CONJUNCTIVE USE—ADVANTAGES, CONSTRAINTS, AND EXAMPLES

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ABSTRACT: Conjunctive use of surface water and ground water can usually increase yields at lower costs than more dams and reservoirs operated separately. There are three main types of conjunctive use projects: (1) Stream diversions; (2) dam and reservoir only; and (3) total system. There are many advantages of ground-water storage compared with surface storage, and of conjunctive use compared to independent use. Physical, operational, financial, and institutional constraints may be encountered by the project proponents. Institutional issues may be the most difficult to resolve. Often, several governmental agencies may provide funds and have responsibilities for various features of conjunctive-use projects. Implementation is more difficult in countries where surface-water development has historically dominated water-supply project formulation. Court decisions in California have provided guidelines for conjunctive-use programs, especially in defining the rights of public agencies. Four areas in California that have experienced basin overdraft and increasing water demands, and where conjunctive-use operations have been implemented, are described.

INTRODUCTION

Conjunctive use of surface and ground waters can be defined as the management of surface- and ground-water resources in a coordinated operation to the end that the total yield of such a system over a period of years exceeds the sum of the yields of the separate components of the system resulting from an uncoordinated operation.

The objective of conjunctive use is to increase the yield, reliability of supply, and general efficiency of a water system by diverting water from streams or surface reservoirs for conveyance to and storage in ground-water basins for later use when surface water is not available.

TYPES OF CONJUNCTIVE-USE PROJECTS

The following are basic types of conjunctive-use projects, categorized by facilities used: (1) Stream diversions; (2) dam and reservoir only; and (3) total system (Fig. 1).

Stream Diversions

Some of the first examples of a form of conjunctive use of surface and ground waters in California were the diversions and spreading of stream flow in the channels of San Antonio Creek in the 1890s and San Gabriel River in the early 1900s east of Los Angeles (Banks et al. 1954).

Dam and Reservoir Only

In 1959, Twitchell (formerly Vaquero) Dam was completed by the U.S. Bureau of Reclamation on the Cuyama River east of the city of Santa Maria

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FIG. 1. Conjunctive Use of Surface and Ground Waters

in Santa Barbara County (Fig. 2). It is unique among Bureau of Reclamation projects because it lacks a water-supply surface-conveyance system. Storm flows stored behind the 184-ft high earthfill dam are released to percolate downstream in the natural streambed of the Santa Maria River. Of the 239,000-acre-ft reservoir storage capacity, 150,000 acre-ft are for combined water conservation and sediment storage, and the remaining 89,000 acre-ft are for flood-control reservation. The average annual yield from the water-conservation space is 24,000 acre-ft, more than enough to overcome the average annual overdraft of the Santa Marie ground-water basin of 14,000 acre-ft, estimated at the time of dam construction (Santa Maria 1955).

The project has functioned successfully since completion, with infiltration of reservoir releases in the river channel reaching rates of 650 acre-ft/day. Ground-water basin overdraft has been eliminated as has the threat of seawater intrusion. Although not claimed as a benefit in justification of the project, the quality of water now percolating along the river and replenishing the underground basin is considerably lower in dissolved salts than without the project. Historically, most of the recharge consisted of low flows of relatively high total dissolved solids with the fresher storm flows running to the ocean. Now the storm runoff is stored for release the next year.

**Total System (Dams and Aqueduct)**

In 1913, the Los Angeles Aqueduct was completed, bringing water over 200 miles from the Owens Valley just east of the Sierra Nevada to San Fernando Valley (Fig. 3). From there, the water went to direct use within the city of Los Angeles, with excess spread in basins in the valley. In 1940, the aqueduct was extended north into Mono Basin (providing a total aqueduct length of 340 miles). Later, wells in Owens Valley were added to the
city's existing Eastern Sierra surface diversion, conveyance, and storage system. The city is currently working with local agencies and environmental groups on a program of ground-water pumping in Owens Valley that will permit conjunctive use at both ends of the original aqueduct (Owens and San Fernando valleys). Lawsuits over export from Mono Basin and well pumping in Owens Valley have postponed full implementation.

**SYSTEM ANALYSIS**

To increase yield, it is essential to add more storage to the system. Adding ground-water storage to existing surface storage and conveyance facilities recognizes that most of the best dam and reservoir sites have already been developed. However, like any other water-supply project, conjunctive-use programs must pass the tests of engineering feasibility, economic justification, financial feasibility, environmental protection, and be the cheapest next increment of supply.

