EFFICIENT WATER USE IN CALIFORNIA: GROUNDWATER USE AND MANAGEMENT

PREPARED IN PART FOR THE CALIFORNIA STATE ASSEMBLY RULES COMMITTEE AND IN PART UNDER A GRANT FROM THE ROCKEFELLER FOUNDATION

DAVID L. JAQUETTE AND NANCY Y. MOORE
WITH THE ASSISTANCE OF ALBERT J. LIPSON

R-2387/1-CSA/RF
NOVEMBER 1978

Rand
SANTA MONICA, CA. 90406

This research was supported by Contract No. LCB 15739 with the California State Assembly Rules Committee and Grant No. RF76077 from the Rockefeller Foundation.

Library of Congress Cataloging in Publication Data

Main entry under title:

Efficient water use in California.

([Report] - Rand Corporation; R-2387/1-CSA/RF)
CONTENTS: [1.] Jaquette, D. L. and Moore, N. Y. Groundwater use and management.--[etc.]--[7] Moore, N. Y., Graubard, M. H. and Shishko, R. Water supply planning.
1. Water-supply--California. 2. Water use--California. I. Jaquette, David L. II. California. Legislature. Assembly. III. Rockefeller Foundation. IV. Series: Rand Corporation. Rand report ; R-2387/1-CSA/RF.
AS36.R3 R-2387/1 [TD224.C3] 081s [333.9'1'009794]
ISBN 0-8330-0158-2 79-21313

Published by The Rand Corporation

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PREFACE

This report is one of seven documenting the findings of Rand's study of water use efficiency in California. The study was commissioned by the California State Assembly in the autumn of 1976 and was supported in part by a grant from the Rockefeller Foundation. Its purpose was to examine current water use efficiency and to suggest ways to improve it. The focus of the study was deliberately set statewide, although particular areas of the state receive attention in some reports. It was not designed to solve problems that have drawn recent attention, such as the 1976-77 drought and its exacerbation of the groundwater overdraft problem in the San Joaquin Valley. Rather, the focus has been widened across a broad expanse of time and across all sources and uses of water. It is a study of long-range water use problems and solutions, rather than of immediately perceived short-term problems.

The present report examines the opportunities for improving efficiency in the entire water system by management of groundwater basins. A companion report, R-2387/2-CSA/RF, discusses groundwater management in Southern California. The companion reports are:

> *Efficient Water Use in California: Executive Summary,* by Charles E. Phelps, Morlie H. Graubard, David L. Jaquette, Albert J. Lipson, Nancy Y. Moore, Robert Shishko, and Bruce Wetzel, R-2385-CSA/RF, November 1978.
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> *Efficient Water Use in California: Water Rights, Water Districts, and Water Transfers,* by Charles E. Phelps, Nancy Y. Moore, and Morlie H. Graubard, R-2386-CSA/RF, November 1978.
>
> *Efficient Water Use in California: The Evolution of Groundwater Management in Southern California,* by Albert J. Lipson, R-2387/2-CSA/RF, November 1978.
>
> *Efficient Water Use in California: Economic Modeling of Groundwater Development with Applications to Groundwater Management,* by Bruce Wetzel, R-2388-CSA/RF, November 1978.
>
> *Efficient Water Use in California: Conjunctive Management of Ground and Surface Reservoirs,* by David L. Jaquette, R-2389-CSA/RF, November 1978.
>
> *Efficient Water Use in California: Water Supply Planning,* by Nancy Y. Moore, Morlie H. Graubard, and Robert Shishko, R-2390-CSA/RF, November 1978.

These reports should be of interest to those concerned with California water policy and its implications for other states and the nation.

SUMMARY

In this report, we review the current status of groundwater as a component of water supply in the State of California. Groundwater, which supplies on average 40 percent of the state's fresh water, is clearly a significant asset. Since it can be stored for long periods, groundwater is particularly valuable in smoothing the long-term year-to-year variation in surface water supply. Recent evidence of this value occurred during the 1976-1977 drought. California's agricultural production remained surprisingly strong, in large part because of the ability to increase extraction of groundwater.

Management of most groundwater basins is essential to achieving efficiency in water use in the state. Unmanaged basins suffer inequity and inefficiency because of the "common pool" resource problem. Individuals pumping groundwater impose current and future costs on other pumpers primarily because they increase pumping lifts. An individual tends to pump excessive amounts of groundwater because his marginal costs do not reflect the societal costs—the negative side effects—of his pumping. Careful management of pumping through pump taxes or quotas establishing groundwater rights is the only way to correct this problem.

Integrated management of groundwater reservoirs with California's surface water system also enhances efficient water use. Under conjunctive use, water is stored in underground reservoirs during rainy years and extracted in dry years.

Groundwater basin management should include a management plan and a management entity to negotiate for terms and rents of storage in the basin, to sell groundwater, to redistribute profits or taxes, as well as to correct the common pool inequities and inefficiency.

If statewide efficiency is to be achieved, water must become more transactable and transferable in the future. Also, increasingly accurate long-range weather forecasting, when integrated into a conjunctive management program, enhances the system's water output. Both these factors improve the opportunities for increased water supply and profit to all water users through conjunctive management.

We conclude that groundwater must be managed in order to achieve efficiency. One means to accomplish this would be for the state to provide incentives and then guidelines for developing a basin management plan. We therefore suggest that the state provide for the establishment of locally run groundwater basin management institutions (the size to be determined by basin geology) and give these institutions the means to develop and then implement an approved management plan.

Specific conclusions of the study are:

1. Groundwater control will be most effective at the basin level, or at least in subbasins where nearly all of the benefits of groundwater management are realized. Less comprehensive attempts at groundwater management cannot be fully successful.
2. Groundwater management at the basin level is desirable. Preliminary analysis shows that benefits substantially exceed the costs of management. The annual benefits from groundwater management of the Tulare/

San Joaquin/Delta-Central Sierra region alone could be as high as $45 million to $180 million. However, in each basin, it must be established that the costs of achieving and sustaining groundwater control do not exceed benefits obtained. A benefit-cost test is prerequisite before basin control is inaugurated.

3. Existing groundwater control activities in California only rarely monitor, let alone control, rates of extraction. The full benefits of basin management cannot be achieved without direct or indirect control of extraction rates. Thus, existing management plans do not in general achieve the full benefits of basin control. In some Southern California groundwater basins extractions are directly controlled under court supervision as part of a legal settlement. And, in some areas of the state pump taxes are used, which lead to indirect controls over extractions.[1]
4. Although many existing groundwater control plans have depended upon surface imports to sustain all historical water using activities, the benefits from groundwater management need not depend upon using surface imports to offset reductions in groundwater pumping. Mechanisms can be established to compensate water users who reduce or eliminate their water consumption as a part of groundwater management plans, and such compensation is likely to be important in achieving political support for basin management.
5. The state should assist groundwater management formation by establishing boundaries of groundwater basins within which management plans can be established.
6. Local control of groundwater extraction, rather than centralized state control, is most desirable for California, for both economic and political reasons.
7. The state has an interest in groundwater control arising in part because of benefits from more enhanced conjunctive use. Possible delay or elimination of surface reservoir construction is one example. Optimal conjunctive use of surface and groundwater cannot be achieved without basin management. To further stimulate local management, the state should have the power to undertake development of a plan if benefits exceed costs and if local entities fail to act within a reasonable time. State action could be justified to promote the constitutional mandate that water be put to beneficial use. Whether the state has a constitutional mandate to require groundwater management, or to undertake it where local management is absent, is an issue for legislative determination.
8. The state should increase its collection and distribution of data on groundwater basin hydrology. Basin management cannot proceed optimally without such data.
9. The state should modify its own water pricing policies in the State Water Project so as to avoid inappropriate subsidies to water users. This policy alone should enhance local interest in achieving groundwater management.
10. A general groundwater basin management act should be established with flexible powers to control and monitor extractions and to provide other tools necessary for local basin management.

[1] Pump taxes have been instituted primarily to raise funds to purchase replenishment water.

11. The state should establish mechanisms to quantify overlying pumping rights and to facilitate their being traded or sold.

Today several of California's groundwater basins are managed. Unfortunately, inefficiencies arise from the actual operating practices of these basins. These inefficiencies can and should be corrected. In this report we review the current role of institutions that actually manage groundwater basins throughout the state.[2]

We were not able to study fully the costs and benefits of the various management alternatives. Clearly in locations where the costs of management exceed the benefits, no management is the efficient solution. Guidelines could be established to allow a basin plan to include the option of no management if costs are demonstrated to exceed benefits.

A variety of tools exist to enforce management. Pump taxes and quotas to establish tradable groundwater rights all have the ability to achieve efficiency. Economic redistributional effects vary considerably among management plans. The equity aspect of control of groundwater basins is socially and politically important. We hesitate to recommend a particular management tool or particular combinations. The actual combination of tools can be selected basin by basin.

[2] A companion report presents an in-depth study of groundwater basin management in the southern part of the state. See Albert J. Lipson, *Efficient Water Use in California: The Evolution of Groundwater Management in Southern California*, The Rand Corporation, R-2387/2-CSA/RF, November 1978.

ACKNOWLEDGMENTS

We wish to thank the many water experts we talked with throughout the state, at the Department of Water Resources and the Bureau of Reclamation, and in the local water agencies. Project leader Charles Phelps helped revise this report and made major contributions to the discussion of the policy implications contained in Sec. IV. We also wish to thank James C. DeHaven and Richard J. Hillestad, who provided useful and thought-provoking reviews of an early draft.

CONTENTS

I. INTRODUCTION

Why are so many of California's groundwater management problems unresolved? What are the physical, legal, and economic constraints on efficient management of groundwater resources? What are the incentives, if any, for management? And what are the existing levels of management and cooperation among pumpers? This report, which in part summarizes other reports from Rand's study of efficiency of water use in California, attempts to answer these fundamental questions relating to groundwater management.

In an attempt to answer the above questions, we surveyed existing literature on groundwater physics, economics, laws, and statistics. We also reviewed federal and state commission findings and interviewed federal and state water officials and representatives from a selected set of over 50 water agencies. Last, we incorporated the findings and conclusions of other reports from Rand's California Water Study.

California's water system managers and planners have found that the state's groundwater is extremely important for two reasons. First, groundwater provides approximately 40 percent of California's water supply. Second, during periods of drought while surface supplies diminish, groundwater extractions can readily be increased to maintain the needed supply. In fact, the recent drought of 1977 proved the importance of groundwater to the state's economy.

California is now faced with the decision of meeting future water needs through demand suppression (water conservation), supply expansion (reservoir construction and waste water reclamation), or improved management of existing supplies (conjunctive use of ground and surface waters, water transactions, and altered pricing policies). This and companion reports show how the state can improve water use efficiency and help meet future water needs through statewide groundwater management.

This report surveys present groundwater use and management in California. In addition to reviewing the physical aspects of groundwater supplies and current groundwater use, we discuss the legal, political, economic, and institutional frameworks that shape current groundwater management and offer potential barriers to efficient use of the resource. Since groundwater use is strongly influenced by water rights, both surface and underground, we also summarize California's water law particularly as it relates to surface and groundwater use.

Determination of groundwater flows and water levels requires a sophisticated hydrologic analysis that was not available until recently. The physical interconnection between regions of California (the aqueducts) was not foreseen by those who initially structured the laws and institutions affecting water supply or use. Legal constraints, evident in the state's constitution or imposed by act of the Legislature, restrict ownership and transactability of both surface and groundwater.[1] Today, California's legal, institutional, and political structures are preventing optimal management of groundwater resources.

[1] For a detailed description of these legal constraints, see Charles E. Phelps, Nancy Y. Moore, and Morlie H. Graubard, *Efficient Water Use in California: Water Rights, Water Districts, and Water Transfers*, The Rand Corporation, R-2386-CSA/RF, November 1978.

Although often treated in management and law as a separate class of water, groundwater is intimately connected physically to surface water sources.[2] Unfortunately, the benefits of managing both sources simultaneously have not always been realized. Recent analysis has demonstrated the economic efficiency of such tactics as groundwater basin management, conjunctive management of surface and groundwater basins, and an open market system to allow water sales.[3] Companion reports confirm the desirability of implementing such management for the state's groundwater.

