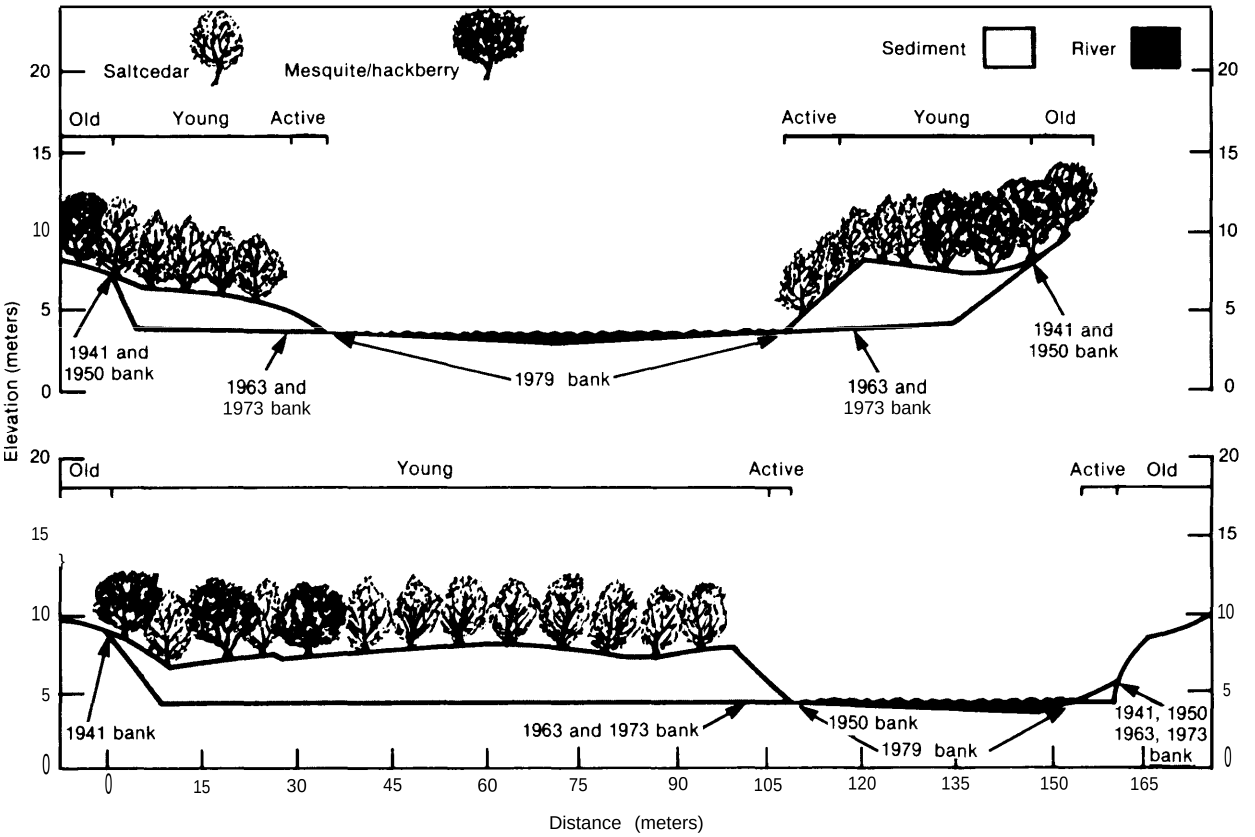
ASSESSMENT

Recent estimates indicate that aquatic plants interfere with irrigation in as many as 60 percent of all canals in the Western United States. As many as 85,000 miles of canals could be adversely affected. Some water managers believe that aquatic weed problems are becoming more severe. Both the introduction and spread of prolific, nonnative plants and the rapid eutrophication, or nutrient buildup, of surface waters contribute to these changes. These problems have a large economic impact. For example, the Bureau of Reclamation spent about $6 million annually to control aquatic plants in its water systems in the late 1970's (36).

Perhaps the most effective and least costly approach to aquatic-plant management is prevention. But if part of the prevention system breaks down, other methods are necessary.