With existing modeling and computer capability, conjunctive-use schemes can be analyzed with respect to size and number of surface reservoirs, size of stream diversions and conduits, number of ground-water basins, and operation schedules to determine best combinations to meet program objectives. These might be satisfying water demands while maximizing yield, net farm income, or net benefits or minimizing costs, adverse environmental impacts, or power consumption. Benefits of joint/conjunctive use can be determined by comparing yields and costs of feasible surface-water and ground-water projects separately and when combined.

**ADVANTAGES OF CONJUNCTIVE USE**

Conjunctive use combines the advantages of ground-water storage with the surface-water system.

**Advantages of Ground-Water Storage**

While dams and reservoirs are needed to block and store flood flows, ground-water storage has certain advantages compared to surface storage ("Ground Water Management" 1972). Some of these follow:

1. They cost nothing to construct. However, like the dead storage in a surface reservoir, there is a cost in pumping the water out for use and a cost for maintenance of wells and pumps.
2. They do not become filled with sediment, except in replenishment areas where sedimentation may significantly curtail infiltration rates.
3. They have no evaporation losses, except in areas of shallow water table where phreatophyte losses may be high and saline residues may accumulate.
4. Except for recharge areas and well fields, they do not preempt the land surface that can be useful for other purposes.
5. They are not subject to eutrophication. They are, however, like surface reservoirs, susceptible to point and nonpoint source pollution.
6. They do not wear out if properly managed. However, indiscriminate over-development or poor practices can dewater aquifers and cause compaction of sediments, loss of storage space, land subsidence, and degradation of quality, especially in coastal aquifers subject to seawater intrusion. Remediating ground-
water quality problems can be expensive and time-consuming.
7. They do not disturb archaeological and cultural sites.
8. They do not interfere with in-stream uses, such as fisheries and rafting.

Advantages of Conjunctive Use
The following are advantages of a conjunctive-use program (Pre-Seminar 1986):

1. Increase in yield. This results from a reduction in loss from the freshwater system in the form of reduced flow to the ocean or salt sink or reduced evaporation from surface reservoirs. For example, excess water in a river flowing to the ocean is diverted and stored underground for subsequent use. Also, average storage in surface reservoirs involved in conjunctive use is usually less because of transfers to ground-water basins; therefore, reservoir spills to the ocean and surface evaporation are less.
2. Tends to offset maldistribution of runoff (too much water in some months, shortages in others).
3. Stores water in ground-water basins closer to users. This ensures a water supply in proximity to consumers in case of interruption of the surface supply.
4. Can operate with smaller surface-distribution system because of wide dispersion of wells.
5. Valuable addition to demand management (water conservation) in satisfying water needs during droughts and supply interruption.
6. Can function with smaller surface reservoirs and can defer funding and construction of more environmentally sensitive and expensive dams.
7. Can be implemented with full basins, such as the Bunker Hill Basin at San Bernardino, California. The basins are drawn down during a drought, and predrought filling with surface water is not required. Even waterlogged basins in India have been considered for conjunctive use. If basins are saline, then pumped water must be desalted or removed from area.
8. Can prevent or reduce drainage problems in some areas because storage and water levels are controlled, with wells acting as vertical drains.
9. Canal lining to decrease waterlogging can be reduced. Unlined canals can be an important source of basin recharge.
10. May provide flood-control space in reservoirs where a portion of the water-supply storage has been transferred to ground-water basins. Reduced flood damage from diverting stream flows to recharge areas is believed to be small.
11. Avoids common problem associated with separate projects, such as drainage with surface projects and overdraft with ground-water programs.

Some of the negative factors of conjunctive use are described later.

Constraints in Implementing Conjunctive-Use Program
Some constraints in implementing a conjunctive use program are as follows.