We begin this report with a discussion of the groundwater resource itself. We define groundwater terminology and discuss the development of groundwater basins. We also discuss the desirability of groundwater use and its role, availability, and storage features in our state, as well as some problems with its use. In Sec. II we also look at the historical role of groundwater in California.

Incentives for cooperation among pumpers and hence for management arise from the groundwater common pool problem, and from the benefits of conjunctive use. Therefore, in Sec. III we summarize the role these factors play in efficient groundwater use and in groundwater management.

In Sec. IV we discuss policy options and summarize our conclusions.

Current groundwater management in California sets the stage for future adjustments toward more efficient use. In the appendixes, we delineate federal, state, and local roles in management of the groundwater resource and describe existing management institutions. In addition, we discuss management tools and their use in efficient management.

This and companion studies have confirmed that current groundwater management leads to inefficient water use and allocation. Since groundwater is one of the state's most valuable renewable resources, and since it is inefficiently managed to one degree or another throughout the state, opportunities exist for California to make very profitable changes in the way groundwater is currently managed.

[2] This physical interdependence of ground and surface waters has led to the recommendation that water systems be managed conjunctively.

[3] National Water Commission, *Water Policies for the Future,* Final Report to the President and Congress, Washington, D.C., June 1973.

II. THE GROUNDWATER SITUATION

GROUNDWATER GEOLOGY

Groundwater is distinguished from other types of water by its location. It is that part of the world's moisture that is contained within the upper porous layers of the earth.

Precipitation, particularly from ocean evaporation, is indirectly the source of virtually all fresh groundwater. About two-thirds of all precipitation reaching land surfaces evaporates off these surfaces or is transpired by plants. Thus, only about one-third of precipitation is available for surface runoff and underground recharge.

Stream percolation provides most groundwater recharge. Since evaporation and plant consumption account for most precipitation, extensive recharge occurs only during exceptionally heavy precipitation when ground surfaces are saturated.

Groundwater and surface water are frequently related. For example, surface streams and lakes often recharge groundwater basins when groundwater levels are below stream surfaces, and groundwater basins often provide the base flow of surface streams when groundwater levels are higher than stream surfaces.

Groundwater basins are typically formed over geological periods by streams depositing sand and gravel on valley floors. Floods and droughts often structured these deposits into heterogeneous layers of permeable (loose sand and gravel) and impermeable (silt and clay) material. Recharge is usually greatest along stream beds especially where the streams leave the mountains. Here stream velocities and turbulence are high enough to move fine silt and clay downstream while low enough to allow coarser sedimentary material to fall from the stream. Effective recharge operations require substantial recharge rates like those found in these areas.

Wells provide the most information about the characteristics of individual groundwater reservoirs. The best understood groundwater basins contain a multitude of wells which yield data on aquifer boundaries, storage, and transmissivity. Unfortunately, private records of well operations (where they exist) are often unavailable to assist in compilation of information about aquifer characteristics.

California's groundwater primarily occurs in alluvial material that was deposited by streams in more that 250 valleys. Groundwater basins vary greatly in size, the largest being the Central Valley's 18,000 square mile basin. About 79 of California's groundwater basins are considered undeveloped (total annual withdrawal is less than 8100 acre-feet). These basins range in size from 40 to 1870 square miles. Data on them are too meager to identify accurately their area, depth, and boundaries of aquifers, or the storage, flow, or quality of the water.

ADVANTAGES AND DISADVANTAGES OF GROUNDWATER STORAGE AND USE

Groundwater storage and use has several advantages over surface storage and use: (1) A groundwater aquifer can act as a distribution system; (2) evaporation from groundwater basins is insignificant compared with that from surface reservoirs; (3) groundwater basins provide natural treatment and purification for both naturally percolating and artificially recharged water; (4) surface systems, including distribution, may be destroyed during catastrophies such as earthquakes or acts of war; (5) groundwater often provides emergency drought relief.

On the negative side, groundwater is subject to water quality problems and development costs. Chemicals and salts can dissolve in water underground and make it unsuitable for residential, industrial, or agricultural use.[1] Near the coast, salt water intrusion can contaminate a groundwater basin and reduce its usefulness. Inflows of sewage, industrial wastes, or water from nearby saline basins can also degrade a groundwater basin's quality, as can the quality of recharge water and physical factors characteristic of the basin. Under influence from man, groundwater quality and quantity change either positively or negatively as percolated waters change in quality, quantity, or source. In addition, a groundwater user must supply extraction facilities and pay the cost of energy for pumping water from underground.

On the other hand, surface water does not naturally pick up many chemical contaminants, and so often has a lower initial concentration of dissolved solids than does groundwater. However, surface waters usually have higher concentrations of undissolved solids (silt, etc.) and they can easily become chemically or biologically polluted.

THE GROUNDWATER ASSET IN CALIFORNIA

California has an estimated 1300 million acre-feet (MAF) of fresh water underground. Some of this water is not physically recoverable, and some is not economically usable at present. California's total groundwater storage capacity is about 1500 MAF. The California Department of Water Resources (DWR) in 1975 and the Bureau of Reclamation in 1971 estimated "economically" usable storage[2] at 143 MAF and over 250 MAF, respectively. These estimates are over four times greater than the combined peak storage capacity of California's surface reservoirs.[3] California's Central Valley alone is estimated to have 126 MAF of economically usable storage at a depth of 10 to 200 ft, half of which has already been mined.[4] Despite an accumulated total overdraft (dewatered or empty storage space) of over 100 MAF throughout the state (over 70 MAF in the San Joaquin-Tulare Valley alone), pumping is continuing in most regions. Hence, economic limits on usable capacity

[1] Geologic formations influence the chemical character of the water underground. Since groundwater is often in place for long periods of time (up to hundreds of years), it exchanges chemicals with its surrounding medium.

[2] The extent of capacity from which water could be withdrawn at a cost competitive with current water costs.

[3] Maximum surface storage capacity of reservoirs in the state is 34 MAF, and the average storage is 25 MAF. If out-of-state reservoirs (on the Colorado River system) are added, peak capacity is 90 MAF, and average storage is 57 MAF. See State of California, Department of Water Resources, *The Continuing California Drought*, Sacramento, California, August 1977, p. 2; and State of California, Department of Water Resources, *The California Drought—1977, An Update*, Sacramento, California, February 15, 1977, p. 6.

[4] U.S. Department of the Interior, Bureau of Reclamation, *An Appraisal of Total Water Management in the Central Valley Basin of California*, Sacramento, California, August 1972, p. 16, revised January 1974.

have not been reached. In addition, since about 40 percent of California's ground surface overlies groundwater basins and large usable capacity exists in those basins, groundwater offers tremendous potential for conjunctive use.

Federal and state agencies have delineated California into hydrologic study areas[5] (see the following figure), and groundwater basins have been named and numerically coded by hydrologic study area. Groundwater basin data usually include a basin's description, water bearing material, well depths, well yields, water quantity, storage capacity, and usable capacity. A basin's current development, future prospects, past studies, and unique problems may also be included in data reports.[6] Typically, those basins not currently utilized or actively studied are merely listed.

CURRENT WATER USE PATTERNS IN CALIFORNIA

California's climatic conditions dominate the supply and use of all water. The favorable climate and soils lead to large agricultural use of water—about 85 percent of the state's total water use. Although most rain and snowfall accumulates during the winter in the northern third of the state, peak demands for water occur in the summer, and primarily in the southern two-thirds of the state. Thus, massive surface storage and transportation systems have developed, supplying some 28 MAF per year of water for the state. Groundwater extractions of 15 to 17 MAF per year provide the remaining supply, and groundwater reservoirs serve the same intertemporal storage function as do surface reservoirs.[7] Table 1 provides a summary of California's average annual total water use and groundwater statistics by region and type.

CALIFORNIA'S GROUNDWATER USE

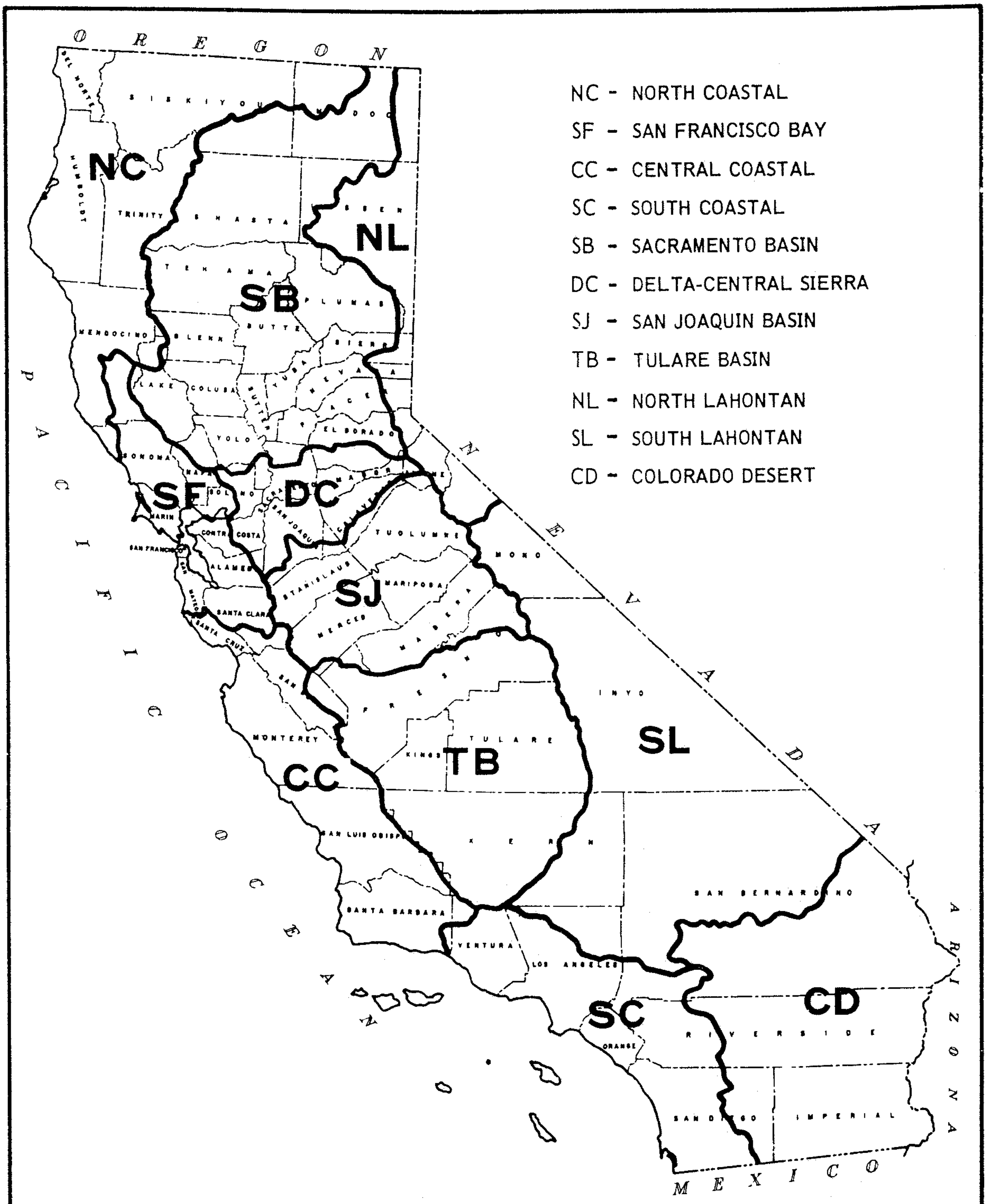
California's groundwater yield is the sum of net natural and deliberate recharge (amounting to about 5.2 MAF), incidental artificial recharge (about 7.6

[5] Both the state and federal agencies have delineated hydrologic basins or regions for water resource studies. Federal regions are basically the same as California's except that parts of Oregon and Nevada are included because they drain into Northern California, and parts of Southern California are excluded because they drain into Nevada and Arizona.

[6] The DWR, U.S. Geological Survey, California Division of Mines and Geology, State Water Resources Control Board (SWRCB), the bureau, and others all have relevant research. Groundwater statistics for California are also presented in: H. E. Thomas and D. A. Phoenix, *Summary Appraisals of the Nation's Groundwater Resources; California Region,* U.S. Geological Survey, Professional Paper 813-E, Washington, D.C., 1976; California Region Framework Study Committee, *Comprehensive Framework Study—California Region,* Appendix V, *Water Resources for Southwest Inter-Agency Committee,* Water Resources Council, June 1971; and State of California, Department of Water Resources, *California's Ground Water,* Bulletin No. 118, Sacramento, California, September 1975.