There has been a resurgence of interest in mechanical methods as stringent restrictions on herbicides take effect and aquatic plants are recognized as a renewable resource (27). Mechanical control is especially important when: 1) herbicide residues cannot be tolerated, 2) water conditions preclude isolation of chemicals, 3) nutrient removal is important, 4) large-scale biomass removal is required before beginning an integrated-management program, or 5) biomass has economic value, Mechanical methods tend to be expensive, time-consuming, and laborious. If the plants are not removed, they can clog downstream structures. Mechanical systems are used by several municipalities,

Figure 45.—Cross Section of Brazes River, Tex., Before and After Saltcedar Invasion



SOURCE W H Blackburn R W Knight, and J L Schuster Saltcedar Influence on Sedimentation in the Brazes River *Jourrral of Soil and Walter Conservation 37(5) 301,* September/Oclober 1982, fig 3

Table 51.—Major Aquatic Weeds and Extent of Total U.S. Infestation

Plants (common/scientific names)	Present extent of infestation (acres)	Potential infestation area (acres)
Waterhyacinth *Eichornia crassipes* (Mart.) Solms.	1,000,000	9,550,000
Watermilfoil *Myriophyllum* spp.	500,000	17,450,000
Alligatorweed Alternanthera philoxeroides (Mart.) Griseb. . . .	60,000	9,850,000
Hydrilla *Hydrilla verticillata* (L. f.) Royle	50,000	4,305,000
Egeria *Egeria densa* (Planch.)	50,000	10,845,000
Waterlettuce *Pistia stratiotes* L.	3,000	9,550,000
Waterchestnut Trapa natans L.	3,000	1,050,000
Total	1,666,000	62,600,000

SOURCES US Department of Agriculture,“Report of the S E A Research Planning Conference on Aquatic Weedontrol” (Davis, C , Sept 13-15, 1977), 1978, p 50 Edward E. Terrell, *A Checklist of Names for 3,000 Vascular Plants of Economic Importance,* Agriculture Handbook No 505 (Washington, D C. U S Government Printing Office, May 1977)

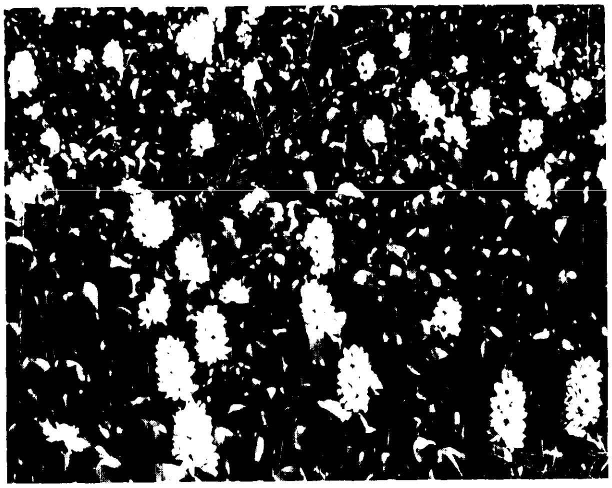


Photo credit USDA Soil Conservation Service

Waterhyacinths are important aquatic weeds in California, other warm parts of the United States, and many of the world's reservoirs and rivers

counties, lake owners' associations, State and Federal agencies, and private contractors. Despite this history, no focused data base exists on the potential for marketing products from weeds (36]. Research at a number of locations is evaluating harvesting equipment, plant processing, and the use of weeds for compost, biogas production, or animal feed.

Biological methods of pest control are generally effective, economical, and minimally detrimental to the environment. Insects are being used to control alligatorweed and there are several promising candidates for controlling waterhyacinth (21). The grass carp, a fish introduced from China, can control many types of aquatic plants, but fear persists that it could become a pest and eliminate native game fish (30). Different species of spikerush *(Eleocharis* spp,), native aquatic plants, are able to eliminate or reduce populations of aquatic weeds by a combination of competition for nutrients and space and chemical "interaction s," or allelopathy (13]. " Nonetheless, effective biological control, which is both widely available and acceptable for a large number of different species, is still rare.

Chemical control by herbicides is sometimes faster and easier than other methods. In some cases, chemicals can nearly eliminate aquatic plants and reduce problems of reinfestation. Some are selective enough to remove only those plants that are undesirable, providing a way to alter the habitat for specific purposes. But some chemical controls have serious drawbacks–e.g,, high cost, toxicity to fish, lack of specificity, toxicity to crops and livestock-or other hazards. Recent restrictions on the use of chemicals, especially in and around water, has limited the chemical controls available [table 52), other types of nonpesticidal chemicals such as plant growth regulators or dyes that darken water and shade plants are promising.