Physical and Operational Constraints
1. Supply of water for recharge of ground-water basin is inadequate.
2. Underground storage space is insufficient.
3. Infiltration and percolation rates are inadequate for basin recharge.
4. Land may not be available at affordable costs for recharge areas.
5. Existing wells are not adequate to withdraw ground water needed to meet demand during dry periods.
6. New surface reservoirs or change in operation of existing reservoirs upstream from stream-diversion point or upstream from surface reservoirs used in conjunctive-use program could reduce quantity or degrade quality of water available for program.
7. Change in land use upstream could alter amount, regimen, and quality of water available. For example, urban development could increase water diversion and use in area, decrease natural percolation, and increase runoff peaks.
8. Water rights and uses downstream from point of diversion from a stream used to recharge a ground-water basin must be protected. Also, natural stream recharge to downstream ground-water basins must be maintained.
9. Ground-water levels in basins where surface water is to be stored as part of a conjunctive-use program should not be lowered to a point that would cause seawater intrusion in coastal areas, invasion of connate brines and other poorer quality water, and land subsidence in basins with clay and silt formations. Impact of lowering ground-water levels below bottoms of existing wells must be mitigated.
10. Ground-water levels should not be allowed to rise as part of recharge and storage activities to an elevation that would cause flooding of low-lying agricultural areas and building basements and inundation of the lower portions of refuse dumps and sanitary landfills. Without proper control, containment, or cleanup measures, ground-water levels should not be allowed to rise and dissolve harmful chemicals in the vadose zone. Also, levels should not rise sufficiently to cause rejection of percolation of storm runoff and consequent reduction in basin yield from natural recharge.
11. The quantity of surface water stored in ground-water basins as part of a program may be restricted if it is inferior in quality to that of the native ground water, particularly in basins with adverse salt balances.
12. Conjunctive use may be restricted by on-going programs of local and regional agencies with respect to available underground storage space, artificial recharge facilities, and well sites.
13. Lack of dependable electrical power for operating wells could cause crop losses and urban rationing during shortage of surface supplies. This applies mostly in developing countries.
14. A subsequent drought may occur before basin can be refilled following earlier surface-water shortage. Periods between wet and dry periods may be seasons or many years.

Financial and Institutional Constraints
1. Program requires users to switch between surface and ground-water supplies. A large disparity in prices of water from these two sources would discourage the use of the more expensive water.
2. Use of ground-water basins to implement a conjunctive-use program may not receive favorable consideration from public officials who suffer from the “edifice mentality” favoring “bigger and better” dams.
3. Project funds may come from different sources. Public funds are usually used for surface facilities, while individual users may be forced to finance ground-water facilities, especially in rural areas.
4. Absence of skilled hydrogeologists and geohydrologists on a study team...
seeking additional water supplies may result in a more feasible ground-water development being overlooked in favor of a surface-water-project solution.

5. Lack of agreement on respective roles and the resulting inadequate coordination and cooperation among governmental agencies may seriously hamper the implementation of conjunctive-use projects. In most countries, the surface-water infrastructure, ground water, and agriculture (large user of water) are under the jurisdiction of different departments/ministries. Also, funding, design and construction, and operation may be the responsibility of different agencies.

Other Institutional Considerations

An institutional issue that has arisen in California is the question of local versus regional versus state ground-water management. Local agencies have traditionally constructed and operated water projects to develop and deliver water to meet local needs. This has included the diversion of storm runoff and delivery of imported water for artificial recharge. However, in recent years in southern California, it has become apparent that certain increased efficiencies and advantages could be achieved if several local agencies jointly, or a regional water district, managed the water resources. One reason is that ground-water basin boundaries seldom coincide with political boundaries of water districts. Also, regional water districts often have the facilities, trained personnel, and financial resources to implement regional management.

For many years, the question of the state transporting northern California to southern California during “wet” years via the State Water Project for storage underground in lieu of surface reservoirs and retaining title to the water stored underground has been discussed (“A Ground” 1979; “California Water” 1987) (Fig. 3). Under this concept, during droughts in northern California, the state would reduce its deliveries of aqueduct water to its customers in southern California and release state water stored underground. In this manner, the yield of the State Water Project would be increased because the state would maintain control and title of the water it placed in underground storage, and it would become part of the firm supply of the project.

There has been some concern expressed by regional water districts over this concept. They may prefer to purchase the water from the state and then conduct their own ground-water storage programs. The net effect of meeting water demands from ground-water storage during periods of drought would be the same whether the state maintained title to the water or merely sold the water to local agencies to store. However, the water would not become part of the state firm yield unless local agencies holding contracts with the state amended their contracts agreeing to reduce their requests from State Water Project surface reservoirs during a drought by the amount previously placed in underground storage.

The agency wishing to undertake a conjunctive-use program should have certain powers. The authority to condemn property for project facilities and levy an ad valorem tax to defray administration costs and pay interest and principal on any outstanding bonds is essential. An assessment on well pumping to pay operating and maintenance costs and any purchase of replenishment water and to control extractions is probably needed. The pumping pattern in the basin can be controlled by varying the amount of the pump assessment.