[7] During the 1977 drought about 20,000 new wells were drilled, old wells were rehabilitated, and pumping increased substantially from an average of 15 MAF to over 18.5 MAF. In fact, groundwater withdrawals exceeded recharge by about 10 MAF in 1977, and groundwater accounted for over 50 percent of agricultural water use. See U.S. Government, General Accounting Office, *California Drought of 1976 and 1977—Extent, Damage, and Government Response,* CED 77-137, Washington, D.C., October 19, 1977, p. 30.

The DWR has estimated that a 10 MAF net reduction in stored groundwater occurred during 1977. During 1976 and 1977, groundwater reservoirs were like an insurance policy. They kept California's vast agricultural industry healthy.



SOURCE: The Resources Agency, Department of Water Resources, *The California Water Plan: Outlook in 1974*, Summary report, Bulletin No. 160-74, November 1974.

Hydrologic study areas of California

Table 1

WATER USE STATISTICS[a]

(In thousands of acre-feet)

Region	Total Water Consumption by Type of Use						
	Irrigation	Municipal and Industrial	Mineral	Recreation, Fish, & Wildlife	Evaporation	Other Losses	Total
North Coast	490	80	2	270	38	55	935
San Francisco	230	1020	30	24	35	63	1402
Central Coast	750	130	8	5	32	15	940
South Coast	790	2010	46	8	120	200	3174
Sacramento	4610	180	9	120	370	260	5549
Tulare	7570	200	11	46	90	180	8097
San Joaquin	3740	60	1	100	250	170	4321
Delta	1820	80	1	15	60	97	2073
North Lahon	300	13	1	14	29	20	377
South Lahon	290	50	11	4	26	4	385
Colorado Desert	3610	80	3	29	0	770	4492
Total	24,200	3903	123	635	1050	1834	31,745

Region	Total Groundwater Use by Source			
	1965[b] Total Use	1965[b] Safe Yield	1965[b] Overdraft	1975[c] Overdraft
North Coast	105	150	0	?
San Francisco	370	300	70	10
Central Coast	970	900	70	180
South Coast	1600	1600	0	?
Sacramento	1700	1600	100	110
Tulare	6500	4200	2300	1060
San Joaquin	1800	1750	50	?
Delta	750	600	150	150
North Lahon	60	60	0	10
South Lahon	600	300	300	140
Colorado Desert	300	100	200	130
Total	14,755	11,560	3240	1940

[a]Included surface water and groundwater. State total consists of 21,359,000 acre-feet of surface water and 10,386,000 acre-feet of groundwater.

[b]*Comprehensive Framework Study--California Region,* op. cit.

[c]Bureau of Reclamation, *Westside Study Report on Critical Water Problems Facing the Eleven Western States,* U.S. Department of the Interior, April 1975.

MAF), which together represent the state's "safe yield,"[8] and 2.2 MAF of average annual "overdraft" (which lowers the average groundwater table). Accumulation of this overdraft has dewatered the upper levels of the state's groundwater basins by approximately 100 MAF.[9] Consequently, substantial groundwater storage capacity exists.

Estimates of total average annual groundwater supply or demand vary. For example, DWR estimates 1974 groundwater use at 15 MAF[10] and the Bureau of Reclamation estimates 10.4 MAF in 1975.[11] A 1976 USGS estimate was 16 MAF.[12] These differences are not explainable simply because they were made in different years; rather they indicate the difficulty in attaining precise numbers.

In California, most pumping quantities are undocumented and pumpers are not required to record or report quantity pumped (many wells are not metered). Hence, indirect procedures are used to estimate amounts pumped. Electric power records, groundwater table fluctuations, regional agricultural demands by crop, and the known applied surface water are four important data sources for regional groundwater use estimation. In addition, in Riverside, San Bernardino, Los Angeles, and Ventura Counties, any person or agency extracting groundwater must file a "Notice of Extraction and Diversion." Failure to file in any year precludes the pumper from claiming adverse use by others.

THE LEGAL ENVIRONMENT FOR GROUNDWATER USE IN CALIFORNIA

Unlike many states, California considers water to be the property of the people of the state, rather than the state itself. However, individuals, companies, public agencies, and municipal, state, or federal governments may acquire rights to *use* surface or subsurface water. Current water law stems from a confusing mix of doctrines derived from Spanish law, the state constitution, court decisions, legislated state law, and federal law. Unfortunately, it has evolved into a vast, complex, sometimes conflicting, and somewhat uncertain set of laws.[13]

The Legal Rights to Use Groundwater[14]

Legal use of groundwater arises from (1) overlying landownership, (2) appropriation, (3) prescription, and (4) pueblo rights. In adjudicated basins, these rights are modified by court action.

[8] The safe yield of a groundwater basin is defined as the average annual extraction that can be continued indefinitely without long-range detrimental effect on the quality and quantity of groundwater in the basin.

[9] See DWR Bulletin No. 118, op. cit., pp. 6, 8.

[10] Ibid, p. 7, and Bulletin No. 160-74, op. cit.

[11] U.S. Department of the Interior, Bureau of Reclamation, *Westside Study Report on Critical Water Problems Facing the Eleven Western States*, Washington, D.C., April 1975.

[12] Thomas and Phoenix, op. cit.

[13] See Charles J. Meyers, *A Historical and Functional Analysis of the Appropriation System*, National Water Commission, Arlington, Va., 1971, pp. 38-39.

[14] Surface water rights are summarized in Phelps et al., op. cit. For a summary of water laws in other states, see Richard L. Dewsnup and Dallin W. Jensen (eds.), *A Summary Digest of State Water Laws*, National Water Commission, Arlington, Va., 1973.

Overlying Rights. Most groundwater extraction arises through the rights of landowners to use groundwater on overlying land. Before *Katz v. Walkinshaw* (1903) overlying landowners had absolute rights to use groundwater with no regard to others affected. Underground percolating water was treated the same way trees, rocks, or minerals were—all belonged to the owner of the land. In *Katz v. Walkinshaw*, the State Supreme Court adopted the theory of correlative rights, wherein during shortages landowners draw water to meet their needs subject to the equal rights of others drawing from the basin. Thus, overlying owners have common rights to groundwater with no priority among themselves. As with all water use in California, water withdrawn must be put to beneficial and reasonable use as required by a 1928 constitutional amendment. In addition, the Water Code now protects the groundwater rights of a pumper who reduces extraction and relies on an imported surface supply. The law specifies that such a pumper is deemed to be continuing extraction.

Groundwater Appropriation. Generally, if overlying owners do not consume a basin's annual safe yield, the surplus may be appropriated for use elsewhere. At this time no permit system exists for this type of right. An exporter can be stopped if the pumping is proven to be adverse to overlying owners. However, if exporting continues long after overdrafting has begun to adversely affect others, a prescriptive right can be established.[15]

Prescription. Only the courts can grant prescriptive rights to groundwater. These rights arise in cases where both overlying owners and appropriators have exceeded the safe annual yield of the groundwater basin. An exporter of pumped groundwater may gain a prescriptive right if his pumping is adverse to overlying owners and the adverse use has continued for a prescriptive period of at least five years. Only through prescription can the groundwater rights of overlying owners be lost. During court proceedings to determine groundwater rights, pumping may be restricted by preliminary injunction if further basin injury (for example, from salt water intrusion) would occur.

Pueblo Rights. Pueblo rights are an additional and unique type of groundwater right in California. They are historical rights to river flows (above and below surface) granted when the state was under Spanish rule. Only two pueblo rights have been judicially perfected; those for the cities of San Diego and Los Angeles.

Private Versus Public Rights. In practice, private rights are inferior to those held by the public. That is, they may be condemned for public purposes or, more likely, be reassigned in legal disputes. California courts have determined that certain public agencies cannot lose their water rights by prescription (see below).

Rights to Underground Storage. California's Water Code considers the storing of water underground a beneficial use. Section 1242 states that "The storing of water underground, including the diversion of streams and the flowing of water on lands necessary to the accomplishment of such storage, constitutes a beneficial use of water if the water so stored is thereafter applied to the beneficial purposes for which the appropriation for storage was made."

Recent Legal Decisions Affecting Groundwater Use

Several state legal decisions have affected groundwater use. In *City of Los*

[15] "Overdrafting" is pumping in excess of the safe yield. Persistent overdrafting of a basin is also known as "mining."

Angeles v. City of San Fernando (1975), the State Supreme Court held that water rights held by public agencies and public utilities could not be lost by prescription. This had three important effects on groundwater users. First, the decision confirmed that imported water, and any return flows from imported water that percolates into a groundwater basin and is not abandoned (i.e., facilities or plans exist for recapture) are owned by the public agency. Further, the public agency has first rights to reclaim the water, and appropriators or overlying landowners in the basin are restricted from taking such water.

Second, elimination of the concept of prescription against public agencies made it more difficult to achieve adjudications to control groundwater extraction. Following the decision in *City of Los Angeles v. City of Glendale* (1943), adjudications had proceeded under the concept of mutual prescription of all pumpers against one another, with the final assignment of pumping rights thereby based upon historical rates of pumping by each basin participant.

Third, because the *mutual* prescription doctrine was modified in the San Fernando decision, an alternative basis for pumping rights may have to be sought out in future adjudications. To establish that basis, courts appear now to have reverted to the overlying use concept.

In the recent Chino Basin adjudication,[16] groundwater rights were the basis for overlying pumpers' use. These overlying rights would not be tradable as they had been under the mutual-prescription-based adjudications.

GOVERNMENT AGENCIES INVOLVED IN GROUNDWATER USE AND MANAGEMENT

Regulation of groundwater use is essentially a private matter. Federal and state governments do not manage groundwater and in most areas of California management is either partial or nonexistent. The role of government agencies is briefly discussed below. A more complete description of these activities is contained in Appendix A of this report.

The Federal Role

The most active role taken by federal agencies is in estimating groundwater basin extractions. The U.S. Geological Survey makes these estimates and shares the cost equally with "client" agencies. Their primary customer in the past has been the state's DWR, but USGS efforts on behalf of the DWR have recently been reduced substantially. The Bureau of Reclamation also undertakes groundwater studies as a part of its management of the Central Valley Project.

The State Role

The state presently has several important roles in groundwater activity, including water quality control, technical and financial assistance to local agencies for groundwater management, modeling of groundwater basin hydrology, and provi-

[16] Albert J. Lipson, *Efficient Water Use in California: The Evolution of Groundwater Management in Southern California*, The Rand Corporation, R-2387/2-CSA/RF, November 1978.

sion of Watermaster services (supervisory authority in adjudicated basins). The state is now defining groundwater basins pursuant to S.B. 1505 enacted in 1978.

The SWRCB is the relevant authority for water quality control. The board may initiate action to restrict pumping that could damage aquifers, primarily through salt water intrusion. The SWRCB can also act to control percolation of waters into basins if it would degrade the quality of water in the aquifer.

In support of groundwater management, the state also investigates and analyzes groundwater basins for local authorities. Current models exist for a variety of major basins, from Southern California through the Kern-Tulare area and for several regions in Sacramento County.

Finally, the state provides Watermaster services for adjudicated basins, with the local authority and DWR each paying half the cost. DWR Watermasters oversee several basin plans within Southern California, including monitoring of pumping rates, informal facilitation of sales or exchanges of pumping rights within the basins (where permitted), and making decisions on modification of total pumping rates within the basin (subject to court-imposed constraints).

The Local Role

The legal authority for groundwater management is contained in a variety of local water district enabling acts, the most common form of management. Local water districts can spread, sink, or replenish groundwater basins, and often can assess landowners for the costs of replenishment. Several types of districts are given specific authority to pump groundwater with district-owned wells. Among general water district acts, only the 1931 Water Conservation District Act provides the explicit authority to monitor or meter wells. The legal ability to tax pumpers is limited to Water Conservation Districts and Water Storage Districts, to one County Water District (through a special law passed in 1978), and to several special-purpose districts (e.g., the Orange County Water District and the Kern County Water Authority).