In the case of large bodies of water, single ownership is rare, and management for multiple uses makes chemical treatments of any kind difficult. Integrated weed management, which combines the best of all types of control technologies in a long-term management plan, is a promising approach under those and other conditions. However, many of the early mechanical and chemical control technologies were not intended for use in integrated weed management systems. Therefore, they are not well adapted for this purpose. New integrated-management schemes are only in early stages of development (29,36),

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*Allelopathy is the production of chemical substances by one species that inhibit the germination, growth, or life of another species.

Table 52.— Restrictions on the Use of Aquatic Herbicides

Aquatic weed	Herbicide	Rate	Restrictions
Algae (phytoplankton, filamentous, *Chara)*	Copper sulfate	2.7 lb/A-ft.	Do not use in trout waters
	Copper chelates (Cutrine Plus)[a]	0.6-1.2 gal/A-ft.	Do not use in trout waters
	Endothall (Hydrothol 191)[a]	1.1 pts/A-ft.	F = 3 days; L, D = 7 days Do not use for crop irrigation
	Simazine (Aquazine)	1-3.4 lb/A-ft.	1, L, D = 12 months
Submersed plants (coontail, watermilfoil, pondweeds such as sage, curly-leaf, leafy)	Endothall (Aquathol K)[a]	1.3 gal/A-ft.	S = 1 day; F = 3 **days; lb, D** = 7 days
	Diquat	1-2 gal/SA	S, L, I = 10 days;
	Simazine (Aquazine)	3.4-6.8 lb/A-ft.	1, L, D = 12 months
Free-floating plants (duckweed, watermeal)	Diquat	1 gal/SA	S, L, I = 10 days; D = 14 days
	Simazine (Aquazine)	3.4-6.8 lb/A-ft.	1, L, D = 12 months
Rooted-floating plants (waterlilies, spatterdock)	2, 4-D (Aquakleen)	200 lb/SA	Do not apply to waters for 1, D, dairy animals
Emersed plants (cattails, perennial grasses)	Dalapon (Dowpon + wetting agent)	15 lb/SA	Restrict spray to plant foliaqe

KEY F = fishing, I = irrigation, L == livestock, D = domestic use, SA = surface area, A-ft = acre-foot

aThese are liquid formulations which are also available as granules

bTreated water may be used for sprinkling bent grass Immediately

SOURCE Carole A Lembi, "Aquatic Weed Control—In Review, " *Weeds Today* 11(3):5, 1980, table 1

Conclusions

Technologies to develop large sources of previously unavailable surface water are limited, For example, large-scale interbasin transfers are feasible technologically but constrained by economic, legal, social, and environmental considerations, Similarly, conversion of saltwater to freshwater is very expensive and likely to be limited to municipal and industrial uses. Neither large-scale interbasin transfers nor current methods of desalination are likely to provide water for agriculture in the near term.

Aging water storage and conveyance facilities require major public and private investments to repair deterioration. This need, combined with economic, physical, social, and environmental factors, makes construction of new, large-scale storage facilities unlikely. Smaller projects, including ones on farms and ranches, continue to be built, often with State and local government or private financing or cost-sharing.

The short-term "losses" of water from storage and conveyance facilities by untimely irrigation water delivery, seepage, evaporation, and interference by plants are large. While a number of technologies have been proposed to "save" this water, few are applied widely. Their application may involve tradeoffs and the effect on the entire hydrologic cycle is often unknown.

Technologies for improving the timing of irrigation water delivery generally are promising. A wide variety of methods is being evaluated, but institutional factors may be the biggest factor limiting their adoption. High costs and low effectiveness limit application of many seepage and evaporation control technologies, especially on large lakes and reservoirs. Similar methods are economical now for use on small reservoirs or stock ponds. Because the amount of water transpired by phreatophytes and other riparian vegetation and the availability for other uses are uncertain, former eradication measures often have been replaced by multiple-use management of streamside lands. In some areas, especially the Southwest, where exotic plants have rapidly spread, control remains necessary, but the effect on the overall water balance is not known. Effective methods are available for managing aquatic plants,

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