LEGAL ASPECTS

The following legal questions have been raised regarding conjunctive-use programs: (1) Who owns the water after it is spread or injected and placed
in storage; (2) who takes the loss for increase in subsurface outflows as a result of artificial recharge; (3) who benefits from higher ground-water levels and lower pumping costs as a result of artificial recharge; (4) who is responsible if raised ground-water levels cause damages to farms and structures; and (5) how are the costs and benefits to be allocated among participants and beneficiaries.

Fortunately, we are obtaining answers to some of these questions. In California, two court decisions have provided guidance to those involved in ground-water management. In 1975, the State Supreme Court in *City of Los Angeles v. the City of San Fernando, et al.* and, in 1974, the First Appellate District Court in *Niles Sand and Gravel Company, Inc. v. Alameda County Water District*, recognized that public agencies have the following rights: (1) store water in ground-water basins; (2) protect stored water from expropriation; and (3) recapture the stored water. These findings are essential to the success of any conjunctive-use project by public agencies who normally own little of the land overlying ground-water basins.

Another question in California (where the state does not administer ground-water rights as it does surface-water rights) is whether a court adjudication of individual ground-water rights is a necessary precedent to a recharge-storage-retrieval program. Some claim an equitable allocation of the natural safe yield of the basin can be made only if the water rights of the individuals are known. A local management water plan, or physical solution, is normally developed by the parties to the lawsuit as part of the adjudication. This permits controlling pumping of the natural safe yield, while public agencies are free to pursue a conjunctive-use operation in the same basin separate from, but coordinated with, the local program.

On the other hand, some areas, like Orange County in California, prefer the utility concept to adjudication. In this arrangement, the water needs of all users are satisfied without consideration of quantity or date of past extractions. Such areas claim that lawsuits are expensive, take years, and produce no more water. Under the utility approach, funds for replenishment (recharge) water are secured from an assessment on well pumping, which also has an inhibiting effect upon excessive extractions.

**CASE HISTORIES**

Four areas in California (Fig. 4) that have experienced ground-water basin overdraft and implemented a form of conjunctive-use program are described below. There are some differences in the manner in which the residents of the areas have responded to the overdraft problem. In all cases, it has been necessary to import water and use it conjunctively with local ground water.

**Santa Clara Valley**

*Setting*

Santa Clara Valley is situated just south of San Francisco Bay and covers 500 sq mi. The average annual precipitation is about 13 in. The ground-water basin consists of a large pressure or confined zone surrounded on three sides by an unconfined zone. Water-bearing sediments extend to a depth of 1,000 ft.
History of Land and Water Use

Prior to World War II, Santa Clara Valley was largely an agricultural area, consisting mostly of irrigated orchards, grapes, and truck and field crops. Urbanization occurred after the war, and in recent years, the expansion in high technology industry has resulted in the area being called Silicon Valley. The population is now about 1,600,000.

Historically, ground-water was the principal source of water supply, with many flowing wells. In 1949, the California State Department of Water Resources estimated the overdraft was 52,000 acre-ft/yr. Observations of ground-water levels indicate this value increased after this date.

In this valley, as in other locations, there has been a shift in resource utilization and responsibility from the private sector to public agencies. Initially, the overdraft was caused by agricultural water users. Later, public agencies serving urban users increased the overdraft and were responsible for financing corrective measures.

Adverse Effects of Overdraft

Ground-water pumping in excess of replenishment caused a loss of arte-
sian well flow and lower ground-water levels. Levels dropped 120 ft since 1910, with most of this occurring before 1950. Declining ground-water levels caused an increase in pumping lifts and costs because of the additional energy required to lift the water. In some instances, it was necessary to deepen existing wells, and new wells were constructed deeper because of the overdraft. The ground-water overdraft caused land subsidence. The point of maximum land-surface decline was near San Jose, where a drop of 13 ft occurred from 1910 to 1970. Further, the overdraft caused deterioration of the ground-water quality as a result of seawater intrusion and the invasion of connate brines from surrounding areas. Seawater came from the southern portion of San Francisco Bay.