A substantial number of water districts engage in replenishment activity throughout the state, some on a very significant scale. Prominent examples include the Central and West Basin Water Replenishment District, the Santa Clara Valley Water District, the Orange County Water District, the United Water Conservation District, Monterey County Flood Control and Water Conservation District, the Desert Water Agency and Coachella Valley County Water District, San Benito County Water Conservation and Flood Control District, Kern County Water Agency, and a variety of local districts within the San Joaquin/Tulare region.

III. FACTORS IN GROUNDWATER MANAGEMENT AND USE

The desirability of groundwater management largely stems from two important problems: Groundwater's common pool nature and groundwater conjunctive use potential. The following discussion summarizes the important problems of lack of management and benefits of management associated with both problems.

GROUNDWATER'S COMMON POOL PROBLEM

Groundwater is a renewable "common pool" resource. It is renewable in the sense that water from streams or rainfall percolates into the ground and thus helps to replenish the groundwater supply. It is a common pool resource because, a priori, there are no clearly defined property rights to its use when two or more pumpers extract water from the same aquifer or basin. Also, each pumper's extraction costs depend, at least indirectly, on all other pumpers' rates of extraction. All common pool resources (e.g. fisheries, wildlife, and certain kinds of minerals) exhibit this interdependence of extraction costs together with ambiguity of property rights to the resource. Without a well-designed management program, individual extractors who pursue their own self interests will cause an inefficient use of their common pool resource.

The open access fishery problem is quite similar to the groundwater resource problem. Taxation schemes to maximize society's return from fishing have been studied extensively.[1] Taxation or quota assignments can be used to force private industries (fishermen or groundwater pumpers) to extract a common pool resource in socially desirable ways.[2] These economic theories have led to the National Water Commission's recommendation that state or local management of groundwater be instituted using the pump tax or a freely marketable quota.

Wetzel, in a companion report from Rand's California Water study, reviews and develops a number of theoretical approaches with specific reference to groundwater management tactics for California.[3] Wetzel presents a theoretical analysis of alternative management schemes such as quotas and pump taxes to improve groundwater use efficiency. He shows that if a groundwater basin is owned or managed by one person, the owner can balance increased immediate returns achieved by extraction with decreased future returns and thus seek an optimal extraction rate that maximizes the present worth of present and future returns.

Wetzel confirmed that in a groundwater basin with many pumpers who individually account for only a small relative share of the basin's total pumping, no incentives exist for any one pumper to consider the effects of his own pumping on the water table level. If an individual pumper did attempt to account for these

[1] Colin W. Clark, *Mathematical Bioeconomics,* John Wiley and Sons, New York, 1976, pp. 116-118.

[2] Ibid., pp. 29, 66-67.

[3] Bruce Wetzel, *Efficient Water Use in California: Economic Modeling of Groundwater Development with Applications to Groundwater Management,* The Rand Corporation, R-2388-CSA/RF, November 1978.

effects he would have to reduce his current pumping. Since his own share of the total pumping for the basin is small, any reduction in his current pumping will have a negligibly small effect on future water table levels. Also, any benefits that do result from his decreased pumping accrue to all pumpers. Therefore, he could expect to receive almost no future benefits to offset his losses (which are certain) from decreased current pumping. Each pumper faces these disincentives to reduce pumping. Unfortunately, this type of individual behavior taken collectively has a significant effect on future pumping lifts and costs. Ultimately, future pumping lifts and costs will be higher than they would be under a managed system of extraction which takes these effects into account. Furthermore, the total present worth of present and future profits for the basin will not be maximized.

Problem Cause

The above problem exists first of all because marginal social costs[4] (in this case the cost to all pumpers in the basin) exceed marginal private costs[5] (the costs of pumping at current lifts). This difference is just the discounted present value of future marginal costs from increased pumping lifts for all pumpers and results from the interdependence of extraction costs. Second, there is no mechanism to allocate the difference between private and social costs and to distribute the benefits that would result from management.

Under California's correlative rights doctrine of groundwater law, owners have the right to take reasonable amounts of groundwater and put it to beneficial use on their lands. The state has almost no statutory control over groundwater extraction. Consequently, pumping is strictly a private matter, with limited regulation. In contrast, in most other western states underground water is owned by the state. Some states require the issuance of an appropriative permit for groundwater use.

California's correlative rights doctrine, which gives absolute ownership of underground waters to overlying owners, creates groundwater common pool problems. The result of unmanaged extraction from the common pool of groundwater is that returns to society are not maximized. Typically, it is argued that once a policy for maximizing society's return is instituted, the additional profits can be distributed to pumpers in a way to make everyone better off. This standard argument avoids the question of redistribution[6] and focuses on the question of how to maximize society's return.

Problem Solution

A formal institution or informal cooperating group incorporating virtually all pumpers on the groundwater basin can agree to manage optimally. One method of

[4] Marginal social costs are the incremental costs to society of pumping one additional unit of groundwater.

[5] Marginal private costs are the incremental costs to the pumper of pumping one additional unit of groundwater.

[6] The redistribution of returns can be the most significant problem. Under any totally managed basin using the pump tax policy, the total annual tax revenue can be many times larger than the value of the efficiency gain to society. Thus, careless redistribution can make a large number of groundwater pumpers worse off. Only a careful, possibly difficult, redistribution can make everyone better off. In a political sense, at least one-half of the basin's voters must be made better off if the management plan is to receive majority approval.

removing the inefficiency in extracting from the common pool is to employ a use tax. The organization could adopt a tax on extraction that raises private costs up to society's marginal cost, and thus reduces extractions. (In fact, a few water districts in California have instituted a pump tax. However, it is not clear that the tax is set to manage efficiently.) Theory indicates that the tax needed to assure optimal pumping rates must reflect the economic value of pumping future water.[7]

Since social costs differ from private costs by the present worth of the effect that current pumping has on future pumping costs, the tax can be designed to increase a pumper's private costs so that his new marginal cost is equal to his part of society's marginal costs. The pumper will then pump groundwater until his marginal revenue equals the sum of direct marginal pumping costs at current lift height and discounted marginal effects of current pumping on future pumping costs to all.[8]

Many researchers have avoided the problem of redistribution of pump taxes, claiming that "the issue of profit distribution can be separated from total profit maximization." Given that total tax revenue can be large relative to societal savings, careless redistribution could make a large number of the pumpers worse off under the management scheme. The fact that such management has rarely succeeded to pass political muster indicates that the redistribution problem is significant.

A quota system has been proposed as an alternative means for regulating withdrawals. If such quotas are tied to the land, they do not generally achieve the economic efficiency and fairness obtainable under a taxation scheme. For example, if new pumpers are excluded, new uses with higher values may also be excluded, while lower valued uses remain. If quotas are freely marketable and exchangable, economic efficiency may be achieved. (Several Southern California groundwater basins have a quota system to control extraction and a subset of these allow the quotas to be traded.) Original quota owners may reap windfall profits from their sale of the water right. However, if quotas are marketable, society's long-run interests are served with increases in efficiency of the water distribution system.[9]

The quota system may have one disadvantage with regard to conjunctive management. Rigid annual quotas independent of surface water availability may prevent optimal conjunctive use of the groundwater basin. A proportional increase or decrease based on the availability of surface water each year is one method of integrating quota system allocation with conjunctive use of a basin's groundwater. Another method is to tax pumping above quotas at a higher rate and credit pumping below quotas.

An Example

To clarify or further illustrate the source of economic gains to groundwater pumpers from achieving basin control, we present a simple example of an individual pumper in a groundwater basin—how that pumper's activities affect others within the basin and how the optimal "tax" for pumping should be established.[10]

[7] See *Water Policies for the Future*, op. cit., pp. 240-241; and Gardner Brown, Jr., and C. B. McGuire, "A Socially Optimum Pricing Policy for a Public Water Agency," *Water Resources Research*, Vol. 3, 1967, pp. 33-42.

[8] Ibid., p. 37.

[9] See Wetzel, op. cit.

[10] The theory underlying this example is contained in Wetzel, op. cit.

We note the correspondence (for purposes of effective management) between a tax and a quota; the desirable level of groundwater extraction can either be set directly by use of quotas, or indirectly by setting a pumping tax that will reduce groundwater use. The only difference is one of certainty—use of a tax to control basin extraction implies some knowledge of how responsive water using activities are to costs, whereas a quota can establish pumping levels directly for the entire basin. (We should also note that knowledge of the responsiveness of water use to price is necessary before the optimal quota can be set, so the informational requirements for good policy choices are the same no matter which control mechanism is chosen.) We now proceed with our example.

Pumper x is considering extracting one additional acre-foot of water. We know that this acre-foot will increase his gross revenue by $100. Let marginal pumping costs (principally electricity and maintenence) be $85, so the pumper's net marginal revenue increases by $15. Suppose, for the sake of the example, that pumper x determines that by deferring extraction of the acre-foot, all future pumping costs (discounted) are reduced by $0.20/acre-foot.[11] Thus, pumping this acre-foot actually makes pumper x better off by only $14.80. Assume that 99 other pumpers in the basin also each receive the $0.20 benefit. The entire basin's gross return from deferment of pumping one acre-foot is $20. Because it costs our pumper $14.80 (forgone profit to defer pumping), the group is better off by having x defer pumping that extra acre-foot.

Without cooperation, x pumps that acre-foot and is $14.80 better off. With cooperation, the group pays $14.80 to pumper x and then distributes the net gain of $6.20 to all 100 pumpers.

This example illustrates the problems that arise with common pool resources such as groundwater. Without a management structure to properly allocate societal costs and distribute societal gains, no private incentive for conservation occurs and extraction proceeds at a higher than optimal rate.[12]

A tax of $14.80 per acre-foot would be needed to raise pumper x's marginal costs to equal marginal revenue and make it inefficient for him to pump that extra acre-foot. However, a tax of $20 (100 pumpers worse off by $0.20 each) is the correct tax to assess because it remains correct under varying market demand conditions and does not require economic analysis of this one farming operation.[13] Only an estimate of the present discounted cost to society is needed.

The question always arises as to where the proceeds of the pump tax should go. Under general conditions, efficiency of groundwater use is unaffected so long as pump tax revenues are not returned to pumpers in proportion to water pumped. To do so would reduce net pumping costs and increase pumping rates. Additionally, taxes should not be returned in a way that would distort some other aspect of the economic system.

If every pumper in the hypothetical basin were taxed $20 per acre-foot, the gross amount of pump taxes collected could be quite large relative to the value of

[11] Higher water levels in the future save him money year after year and the present worth of this discounted savings is $0.20/acre-foot.

[12] For example, current groundwater extractions in the Central Valley and other areas with declining water tables are virtually unmanaged. Therefore, individual pumpers will continue to pump and ignore the social costs of extraction.

[13] See Wetzel, op. cit.

deferred extraction to society. A carefully conceived increasing block tax rate could reduce total tax revenues significantly (see p. 19).

How Much Actual Benefit Stems from Groundwater Management?

It is impossible to compute the gains from basin management for the state as a whole, due to lack of appropriate data for many important basins. Anticipated gains are sensitive to surface water prices, basin-specific hydrologic information, electricity and pumping costs, the discount rate chosen, natural recharge rates, and current pumping rates. Actual benefits can be higher than calculated if pumping costs increase relatively more than other things in society, but lower if the value of water has increased today more than other things in society, for example. Thus, one can consider any example only as roughly illustrative, and not a promise of actual benefits to be found. Given these caveats, we present an example of the magnitude of gains that might be anticipated from basin management, from an analysis by Brown and McGuire, op. cit.

In the Kern River Delta and surrounding regions, there were pumping lifts ranging from 700 ft to 1150 ft in 1967. This represented the pumping lifts in an uncontrolled basin. In a basin operated with optimal management, taxes on groundwater extraction would be imposed ranging from $.40 to $11.72 per acre-foot in 1967 dollars, varying by region. In current (1979) dollars, equivalent amounts would be around $.75 to $22 per acre-foot. The optimal management program would yield benefits of $4 million yearly (1967 dollars) to those in the Kern River Delta area alone, and about $4.3 a million for all the water districts they considered in their study. (The Kern River Delta area accounted for 75 percent of the total pumping in their study region.) It must be emphasized that the $4.3 million figure is an *annual* benefit to the water using community. The *present value* of such an annual benefit is over $60 million (1967 dollars) using a discount rate of 7 percent. In current (1979) dollars, this benefit would exceed $100 million, to be distributed among an estimated 821 farms in the region studied. Thus, the average farmer's position would be increased by over $120,000 through institution of pumping controls in their study region, less the costs of forming and managing the organization that would control the groundwater.