**Conjunctive-Use Programs**

The first response in most areas to some type of water problem is the creation of a water association to provide a forum for discussion of possible solutions to the problem. In this area, the Santa Clara Valley Water Conservation District was created in 1929 for just such a purpose. It was subsequently merged with the Santa Clara Flood Control and Water District in 1968. The conservation district had constructed 10 local conservation dams by 1955 to store floodwaters for subsequent release to ground-water recharge facilities.

It soon became evident that local water resources were fully developed and an imported supply was required. Accordingly, in 1961, the County Flood Control and Water District signed a contract with the State Department of Water Resources for up to 100,000 acre-ft/yr of water from the State Water Project. In 1965, water from the project was first received and spread in basins. In 1967, state water was first treated and delivered directly. The local district also has arranged for the importation of water from the Federal Central Valley Project through Pacheco Pass Aqueduct. Delivery of this water commenced in 1987.

It became obvious that, in addition to the importation of water and the full use of local supplies, some type of ground-water pumping control would be necessary. Adjudication of ground-water rights was rejected as a solution. Instead, ground-water zones were created and a pump tax levied, which varied from one zone to another on the basis of the cost of alternative supplies. In the main portion of the Santa Clara Valley, the pump tax in 1989 was $100/acre-ft for the extraction of ground water for municipal and industrial use and $25/acre-ft for agricultural use.

The management plan now being implemented provides a utility approach where all water from the various sources is priced the same with surcharges assessed based on benefits received. To halt seawater intrusion, an experimental seawater intrusion barrier was created using injection wells and treated wastewater.

**Current Conditions**

Ground-water levels in the Santa Clara Valley have stabilized at about 30 ft above historic lows. Land subsidence has essentially ceased. Intrusion of saline water was minor, existing only in the shallow, tight aquifer. The seawater intrusion barrier has been discontinued.

**Outlook**

The full yield of the State Water Project of 4,230,000 acre-ft/yr needs to
be developed to permit increased deliveries of imported water to the Santa Clara Valley for recharge of ground-water basins and direct use. An improved method of moving water across the Sacramento-San Joaquin Delta would not only increase the yield of the State Water Project but would improve its water quality.

Coastal Plain of Los Angeles County

Setting

The coastal plain of Los Angeles County is located southwest of downtown Los Angeles and encompasses about 420 sq mi. The average annual precipitation is about 15 in. Ground water is obtained from several confined aquifers at various depths and from an unconfined area (forebay) in the northeastern part of the plain. The plain is composed of the West Coast Basin and the Central Basin.

History of Land and Water Use

Before World War II, a mixture of agriculture, oil production and refining facilities, and isolated communities existed on the coastal plain. The chief crops were beans, truck, and cut flowers. Ground water was the principal source of water.

After World War II, the area urbanized rapidly, with imported Colorado River water from the Metropolitan Water District of Southern California (MWDSC) and ground water from overdrafted aquifers used to meet the increasing demands. The population now exceeds 3,000,000. Accumulative overdraft in the coastal plain in the 1940s was estimated to be about 1,000,000 acre-ft.

Adverse Effects of Overdraft

As a result of overpumping, ground-water levels dropped to more than 100 ft below sea level in the 1940s. Pumping costs increased, and it was necessary to deepen some wells. Seawater intrusion occurred along the coast of Santa Monica Bay, and many wells were abandoned.

Conjunctive-Use Programs

Because of declining ground-water levels and seawater intrusion, the West Basin Water Association was created in 1946 for the purpose of developing solutions to the overdraft. In 1950, the Central Basin Water Association was created. To permit levying an ad valorem tax to raise funds to purchase imported water for artificial recharge and to permit direct deliveries of imported water to purveyors, two municipal water districts were created: in the West Basin in 1947 and in the Central Basin in 1952.

Local water interests in the Coastal Plain of Los Angeles County concluded it was necessary to adjudicate ground-water rights to allocate equitably the ground water supply among pumpers. Adjudication was completed in the West Coast Basin in 1961 and followed a year later in the Central Basin. The court decree restricted ground-water extractions to 290,000 acre-ft/yr and appointed the State Department of Water Resources as water master.

The Central and West Basin Water Replenishment District was created in 1959 to manage more fully the coastal plain, including the purchase of im-
ported water for artificial recharge and operation and maintenance of spreading basins and seawater intrusion barrier facilities. It was the first and is still the only replenishment district created under laws of the state of California. The replenishment district levied a pump tax to obtain funds to purchase supplemental water. This shifted the costs from property owners to the pumpers. The pump tax in 1988–89 was $61/acre-ft.

To prevent seawater intrusion from Santa Monica Bay, an experimental barrier was constructed in the mid-1950s using injection wells and imported water. The barrier was designed, constructed, and operated by the Los Angeles County Flood Control District with state funds. Subsequently, a longer, permanent barrier was completed at local expense.

About 300,000 acre-ft/yr of water from the MWDSC is being used in the coastal plain. The imported water is a mix of Colorado River water and State Water Project water from northern California. It is used for direct use, spreading in the forebay or unconfined zone, and well injection at the seawater intrusion barrier. In addition to storm flows and imported water, reclaimed wastewater is spread in the forebay.

Current Conditions

Seawater intrusion has been controlled as a result of operation of the barrier. Further, ground-water levels have been raised to reduce pumping costs and expenses of operating the barrier.

Outlook

Maintaining a conjunctive-use program and stability within the coastal plain ground-water basin depends upon an assured imported supply. This, in turn, requires firming up the yield of the State Water Project, which provides the major part of this supply.

Orange County Coastal Plain

Setting

The coastal plain of Orange County, southeast of Los Angeles, covers most of the county and encompasses about 300 sq mi. The average annual precipitation is about 13 in. The Santa Ana River traverses the area and contributes about 50,000 acre-ft/yr to the ground-water supply through deep percolation. Ground water is obtained from several confined aquifers at various depths and from the forebay in the northeastern part of the plain.

History of Land and Water Use

The coastal plain consisted of irrigated agriculture and scattered communities before World War II. Major crops were citrus and truck. After 1945, the area rapidly urbanized, with the population increasing more than 10%/yr and assessed valuation increasing at the rate of $200,000,000/yr. The population in the county in 1988 was 2,200,000. The accumulated overdraft was estimated in 1956 to be 700,000 acre-ft.

Adverse Effects of Overdraft

Overdraft caused a decline in ground-water levels until they were 10 ft below sea level in the forebay and as much as 23 ft below sea level in the pressure area. This caused well construction and pumping costs to increase.
Seawater intrusion occurred at two locations along the coast where geologic conditions permitted.

**Conjunctive-Use Programs**

Because of rapidly dropping ground-water levels, the Orange County Water District was created by the state legislature in 1933. Subsequently, there were many amendments to the original district act to provide greater powers to manage the basin.

Approximately 100,000 acre-ft/yr of imported water has been spread in the forebay. Currently, this is about an equal mix of Colorado River water and State Water Project water. Seawater intrusion barriers have been constructed using both injection and extraction wells. Some of the injection water at the main barrier is wastewater that has received tertiary treatment by the Orange County Water District.

To secure funds for imported water and other expenses, a pumping assessment was levied uniformly among well users and, in 1988–89, was $45/acre-ft. An additional pump tax (basin equity assessment) is applied to some pumpers to control the ground-water pumping pattern. The Municipal Water District of Orange County, a member agency of MWDSC, has expanded its surface distribution of imported water. Similarly to Santa Clara County, the ground-water rights of the Orange County coastal plain have not been adjudicated. The local water interests have adopted the water-utility concept instead, in which a water supply is guaranteed and water from all sources is priced the same.

**Current Conditions**

As a result of the physical and policy responses described earlier, seawater intrusion has been controlled, and ground-water levels have been stabilized.

**Outlook**

As in the Santa Clara Valley and the coastal plain of Los Angeles County, the success of conjunctive-use programs in the Orange County coastal plain depends on firming up the yield of the State Water Project to provide a reliable imported supply.

**Kern County (within San Joaquin Valley)**

**Setting**

The portion of Kern County located in the southern part of the San Joaquin Valley covers 6,840 sq mi. The average annual precipitation is about 7 in. The area is traversed by the Kern River, which is the major source of replenishment to the ground-water basin. The thickness of water-bearing sediments is as much as 4,500 ft. There is an upper unconfined aquifer and a lower confined member, which is the principal aquifer. About 20,000,000 acre-ft of water are in storage within the top 200 ft of saturated sediments. The dewatered storage capacity is 11,000,000 acre-ft.

**History of Land and Water Use**

Kern County remains primarily an agricultural area. Unlike the other areas discussed, it has not become an urban complex. Irrigation commenced with diversions from the Kern River in the early 1900s. After development of
deep-well drilling and pumping techniques in the 1940s, ground water became the main source of supply.