If extrapolated to a larger scale, the general magnitude of potential gains to groundwater control for the state can be crudely estimated. Consider the case where the average benefit throughout the Delta/Central Sierra, San Joaquin, and Tulare regions is only one-fourth of that estimated by Brown and McGuire, i.e., about $5 per acre-foot (1979 dollars) of water pumped. Estimated total groundwater pumping in these regions is near 9 MAF per year (see Table 1), so the total benefit might conservatively be estimated as $45 million per year (1979 dollars). The actual number could be higher than this, because of the quartering of inferred benefits, and because pumping costs have increased so considerably since Brown and McGuire's study. If in fact the $22 per acre-foot benefit (which was estimated for the Kern River Delta area) were applicable for the entire Delta/Central Sierra, San Joaquin, and Tulare regions, the benefit would be over $180 million per year. There are not sufficient current data to confirm which estimate is more accurate at present. Further studies are indicated.

Offsetting these benefits are the costs of forming and operating a groundwater management organization. The formation costs should be offset against the present value of the anticipated benefit. Using a 7 percent discount rate, an annual benefit of $45 million equates to a present value of benefits of over $640 million. If benefits are at least as large as the "low" estimate presented above, farmers and other water users within the Delta/Central Sierra, San Joaquin, and Tulare regions would be better off if they could form and operate a management plan for anything under $640 million in present value.

We must stress the tentative nature of these calculations. New data on pumping rates, groundwater levels, pumping costs, and aquifer conditions must be obtained before accurate calculation of the benefits achievable from groundwater management can be made. The calculations must be made basin by basin and offset against the costs of forming and operating the management entity in each case. It was not the purpose of this study, nor did we have the resources available, to make such calculations, but we believe that they must be made before groundwater management is mandated in any region.

CONJUNCTIVE USE

We turn now to a separate consideration, that of *conjunctive use* of surface and groundwater. Many physical, environmental, energy, economic, and political constraints may prohibit development of substantial additional surface water supplies. In such a case, the water demand buildup can be reduced by making more efficient use of existing supplies. Another alternative is to expand supplies by management tactics such as conjunctive use. Jaquette, in a companion report, specifically examines the savings achievable by increased conjunctive management.[14] A summary follows.

Conjunctive use of California's ground and surface reservoirs is technically feasible and economically advantageous. Jaquette's analysis confirmed this fact and reached several additional conclusions. In the absence of political, legal, and institutional barriers, state water planners should undertake a conjunctive management program that is more aggressive than those currently planned. Furthermore, with even modest improvements in weather forecasting reliability, integrating long-range (3 to 6 month) forecasting with ground and surface reservoir management proved even more economically advantageous to the water users in the state.

Jaquette simulated the operations of California's year 2000 facilities to illustrate the quantity and cost of developing new yield. Additional water can be developed from the state's existing physical facilities by management strategies that release more carryover storage water for conveyance to groundwater basins. Although this strategy is risky in that the subsequent year's runoff might fail to resupply the surface reservoir, a large project, such as the State Water Project or the Central Valley Project, is in an excellent position to underwrite an insurance against the risk. Project groundwater can be repumped at project expense from groundwater basins during times when excess groundwater pumping capacity exists. The extra water released under this plan is never lost—its recovery simply

[14] David L. Jaquette, *Efficient Water Use in California: Conjunctive Management of Ground and Surface Reservoirs*, The Rand Corporation, R-2389-CSA/RF, November 1978.

requires energy. When runoff is heavy, more water is captured by the state's surface system, thus developing new water yield.

An important political factor in implementing a conjunctive use plan may be whether a statewide project or a more local groundwater basin management district owns and manages the plan. From a physical and economic point of view, there is no difference between local versus state conjunctive management, as long as water profits and water transfers can be made and take place freely. Thus it is the management plan rather than the management entity that is important in conjunctive use.

Jaquette's study concluded that (1) increased conjunctive use was most profitable in areas with high groundwater tables, such as found in the Sacramento Valley; (2) increased conjunctive use can generate significant amounts of new yield at costs less than the estimated $150 per acre-foot for water from many new physical facilities being planned; (3) conjunctive management plans are more profitable for reservoirs with higher inflow to storage ratios, such as Shasta, than for reservoirs with lower inflow to storage ratios, such as Oroville; (4) since increased conjunctive use is economically viable and physically feasible, and since increasing reliability of weather forecasts makes it even more advantageous, the state should direct attention to overcoming the political, legal, and institutional barriers to conjunctive management. The extent to which aggressive conjunctive use can be undertaken may be inhibited by effects on electrical power production. The specific applications of aggressive conjunctive use depend on the characteristics of each reservoir and the effects on electricity generation from varying water levels. Data were not available to us to include complete analyses of these issues in our research, but should be included in any final planning strategies involving conjunctive use.

MANAGEMENT OPTIONS

The preceding sections and Appendixes A and B illustrate the wide variety of groundwater management alternatives currently available in California. In the following we summarize the advantages and drawbacks to various management schemes or procedures.

Metering

Metering of groundwater extraction is required by law in most Southern California counties. Elsewhere in the state, where it is not mandatory, metering is minimal to nonexistent.

Wherever pumping is to be controlled or a pump tax is to be levied, metering is necessary. Without metering there is less information about groundwater basins and their use. It has often been argued that the expense of metering does not justify the benefits. However, most wells use electricity as the power source and thus already have a separate power meter which has been successfully used by the USGS in combination with data on pump efficiency and pumping depth to closely approximate the volume of water pumped.

Artificial Recharge

Artificial recharge of groundwater allows for increased pumping without overdraft, for reduction in overdraft, or for cyclic storage and recovery of water (especially if the recharge is coupled with a well field for increased withdrawals).

Many water agencies in California have artificial recharge programs. Unfortunately, most, particularly outside Southern California, are not coupled with metering and a pump tax, hence the costs of the programs are not directly related to water use but rather are recovered by property taxes or land assessments. Thus, while many of these programs enhance groundwater use, they may not be efficient. That is, they tend to overstimulate water use because they make pumping less expensive through raising the water table, while at the same time do not account for the externality of common pool pumping. Those agencies that do have a pump tax usually calculate the tax by averaging the cost of replenishment water with "free" native waters. Hence, pumpers who benefit from replenishment still do not face the true marginal cost of their pumping, but rather pay a lower average cost. They too will pump more water than if they faced the marginal cost of additional water.[15]

Pump Assessment or Tax

Only a handful of water agencies in California actually levy a pump tax although many have the power to do so. Typically, the level of the pump tax is set to just finance recharge operations, rather than to put the socially optimal price on extraction.

Under nearly all optimal pump tax plans, the taxing agency will collect revenue in excess of costs and will be faced with the problem of redistributing the profits. (For the most efficient use of water, such profits should be distributed in a manner that does not affect water use.) Alternatively, to prevent profit accumulation, the agency can develop a stepped tax, that is, set no replenishment tax on the first block of water attributed to natural recharge and impose a replenishment tax equal to the marginal cost of replenishment on the increment of pumped water above natural recharge.[16] One problem with a stepped tax is how to initially allocate each user's zero-tax share of groundwater. Conceptually, large pumpers could argue that a proportionate share of pumping should be tax-free, whereas small pumpers would probably prefer an equal tax-free amount for all pumpers. The pump tax can also be used to alleviate the common pool problem even without replenishment.[17]

Property Rights to Groundwater or Quotas

Assigning property rights to groundwater is another management tool. Unfortunately, court adjudication, often quite long and costly, is necessary to determine property rights. In California, groundwater property rights exist for a fixed pumpage (safe yield) and for a fixed percentage of an annually determined safe yield.[18]

[15] We must qualify this still further for cases where the pumper has salable property rights to the water. We discuss this notion a little later.

[16] This is analogous to a problem with surface water costs, as discussed by Phelps et al., op. cit.

[17] See Wetzel, op. cit.

[18] These systems are discussed in Lipson, op. cit.

Assigning property rights to a fixed pumpage amount can limit a basin's potential for conjunctive use unless a basin management agency has the power to store and recover water in excess of the basin's allocated safe yield. Also, it may be desirable to lower the basin's water table below the current operating level, and to vary that level as a buffer against drought. A fixed safe yield policy prohibits such actions.

The ability to transfer groundwater rights within and outside of the basin has implications for water use efficiency as well. Allowing export of water from a basin enhances statewide water use efficiency. Allowing within-basin transfers enhances water use efficiency within the basin, but some statewide benefits may be forgone. Even if water transfer is not allowed either within or outside the basin, water use efficiency above today's level can be achieved if basin users pay the full marginal cost of replenishment or of supplemental surface water,[19] or face the social cost of their pumping.

Orange County presents a special (fixed percentage) case of groundwater rights allocation. Rather than determining specific rights of pumpers, Orange County allocates groundwater proportional to total water use. Thus, the more water one uses, the more cheap groundwater one is entitled to. This policy acts to subsidize the use of surface water because each additional unit of more expensive surface water is offset by a proportional increase in rights to use less expensive groundwater. This theoretically leads to more water being used in Orange County than would be used if groundwater rights were not proportional to surface water used.[20]

IMPLEMENTING A BASIN MANAGEMENT SYSTEM

The crux of basin management is to control the rates of extraction of water from the ground to socially optimal levels. The two most prominent mechanisms by which such control can be achieved are explicit quotas on allowable rates of extraction, or *taxes* levied on water as it is pumped from the ground. There are also two common forms of management chosen, namely, the groundwater basin *adjudication* (a legal agreement between groundwater pumpers, supervised by a court) or a groundwater management control *district*. Each of these forms of management (adjudication or district) can in concept choose either of the prominent tools of management (quota or tax), and in fact the tools can be combined in effective ways to achieve control through mixes of taxation and quotas. For example, a management organization could issue quotas for pumping and levy taxes or assessments on any pumping beyond the rates specified in the quota.[21]

Our research on the activities of water districts (which primarily analyzed districts engaged mostly in the development and delivery of surface water) shows

[19] See Phelps et al., op. cit., for a description of the benefits of marginal cost pricing.

[20] This is in addition to a policy of averaging replenishment costs over all groundwater. An analogous problem arises in the U.S. Department of Energy regulations of domestic crude oil pricing, which subsidizes imports of foreign oil. There, analysts are in agreement about the adverse effects of the subsidy of expensive (foreign) oil, which is analogous to surface water in the Orange County Water District case. See Charles E. Phelps and Rodney T. Smith, *Petroleum Regulation: The False Dilemma of Decontrol*, The Rand Corporation, R-1951-RC, January 1977.

[21] The Main San Gabriel Basin management, for example, uses a pump tax for all pumping above predetermined quotas. This plan is managed through an adjudication agreement. See Lipson, op. cit., for details.

some important problems in the district form of management that must be considered if basin control is to be achieved by means of water districts.

For purposes of achieving efficient water use, the most serious problem to overcome is the potential acquisition, and the final distribution, of tax receipts or net revenues from district operations. Under current forms of water district activity, if a groundwater tax is set at a level to encourage optimal rates of extraction, the tax receipts of the district will likely be larger than its operating costs. In fact, the tax receipts themselves are likely to be larger than the net benefits to the groundwater pumpers.[22] Thus the distribution of those tax receipts becomes a crucial issue. Because the water district is essentially a single-purpose district (rather than, say, a municipal or state government), there is little the district could do with tax receipts except use them to subsidize surface water use or to subsidize groundwater replenishment activities. While the district may find that some replenishment activity is desirable, the amount of that activity should not be determined by available revenues from groundwater taxes but by considerations for basin management. Under the district form of management, this redistribution can be accomplished in several ways, including rebates on property taxes or use of quota or tax plans, whereby taxes are levied only on extraction in excess of a predetermined amount. However, our research has shown redistribution of tax revenue and assignment of pumping quotas to be an important, if not dominant, aspect of the ability of a water district to form an efficient management plan.

[22] See Wetzel, op. cit.