In 1988, the population in the San Joaquin Valley portion of the county had reached 412,000. Irrigated acreage in that year was about 900,000 acres, including 780,000 overlying ground water. The value of agricultural products was $1,270,000,000 in 1980.

The area irrigated in Kern County has increased constantly since World War II despite the overdraft. The overdraft was estimated in 1950 to be 500,000 acre-ft/yr. In 1987, because of increased artificial recharge operations, it had been reduced to 400,000 acre-ft/yr.

**Adverse Effects of Overdraft**

The overdraft has caused ground-water levels to drop about 200 ft. This has caused an increase in pumping and well construction costs. As in the Santa Clara Valley, overdraft has caused land subsidence, amounting to as much as 10 ft during 1925–82. Overdraft also has caused water-quality degradation. This has occurred as a result of water of inferior quality moving from the western part of the county to the pumping trough.

**Conjunctive-Use Programs**

It became obvious in the 1930s that the agricultural economy could not be supported solely by local water resources, and part of the area was included in the service area of the federal Central Valley Project. Water from the project was received through the Friant-Kern Canal starting in 1955.

To provide a public entity that could contract for water from the State Water Project, the Kern County Water Agency (KCWA) was formed in 1961. Subsequently, 15 water districts were created as members of KCWA. The state signed a contract with KCWA in 1963 for the delivery of up to 1,100,000 acre-ft/yr of state water plus any surplus water that might be available. State water was first delivered in 1968. In order to provide an institutional mechanism of apportioning costs and benefits, Improvement District No. 4 (Bakersfield) was created in 1972.

To help alleviate the overdraft, water has been spread for many years on the Kern River fan. Artificial recharge also occurred in unlined canals. In 1987, a dry year, amounts of artificial recharge were as follows: 127,200 acre-ft in the Kern River; 56,100 acre-ft from the State Water Project; 6,900 acre-ft from the Central Valley Project; 27,200 acre-ft from minor streams, and 9,700 acre-ft of treated wastewater, providing a total of 227,100 acre-ft.

An innovative banking concept was initiated in 1982, which supplemented the overdraft correction program. The advantage of the banking program is that water in storage belongs to KCWA or is sold to an agency that is a member of KCWA. The water in storage can be used during droughts when surface water is not available from the import projects.

To provide a source of revenue and to offset special benefits received, a pump tax was initiated in 1975 in Improvement District No. 4. Currently, the tax is $10/acre-ft for water used for agriculture and $20/acre-ft for all other uses. The funds from the pump tax are used to offset costs of local transportation of state water, treatment of water delivered directly to the users, and for artificial recharge. A pump tax is not required in other areas to discourage ground-water pumping because ground water costs exceed the
TABLE 1. Summary of Selected Conjunctive-Use Programs in California

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<th>Item (1)</th>
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<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Land subsidence</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Adjudication of water rights</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Imported water</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Spreading</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Well injection</td>
<td>Test seawater intrusion barrier</td>
<td>For seawater intrusion barrier</td>
<td>For seawater intrusion barrier</td>
<td>No</td>
</tr>
<tr>
<td>In-lieu recharge</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Potential</td>
</tr>
<tr>
<td>Local management</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Regional management</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>State management</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Potential</td>
</tr>
</tbody>
</table>

cost of surface-water supplies. Another mechanism to equate costs with benefits is a zone-of-benefit charge (ad valorem tax) levied by KCWA against those who do not receive or pay for state water but benefit from higher ground-water levels caused by those who do.

Current Conditions

The accumulative overdraft in Kern County is still large but decreasing. The KCWA is continuing to spread Kern River water and state water when it is available and not used directly for irrigation. In recent years, the State Department of Water Resources completed feasibility and environmental studies and purchased about 24,000 acres of land on the Kern River fan for the purpose of a state conjunctive-use program ("Final Environmental" 1986). The project, called the Kern Water Bank, will have two functions: to increase firm yield of the State Water Project and to increase the amount of local water that can be captured and stored underground. The initial direct basin recharge phase will increase the State Water Project yield by about 140,000 acre-ft/yr, with a second in lieu recharge phase increasing the yield further. The second phase includes direct delivery of state water and a decrease in ground-water pumping.

Outlook

The success of conjunctive-use programs and the magnitude of future overdraft depends on several factors: (1) Availability of surplus water from the State Water Project; (2) dependable supplies from the State Water Project; (3) whether new lands go under irrigation; and (4) additional supplies from the Central Valley Project. Local water interests report they will continue to avoid adjudication of water rights. They feel adjudication would be an expensive and time-consuming process.

In addition to overdraft, there is another problem that worsens each year: the adverse salt balance in the county. Importation of water brings not only water but salts. There is no natural outlet to the basin so salts are accumu-
TABLE 2. Conversion Factors

<table>
<thead>
<tr>
<th>Quantity (1)</th>
<th>To convert from metric unit (2)</th>
<th>To customary unit (3)</th>
<th>Multiply metric unit by (4)</th>
<th>To convert to metric unit multiply customary unit by (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>millimeters (mm)</td>
<td>inches (in.)</td>
<td>0.03937</td>
<td>25.4</td>
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<tr>
<td></td>
<td>centimeters (cm)</td>
<td>inches (in.)</td>
<td>0.3937</td>
<td>2.54</td>
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<tr>
<td></td>
<td>meters (m)</td>
<td>feet (ft)</td>
<td>3.2808</td>
<td>0.3048</td>
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<td></td>
<td>kilometers (km)</td>
<td>miles (mi)</td>
<td>0.62139</td>
<td>1.093</td>
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<td>Area</td>
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<td>square inches (sq in.)</td>
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<td>square meters (m²)</td>
<td>square feet (sq ft)</td>
<td>10.764</td>
<td>0.092903</td>
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<td></td>
<td>hectares (ha)</td>
<td>acres (acre)</td>
<td>2.4710</td>
<td>0.40469</td>
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<td>square kilometers (km²)</td>
<td>square miles (sq mi)</td>
<td>0.3861</td>
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<td>Volume</td>
<td>liters (L)</td>
<td>gallons (gal)</td>
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<td>3.7854</td>
</tr>
<tr>
<td></td>
<td>megaliters</td>
<td>million gallons (10⁶ gal)</td>
<td>0.26417</td>
<td>3.7854</td>
</tr>
<tr>
<td></td>
<td>cubic meters (m³)</td>
<td>cubic feet (cu ft)</td>
<td>35.315</td>
<td>0.028317</td>
</tr>
<tr>
<td></td>
<td>cubic meters (m³)</td>
<td>cubic yards (cu yd)</td>
<td>1.308</td>
<td>0.76455</td>
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<tr>
<td></td>
<td>cubic dekameters (dam³)</td>
<td>acre-feet (acre-ft)</td>
<td>0.8107</td>
<td>1.2335</td>
</tr>
<tr>
<td>Flow</td>
<td>cubic meters per second (m³/s)</td>
<td>cubic feet per second (cu ft/sec)</td>
<td>35.315</td>
<td>0.028317</td>
</tr>
<tr>
<td></td>
<td>liters per minute (L/min)</td>
<td>gallons per minute (gpm)</td>
<td>0.26417</td>
<td>3.7854</td>
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<td></td>
<td>liters per day (L/day)</td>
<td>gallons per day (gpd)</td>
<td>0.26417</td>
<td>3.7854</td>
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<tr>
<td></td>
<td>megaliters per day (ML/day)</td>
<td>million gallons per day (mgd)</td>
<td>0.26417</td>
<td>3.7854</td>
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<tr>
<td></td>
<td>cubic dekameters per day (dam³/day)</td>
<td>acre-feet per day (acre-ft/day)</td>
<td>0.8107</td>
<td>1.2335</td>
</tr>
</tbody>
</table>

Available alternative water supplies, used separately or conjunctively, can improve water-service reliability and flexibility and provide increased control of quantity, quality, and costs. Conjunctive use can increase yields at lower costs than more dams and reservoirs and furnish positive ancillary impacts, such as a stored supply near demand centers, increased drainage, and long-term ground-water quality improvement. The institutional issues involved in implementing a conjunctive-use program are often more difficult to resolve than the physical and operational constraints.

CONCLUSIONS

Availability of alternative water supplies, used separately or conjunctively, can improve water-service reliability and flexibility and provide increased control of quantity, quality, and costs. Conjunctive use can increase yields at lower costs than more dams and reservoirs and furnish positive ancillary impacts, such as a stored supply near demand centers, increased drainage, and long-term ground-water quality improvement. The institutional issues involved in implementing a conjunctive-use program are often more difficult to resolve than the physical and operational constraints.

APPENDIX. REFERENCES