IV. POLICY IMPLICATIONS

The California constitution provides that the water resources of the state

> be put to beneficial use to the fullest extent of which they are capable, and that the waste or unreasonable use or unreasonable method of use be prevented, and that the conservation of such waters is to be exercised with a view to the reasonable and beneficial use thereof in the interest of the people and for the public welfare . . .[1]

The California Water Code establishes the state's interest in groundwater use and development:

> Section 104. It is hereby declared that the people of the State have a paramount interest in the use of all the water of the State and that the State shall determine what water of the State, surface and underground, can be converted to public use or controlled for public protection.
>
> Section 105. It is hereby declared that the protection of the public interest in the development of the water resources of the State is of vital concern to the people of the State, and that the State shall determine in what way the water of the State, both surface and underground, should be developed for the greatest public benefit.

If this constitutional and statutory mandate is interpreted to include efficient use of water, then state law already requires groundwater management.

There is a considerable amount of groundwater management in evidence in the state today, but, particularly outside the southern coastal region, existing management plans are incomplete and unlikely to be able to solve the common pool problem facing every groundwater basin. Most current groundwater management concentrates solely on replenishment of groundwater basins, without controlling rates of extraction. In fact, many such replenishment activities actually make groundwater levels higher than would occur through natural processes alone and thereby provide incentives to groundwater users to increase their rates of pumping within a basin. While recharge operations can be useful, particularly in concert with conjunctive use, they must be coupled with controls on extractions to provide the full benefits achievable from basin management. The essence of efficient groundwater use is control of pumping from common pool reservoirs. Without such control, and without clear determination of the rights to use groundwater basins for interim storage of water, fully efficient use of the state's water resources cannot be realized.

In this section, we summarize our recommendations regarding the state's role in groundwater management. We discuss the problems and costs of groundwater control mechanisms, and argue that such costs should be taken into account when considering the efficiency of groundwater basin management. We discuss implementation of a basin groundwater management system and some of the economic and social consequences affecting groundwater users with and without basin management.

[1] Article 14, Section 3, of the constitution.

POLICY CONCLUSIONS AND RECOMMENDATIONS

1. *A management plan must encompass entire zones of benefit to achieve effective groundwater control.*

Effective control of groundwater extraction occurs best at the basin or subbasin level, the area in which the benefits of basin control can be largely captured. Basin hydrology sometimes allows some users within a basin to capture much of the gain from their own efforts to manage a basin. More typically, however, other pumpers within the basin can capture some of the benefit of controlling the basin, without having to pay for that control. This "free rider" problem cannot be eliminated without management.

2. *Groundwater management at the basin level generally produces cost savings and is thus inherently desirable. Groundwater management should be instituted and will be efficient where the benefits exceed the costs.*

Benefit-cost tests must be made basin by basin and must consider the full costs of control as well as all benefits.[2] The benefits arise from long-term reduction in pumping lifts[3] and from improved abilities to implement conjunctive use[4] These benefits will accrue in all future years, but future years' dollar benefits must be discounted to the present for correct calculation of the benefits and costs.[5] The costs include legal and administrative costs to form a basin control system,[6] the ongoing management costs (which must also be discounted to the present for correct calculations), and the costs of metering groundwater extraction as required by the management plan. It is important to note that *anticipated* withdrawals in future years may not be the same as *current* rates of groundwater withdrawal, and this must be considered when calculating benefit-cost ratios for groundwater basin management. Available studies suggest to us that groundwater basin management is likely to be desirable in most areas of the state, but there are not sufficient data at present to draw completely firm conclusions on this matter.

3. *Control of rates of groundwater extraction is necessary to achieve efficient use of water. This may be achieved by determination of quotas or imposition of pump tax or a combination thereof. Only a few existing basins have such control.*

Of the very few agencies that do control extraction, most set their extractive tax at incorrect levels, or use the tax receipts to subsidize surface water consumption inappropriately, or do not allow fully optimal use of the groundwater basin to offset wet-dry cycles.[7]

[2] For purposes of this report, we will assume that groundwater basin management plans must pass a benefit-cost test before they are considered to be desirable, and when we speak of the desirability of such management plans, we always intend such a benefit-cost test to be requisite.

[3] See Wetzel, op. cit.

[4] See Jaquette, op. cit.

[5] For a discussion of benefit-cost analysis in water planning see Nancy Y. Moore, Morlie H. Graubard, and Robert Shishko, *Efficient Water Use in California: Water Supply Planning,* The Rand Corporation, R-2390-CSA/RF, November 1978. Identical considerations arise here.

[6] See Lipson, op. cit., for costs of recent adjudications.

[7] One important groundwater control basin, the Orange County Water District, meters production and imposes an extraction tax but is forced through its legal structure to use its groundwater tax receipts (especially the basin equity tax) to subsidize the consumption of surface water within its basin, which

4. *It may be desirable to institute groundwater management even when surface water is unavailable.* (This is discussed further below.)

Groundwater management plans in California have in the past relied to some degree on imported surface water to ease transition from an overdrafted basin to a controlled basin. This is not necessarily the only desirable strategy for all groundwater basins in California.

5. *Surface imports should be priced or valued at their full marginal cost to society in order to achieve optimal and efficient use of both surface and groundwater within the state (particularly if maintenance of the present (or future) levels of water using activity requires surface imports).*

If the water is not valued as highly as the costs of bringing that water into the basin, then water using activities should logically decline. (We will discuss below the mechanisms by which such transitions can be made, the methods of sharing the costs of transition (or, put differently, the methods of sharing the gains from groundwater basin control among all current water users), and the anticipated patterns of land use under an optimally controlled groundwater basin.)

6. *The state is in the best position to define groundwater basins or subbasins (zones of benefit) in a comprehensive and mutually exclusive manner.*

By so doing, the state can guarantee that every groundwater using area is involved at least potentially in a basin control plan, and the problem of free-riders can be eliminated. Recent legislative action has initiated this type of activity.

7. *Local control of groundwater basins will be the most desirable for California, given the basin definitions established by the state.*

We belive this to be true because of economic, and political factors. These issues will be discussed below in further detail.

8. *Optimal conjunctive use of surface and groundwater cannot be achieved without basin management.*

Because of the difficulties in achieving optimal conjunctive use of surface and groundwater without basin management, we believe that the state has a bona fide interest in establishing groundwater control. Should local management fail to materialize, there are several options open to the state. An obvious sanction is to reduce or eliminate new surface water deliveries. If the constitutional requirement for reasonable and beneficial use is interpreted to require efficient water use and hence to require groundwater management, the state has a mandate to proceed with groundwater management directly, either through organizing a local control agency or through direct state control. This appears to us to be an issue of constitutional interpretation and concerns the appropriate role of different levels of government, and hence is not a problem readily resolvable by our research. If the state

leads to overconsumption of water in that area. This occurs because the OCWD has no real purposes to which the pump tax revenues can be put, except to reduce surface water prices to water users. It may be necessary to modify the mechanism of control, or the legal abilities of the managing district, to avoid such problems (see below for a further discussion).

takes such a role, it must assist in conducting benefit-cost analysis of basin control plans, e.g., by providing technical assistance to local agencies.

9. *The state has a clear role in producing and analyzing data necessary to control groundwater basins.*

Past state activity in this area, including cooperation with the USGS, has diminished. We believe that much better basin hydrology and extraction data are required to manage effectively most groundwater basins in the state. Such data are not currently available, nor do we know actual extractive rates, except through crude and sporadic data sources.

10. *The state should modify its own water pricing policies to conform to criteria of efficient use.*[8]

If pricing policies are modified, the state's own surface supplies will not inappropriately subsidize water users involved in replenishment activities.

11. *The state should establish a general groundwater basin management district act which could be employed throughout the state.*

Such an act, with generally flexible powers, could facilitate achieving basinwide groundwater management. This is analogous to the state's current assistance to surface water agency and air pollution control district formation.

12. *The state should also establish mechanisms to quantify overlying pumping rights and to facilitate their being traded or sold.*

As we discuss in more detail below, the recent San Fernando decision, by restructuring mutual prescription as a basis for establishing pumping quotas, also apparently restricted the possibility for quantification and selling or trading of rights by overlying pumpers. Thus legislative action to increase the ability to quantify and trade these overlying pumping rights may prove desirable.

CONSEQUENCE OF ADOPTING BASIN MANAGEMENT

The Time-Path of Basin Extraction

The amounts of water extracted from a basin and the timing of those extractions are of obvious importance to basin pumpers. The perceptions of how basin control would affect the amounts and timing of pumping and the extent to which the controls would affect individual pumpers determine in a large part the support for or opposition to a basin control plan. In this subsection, we compare the rates and timing of groundwater extraction under free entry (as is commonplace now in California) with the situation that might be expected under a groundwater control plan.

The Free Entry Case. Under free entry and uncontrolled extraction from a groundwater basin, the typical time-path of basin extraction would be for the groundwater level to decline systematically through time until the private pump-

[8] See Phelps et al., op. cit.

ing costs exceeded the benefits from pumping. At such a time, some producers would reduce or eliminate their extraction (in farming, typically, those with the least productive lands, the highest pump lifts, or some combination thereof), and the basin extraction would come into an ultimate equilibrium with natural rates of recharge. Where artificial recharge is used, the ultimate equilibrium will be reached at a later date, and the equilibrium pumping quantities will equal the natural plus the artificial recharge, on average. We would expect year-to-year variation in pumping rates as the value of water used on the surface changes (e.g., with crop prices changing), or as the cost or availability of surface water changed. The interim years of pumping activity, between initial extraction in a basin and the time when the ultimate equilibrium is reached, would find larger rates of water use occurring than in the ultimate equilibrium.

The higher rates of extraction during earlier years (groundwater mining) produce a penalty in later years in the form of higher pumping costs to all those who are still using the groundwater basin. This must occur because the basin level generally declines until it reaches an equilibrium level that is lower than what it was in intervening years. The level of the basin must also be lower (higher pumping costs) than would occur with an effective basin control plan in operation, so that pumpers' costs are *forever* higher in the uncontrolled basin after the equilibrium is reached than would be true in a controlled basin. It is exactly this tradeoff—higher pumping costs later versus more water in the present—that optimal basin management seeks to balance.

The Controlled Basin Case. In a well-controlled groundwater basin, a similar —but not identical—time pattern of groundwater pumping would emerge. Initially, with high groundwater tables, it would probably be optimal to mine the basin, so that extraction would exceed natural recharge and the basin level would fall. But the rates of extraction would take into account the common pool costs imposed by each pumper on all other pumpers. (The control could either be a pump tax, a constraint on the actual rates of pumping, or combinations of these strategies.) The ultimate equilibrium pumping—where extraction equals natural recharge—would occur sooner than under free entry, and the groundwater basin would be stabilized at a higher level. All groundwater pumpers using the basin at that time would forever enjoy reduced pumping costs relative to what they would have experienced in an uncontrolled basin. The equilibrium amount of water used in the eventual equilibrium would be similar to that found in an uncontrolled basin, but the groundwater basin water level would be higher and pumping costs lower.[9]

What Happens During Intervening Years? In every groundwater basin plan, the controlling authority (a water district, an adjudication plan, or a contract between pumpers) must decide who gets to pump the groundwater available and who will have to cut back pumping. The essence of basin management is to control the amounts of groundwater extraction, which necessarily means that some (or all) pumpers will have to use less groundwater than they otherwise would *in the early years of the basin management.* During the later years of the basin's history, total pumping rates will tend to be the same with or without a basin management plan, which raises the question of how to compensate those parties who reduce their pumping under the basin management plan.

[9] For a discussion of these issues, see Wetzel, op. cit., and the references contained therein.

In most current California basin control systems, interim users—those whose pumping largely contributes to the overdrafting of the basin in the short run—are supported by imports of surface water supplies. Existing groundwater management authorities have in general chosen to keep all water users within the basin at least to their historical water using levels through imports of sufficient surface supplies to offset any reductions in groundwater use imposed by basin management. This has usually been accomplished by selling surface water to those users at a cost below the true cost of importing that surface water into the basin.[10]

As a general rule, *it is not necessarily desirable to continue total support of all water using activities within a basin when groundwater management is imposed.* Under efficiency criteria, any subsidized supply of water causes inefficient use of water and hence is undesirable.[11]

If overall water use in a groundwater basin declines as control is introduced, it may be politically necessary to compensate those persons who reduce their water use to support the basin management. For example, if the state imposed a pump tax but sent the revenue to general state funds, most or all pumpers in a given basin could be made worse off, even though overall the state would be better off. Similar problems could emerge in decisions about allocating pumping quotas among basin pumpers.

The ultimate effects of groundwater management on farm output and farm profitability are impossible to quantify explicitly at this point, but some general conclusions can be reached. Perhaps the most important point to make is that farm profits in the controlled basin will be larger in the long run than they would be in an uncontrolled basin, so long as the administrative costs of forming and continuing the basin management plan do not exceed the gains. Whether the gains are sufficient to support a basin management plan in each groundwater basin is an issue that must be studied for each basin, taking into account the number of parties involved, the type of management plan chosen, etc.

Next, we must consider the effects on farm output. In general, controlling a basin will lead to less water use in the short run, but the same general amount of water use in the long run. The difference is that in the absence of a control plan costs of farmers will be higher in the long run. In the intervening years (those between introduction of basin control and the time when the eventual equilibrium is reached), water use (and hence probably farm output) will be less or of a different type in the controlled basin than in an uncontrolled basin, possibly causing higher food prices in the intervening years. (If such is true, then the same reasons will cause food prices to be lower in those years of eventual equilibrium pumping.)

There are several mechanisms by which a groundwater control organization (district or adjudication) could share the gains from groundwater control with all pumpers in a basin, *even those who would normally be forced to exit from pumping in an uncontrolled basin.* There appears to be a case for using quotas in the management plan, rather than taxation and redistribution, to accomplish the desired sharing of the gain from basin management. Pumping quotas can be assigned on any basis, including (presumably) past pumping records or estimated past

[10] See Lipson, op. cit.

[11] The efficiency test to be applied is to ask whether the benefits from using the additional water exceed the costs of supplying that additional water. If this test fails, i.e., if the marginal costs of the water exceed the marginal benefit to its users, then water use should stabilize or decline, and the water supplies should be used elsewhere (where they are more highly valued).

groundwater use, or even per unit of land, independent of past pumping use. If such quotas are transferable within the basin, then the use of the quota can go to the pumper who finds it most valuable, whereas the wealth associated with the right to pump can be retained by the original right-holder.[12]

The benefits from controlling basin pumping (or, put differently, the costs of not controlling basin pumping) accrue to different people, depending upon when basin control is instituted. If no controls are ever established upon basin pumping, then the costs will eventually be borne by those water users who remain in pumping activity as groundwater levels fall to their eventual equilibrium level. (This is the level at which enough pumpers cease pumping activity, due to high pumping costs, that extraction is just equal to replenishment.) Typically, such pumpers will be agricultural water users, and those remaining in pumping activity will be those with the most productive land, lowest pump lifts, or combinations thereof. If basin control is put in place immediately, and the mechanism of control does not compensate in any way those whose pumping is diminished or ceases, then those landowners who reduce pumping bear the brunt of establishing basin control, and those who sustain their pumping activity reap the benefit. Typically, we would expect the "losers" in such a scenario to be those with the least productive lands, those with the highest pumping lifts, or combinations thereof. Basin management, particularly with tradable quotas distributed on the basis of past pumping activity, offers the possibility of sharing benefits of basin control among those who remain in pumping as well as those who eventually cease pumping. Those who cease pumping can sell their water rights at prevailing market prices. Those who continue to pump have potentially valuable tradable rights.

The transferability of quotas is important, if not crucial, in achieving efficient use of the water resource at minimum total pumping cost, particularly if the quotas are issued to preserve a given distribution of income, rather than to minimize total pumping costs. It is for this reason that we believe the state should adopt a legal change allowing transfer of quantified overlying pumping rights.

The San Fernando decision had two major effects on adjudications, one better known than the other. The effect on the ability to force municipalities into an adjudication is well known.[13] The sole adjudication completed after the San Fernando decision (the Chino Basin) did not quantify the rights of overlying agricultural users. All overlying rights (i.e., agricultural and nonagricultural) were determined to be "appurtenant to the land" and not separately transferable, whereas appropriative rights of public entities and private water companies are transferable.[14] The inability of overlying pumpers to sell or trade their pumping rights appears to us to be a serious stumbling block in achieving truly efficient use of groundwater basins. This suggests that a method of allowing participants in an adjudication to quantify and trade quotas arising from overlying rights would be important to achieve. Specific legislative action appears necessary to accomplish this.

We had previously discussed the difficulties that water districts appear to encounter in disbursing pump tax revenues (or other net revenues from operations)

[12] The transferability may cause increases in pumping cost beyond the optimal level in some circumstances. This occurs if there are local (within-basin) zones of depression of the groundwater table that affect more pumpers than would arise with the same pumping taking place in other locations. This problem is considered in part in Wetzel, op. cit., but deserves further study.

[13] Anne J. Schneider, *Groundwater Rights in California, Background and Issues*, Governor's Commission to Review California's Water Rights Law, Staff Paper No. 2, Sacramento, California, July 1977.

[14] See Jaquette, op. cit.

to basin pumpers or other residents of the district. This suggests that it will be more difficult to find a method of compensating those landowners who are currently in active production, but who would find continuing groundwater use uneconomical or unprofitable if subject to a significant pump tax. If some lands were taken out of water using activity, tax receipt distribution by means of a stepped (increasing block) pump tax would become irrelevant because some landowners would pump no water. Thus only direct property tax reductions or rebates would be available to compensate such landowners. One alternative available to the water district (or, for that matter, in an adjudicated agreement using some tax-like pumping assessment) would be to purchase some lands from farmers, and withhold them from water using activities. While conceptually workable, there would be in reality some substantial difficulties in using such a tool to manage a basin optimally. For example, it is desirable, as crop prices rise or surface water prices fall, to put more land into agricultural production, if only for an interim period. With a quota or tax system, the extraction incentives can be altered rapidly by proportionately increasing or decreasing every quota by a given percentage. With a water district attempting to control water extraction through land purchases, the land would probably have to be resold or leased to achieve temporary increases in the amount of crop production within the basin, and this cannot be accomplished as rapidly as a quota change. Further, the district would then face the problem of disposing of the receipts from the land sale or lease, thus generating problems similar to those a district faces when trying to distribute pump tax receipts generally, or even when distributing receipts of surface water sales.

The Issue of Conjunctive Use Storage

One additional benefit of a groundwater control system is the potential to establish clear rights to the use of dewatered spaces to store imported water for carryover to dry periods (when surface supplies are reduced). A local groundwater management entity, whether district or adjudication, could in concept undertake conjunctive use itself, buying and percolating surface supplies when they are plentiful and cheap, and extracting for later use or sale when water becomes scarce or expensive.[15] If the agency controlling the basin has sufficiently flexible powers to distribute the net receipts from such an activity, it does not matter whether the state or the local management entity conducts the actual conjunctive use operation. The local entity could carry out the procedure itself, or it could in effect lease out the rights to store water in the basin. Alternatively, if the rights to use that storage space are assigned to the state, then the rental relationship might be reversed. What is important is that the rights to use the storage area become clearly defined. In current practice, compensation is provided to large numbers of persons for oil pumping royalties, even for homeowners in large cities. Perhaps similar direct compensation for storage space use is also feasible.

Court decisions from the San Fernando and Niles Sand and Gravel cases have established the rights of public agencies to store, and then later extract, water in groundwater basins. What has *not* been determined is how priorities become established if different parties wish to have access to underground storage for conjunc-

[15] Adjudications in the Main San Gabriel and Chino Basins provide for storage agreements. (See Jaquette, op. cit.)

tive use. If local basin control entities are established, it seems plausible although not necessarily essential that they have first rights to conjunctive use. However, the key element is that the rights to access can be determined; this seems to be fertile ground for legislative action.

SUMMARY OF CONCLUSIONS

Groundwater management is a crucial component of California's water use efficiency. The need for management is based on the desirability of correcting inefficiencies that inevitably arise from common pool extraction now occurring throughout the state's groundwater basins. At present this inefficiency primarily hurts the local pumpers themselves. (Some individual pumpers, however, are not hurt under current extraction as they benefit at the expense of others on the basin.) In addition, some economic loss due to this inefficiency extends to others throughout the state because opportunities for conjunctive use are restricted, and the possibility exists for over-reliance on surface water development in unmanaged, overdrafted basins.

A more open market system of freely transferable and transactable water would move the state toward water use efficiency. This will further increase the opportunity for profitable returns from conjunctive use. Groundwater basin owners can contribute to efficient water use in the state and profit economically as well by cooperatively managing their groundwater basin. They can accomplish this by developing a management plan and a management entity that would negotiate for the terms and rents of groundwater storage space, sell groundwater, redistribute profits, and correct the inequities resulting from the current unmanaged "common pool" groundwater basin.

We do not feel that any one form of groundwater management is to be preferred over any other. The costs of forming and maintaining specific types of management will vary, depending upon the number of persons, corporations, and public entities involved in basin pumping, the hydrology of the basin or subbasin, and the strength of local water industry leaders in their areas. Since the costs of management are an important determinant of the true efficiency of basin management, it will be important to allow flexibility across regions in choosing the most appropriate form of management. The tools of management—quotas, pump taxes, or combinations thereof—are readily available and can in concept be adopted to local conditions to achieve efficient water use. An important role for such management entities to play is distributing (or redistributing) the economic gains associated with basin management. Most important for achieving efficiency is that the redistribution be done in a way that does not lead to incorrect incentives for water use. Most important for establishing political support for groundwater management is that it be done equitably.

Appendix A

GROUNDWATER MANAGEMENT POWERS IN CALIFORNIA

California has a wide variety of groundwater programs and activities that affect the state of the resource as well as patterns and amounts of use. The most direct and explicit control of groundwater occurs in Southern California. The most use of the resource occurs in the San Joaquin Valley, and the most potential for additional groundwater utilization is in the Sacramento Valley. In this appendix we summarize the most prominent groundwater activities in California. In addition, we delineate the current role of federal, state, and local agencies in groundwater management and use.

The term groundwater management can be interpreted in many ways. To some it means importation of surface water to slow overdrafting, to others it means artificial recharge, and to still others it is the use of a pump tax. Our working definition of groundwater management is based on efficient use and follows from previous discussions of the common pool problem and conjunctive use. We conclude that *total* groundwater management includes the *power* to control extractions, to tax extractions, and to store and recover excess surface waters underground.

THE ROLE OF THE FEDERAL GOVERNMENT IN GROUNDWATER MANAGEMENT

> The Federal Government does not have a direct role in the management of ground water resources except on public lands. It does provide assistance to State and local agencies with management responsibilities. The major contributions are providing data and technical assistance and assisting in increasing available water supplies.[1]

Although the federal government through its various departments and agencies has vast powers and priority in the water field, the federal role in groundwater is minimal. In California the Bureau of Reclamation, the Geological Survey, and the Army Corps of Engineers provide the major federal input to water matters. The Fish and Wildlife Service, Soil Conservation Service, Department of Defense, National Forest Service, and Bureau of Indian Affairs have minor influence on water management.

The U.S. Bureau of Reclamation's mission is reclamation of arid lands through water project development. The bureau's position is

> ... that the Federal Government should not be directly involved in the management of ground-water basins. The management of ground-water basins is not a Federal responsibility, and ... should be handled by State or local agencies under the various authorities available or made available by State law.[2]

[1] U.S. Government, General Accounting Office, *Ground Water: An Overview*, June 21, 1977, Washington, D.C., p. 20.

[2] Remarks by Billy E. Martin, Regional Director, Mid-Pacific Region, October 1977.

The bureau does conduct groundwater studies for project planning investigations, preconstruction, design data, construction work, water contract negotiations, and operation plans. It does not perform long-term studies (a USGS role). Typically, the bureau studies the groundwater geology, depth, movement, quality, recharge, overdraft, usable storage, use, and pumping costs. Pumping is usually estimated from crop data and knowledge about average water use per crop. If actual pumping amounts are needed, the USGS provides estimates of pumping from power records.

In California the bureau's Sacramento Office summarized past groundwater investigation in a 1976 groundwater studies document.[3] The office often cooperates with the USGS and the DWR on these studies. In addition, the office continually monitors groundwater levels and estimates pumping and groundwater storage changes in selected areas.

The primary mission of the Army Corps of Engineers is flood control and navigation. Their role in groundwater is minimal. The corps does monitor groundwater at a few locations and several multipurpose corps projects have included specific authority for spreading or replenishing groundwater supplies. But local agencies divert and spread the water.

Unlike the bureau and Army Corps of Engineers, which are action agencies, the USGS is a research and data-gathering agency.

> U.S.G.S. provides data and technical assistance for ground water management through its Federal/State Co-operative Program. Under this program, the Federal Government and over 500 State and local agencies share cooperatively in the cost of U.S.G.S. Performing investigations and research programmed in collaboration with State and local agencies. These cooperative projects are designed to provide the continuing appraisal of water quantity and quality and to improve hydrological information and understanding and make the results available to Federal, State, and local agencies for use in developing, utilizing, conserving, and managing water and land resources. More than half of the water resources data gathered in the United States, including most stream gauging, is provided by the cooperative program . . .[4]

The California District Office of the USGS conducts cooperative studies with about 120 local agencies, sharing the cost 50-50. Their largest cooperator is the DWR. In fact, the district often has a backlog of cooperative programs because of personnel or funding constraints.

At one time the California District was involved with the DWR in a large cooperative program to estimate groundwater pumping from well power records (pumpages are valuable inputs to any management or modeling plan). In the early 1970s the DWR changed priorities and the program was essentially stopped. The USGS continues to collect pumping power records, but it does not convert them to pumpages, except when studies are specifically funded.

The USGS has developed several general groundwater models that the California District has applied to selected local basins. The biggest problems with model application are data availability and model verification, and of course application of these models requires funding and support from local agencies.

[3] *Total Water Management Study for the Central Valley Basin, California*, "Environmental Baseline: Ground-Water Studies," Bureau of Reclamation Mid-Pacific Region, Working Document No. 3E, March 1976.

[4] *Groundwater: An Overview*, op. cit.

CURRENT STATE ROLE IN GROUNDWATER MANAGEMENT

Legal Authority

The state's role in groundwater management can be separated into two categories: the state's legal authority and the state's actual actions under this authority. California's Water Code (Sections 2100-2102) sets forth the state's ability to enter into active groundwater management. The SWRCB may now initiate actions to restrict pumping and may propose physical solutions to prevent injury to the aquifer. The state may not invoke the statutory adjudication process, available for use on surface water (Sections 2500-2900), and is limited to investigations and hearings to determine the necessity of adjudication. Also, the SWRCB can enjoin pumping from basins suffering from salt water intrusion while adjudication is in progress. The state currently requires recordation of water extractions in certain southern counties.

The Porter-Dolwig Groundwater Basin Protection Law (1961) declared that the people had an interest in correcting and preventing damage to groundwater basins. It instructed the DWR to conduct investigations and studies for projects to accomplish this purpose and to provide local agencies with technical assistance for collecting information, making recommendations, and modifying proposals that would protect the groundwater resources of the state. The original act provided financing which was withdrawn in 1967.

Unlike surface water statistics, those for groundwater are not automatically recorded. As previously mentioned, groundwater use is not tied to the appropriative permit system administered by the SWRCB. Furthermore, most water districts throughout the state excercise no powers over groundwater. Consequently, the DWR has to estimate most groundwater use. The DWR also gathers groundwater data on quality, water table fluctuations, and management activities.

The DWR's statutory authority to conduct studies of subsurface water conditions is in Section 226 of the Water Code. The Porter-Dolwig Groundwater Basin Protection Act, Water Code Section 12920, and Water Code Section 231 also convey groundwater investigative authority to the DWR. The state conducts studies, models groundwater basins, and acts as Watermaster for several adjudicated basins.[5]

DWR Conjunctive Use Proposals

The Southern Regional Office of the DWR conducted one of California's first major groundwater studies during the 1960s.[6] Over fifty physically different ways

[5] A Watermaster divides the waters of streams or other sources so as to insure a distribution among users according to existing rights. Watermaster committees are appointed by the DWR (California Water Code Sections 4050 and 4151).

[6] The findings are reported in State of California, Department of Water Resources, *Planned Utilization of Ground Water Basins: Coastal Plain of Los Angeles County*, Bulletin No. 104, Sacramento, California, September 1968; and State of California, Department of Water Resources, "Operations and Economics," Appendix C, in *Planned Utilization of Ground Water Basins: Coastal Plain of Los Angeles County*, Bulletin No. 104, Sacramento, California, September 1966. The report conducted economic evaluations of alternative operation plans out to the year 1990. The study concluded that (1) barrier injection is preferred to raising the basin's water level as means to offset salt intrusion, (2) changing the geographic aspects of pumping (spatial pattern of extractions) produces a very minor cost difference (however, a shift of coastal pumping to inland locations produces a beneficial effect on barrier injection operations), (3) the price of imported water and the price differential between groundwater recharge water and surface water are the principal determinants of alternative plan costs.

to extract and spread water, to install injection barriers, and to import supply, varied by time and location, were evaluated. The report assumed that groundwater extraction only up to safe annual yield would be imposed under all alternatives in 1990 and that before 1990, mining would persist under some strategies. Mathematical models were used to estimate the movement of underground water.

More recently DWR's Southern District has researched long-term storage of SWP water in dewatered spaces of Southern California's groundwater basins.[7] Because median water supplies in the Delta can provide more water than is needed to meet contractual commitments and expected surplus requests, the DWR could convey about 2.6 MAF of surplus water south of the Tehachapi Mountains between 1975 and 1982.[8] Available underground storage exists in the San Fernando Valley Basin, the Chino Basin, and the Bunker Hill Basin.

During basin charging years, groundwater levels would rise about 100 ft above current levels. As SWP contractors take increasing contracted amounts, excess water becomes unavailable, and recharge halts in 1983. This coincides with anticipated electricity rate increases for power to transport water. Because projected supplies equal demand between 1983-1989, water would remain in underground storage. SWP contractors' demands are scheduled to exceed state supplies after 1989, and from then on the stored water would be used to meet the need, and construction of additional surface water facilities would be postponed. All SWP water stored in Southern California groundwater basins would be extracted by 1995.

The present worth of net benefits to the SWP and to the state from this proposal is almost $100 million. Unfortunately, SWP contract changes and institutional cooperation to distribute gains are necessary before the proposal can be implemented. In addition, a number of assumptions in the report are outdated. Accounting flaws exist in estimates of project power pumping costs and perhaps in other pumping costs. In lieu recharge and subsequent monetary benefits were not considered or included. These minor flaws probably would not make the proposal uneconomical if corrected.[9] The present value of deferring large capital expense for new surface facilities is the program's major benefit.

DWR Bulletin No. 118 (op. cit.) summarizes information collected by the DWR, the USGS, and other agencies, in addition to basin information. The report updates current use and potential for management improvements and surveys groundwater conditions and current management problems. The DWR notes that limited conjunctive use has been taking place in California without state planning. While conjunctive use is clearly beneficial to the users, a number of legal and institutional roadblocks prevent further expansion.

[7] State of California, Department of Water Resources, *Groundwater Storage of State Water Project Supplies*, Southern District Report, June 1974.

[8] The capacity of conveyance facilities limits maximum delivery to 2.6 MAF, and contractual commitments limit availability of excess waters to 1975-1982. Benefits of the program include: (1) less pumping lifts for 20 years for all groundwater basin pumpers, and (2) deferment of SWP construction and carrying charges of a major surface supply addition for six years. Program costs include: (1) electricity cost of pumping over the Tehachapis, (2) interest costs on money spent during the early years, and (3) groundwater pumping costs.

[9] We have not thoroughly reviewed the DWR's conjuctive use study and thus we cannot comment upon its desirability. The concept appears sound. Similar studies continue within the DWR. Bulletin 186 on the San Fernando conjunctive management experiment is expected shortly.

Statewide the DWR has been studying augmentation of state water supplies through large-scale groundwater conjunctive management. DWR's ongoing and planned groundwater studies primarily deal with its investigations of Delta alternatives. This augmentation plan, expected to yield 0.4 MAF annually, was included as part of S.B. 346, the Peripheral Canal bill proposed in 1977, but the proposal has met with considerable opposition from local groundwater users.

DWR's Modeling Role

The DWR has constructed mathematical models for selected groundwater basins. The models, which require large computers, can determine the effects of artificial recharge and extraction on water quantity and quality as well as determine quantitatively physical and economic effects of various management plans. Currently models exist for the Kern-Tulare Basin, the San Gabriel Valley, the Chino-Riverside Basin, the Central Basin, the West Basin, the Ventura-Oxnard area, the Santa Paula (Santa Clara River Valley) area, the Santa Clara (County) Valley area, and the Livermore and Sunol Valleys, Sacramento County area.

DWR's Watermaster Service

The DWR has been appointed Watermaster of several groundwater basins. During a groundwater adjudication, the DWR and SWRCB may act as scientific advisors to the court. After a basin's water rights have been adjudicated, and with court approval, DWR may administer the decision by keeping accounts of water consumed and managing the basin within court-established limits. Pumpers pay one-half the costs of Watermaster service and the state subsidizes the rest.

As Watermaster, the DWR may change the split or total amount of extraction permitted if conditions warrant such actions. For example, drought-caused limits on surface water deliveries may justify temporary mining. Examples of basins with this type of Watermaster include the Central Basin, the West Basin, and the Raymond Basin.

A basin need not be adjudicated to request DWR's Watermaster service. A mutual agreement to regulate basin pumping can lead to appointment of a Watermaster such as the DWR or even local water districts.

LOCAL GROUNDWATER MANAGEMENT

California's groundwater is currently managed at the local level, since neither the state nor the federal government actively manages groundwater. Most of California's groundwater basins have not been adjudicated and have no central basin-wide management authority, although a substantial number of local water agencies have some local groundwater management programs. As we will summarize below, the large majority of such programs rely upon supplementing groundwater supply with deliveries of surface water or recharging of groundwater basins, rather than explicitly controlling groundwater extractions within the basin. These programs, which exist to some degree in many parts of the state, were developed to solve problems of sea water intrusion, subsidence, declining water tables, and quality degradation. Appendix B describes the actual practices of groundwater management programs; we summarize here the legal authority of various water agencies to undertake groundwater management programs in California.

Legal Authority for Groundwater Basin Management

1. The Local Water User. As outlined previously, the rights of the local water user to control groundwater depend almost exclusively upon his rights to use groundwater, i.e., his ability to extract water under overlying use rules or for appropriative (nonoverlying) use. To control other pumping in a basin, the individual groundwater pumper may either seek a cease-and-desist order from the courts, if the pumper feels he is being damaged by other pumpers, or he may seek an adjudication of a basin through court action, a costly and time-consuming procedure.

2. Private and Public Water Companies. Relying primarily upon appropriative groundwater rights for any groundwater supply, these companies are essentially in the same position for groundwater management as the individual groundwater pumper.

3. Municipal Water Departments. A substantial number of municipal water departments depend, at least in part, on groundwater supplies to provide water for their customers. Typically, the municipality and the groundwater basin do not coincide in boundaries, so that the municipality is unable to control basinwide extraction completely, or sometimes even partly. Their basins are shared with other users, including agricultural, industrial, and other municipality pumpers. Cities do have limited abilities to restrict pumping of residents and other domestic and commercial users of groundwater, for example through health ordinances. A few cities engage in recharge programs with surplus water.

Two cities—Los Angeles and San Diego—have pueblo groundwater rights, stemming from Spanish law, providing them rights to water that are generally superior to rights arising later in time. Los Angeles also has unique groundwater extraction programs in the Owens Valley, which provide a significant supply of water for the city.

Water District Management

California has about 1000 water districts. These districts fall into two categories: those formed under general district acts and those formed by special district acts. California has about 40 different general water district acts and 100 special water district acts, each conferring differing powers and responsibilities.

Areas with water problems, particularly groundwater problems, either created a special-act district to solve their problem or selected a water district type most able to meet their needs. If an area's needs changed, they changed their district type, changed their district type's powers, sought special district powers, or broadly interpreted existing district powers.

Water Districts—General Act. Most water districts are given general powers to acquire, store, distribute, and dispose of water to the benefit of members of the district. On numerous occasions, these general power statements have been used to support groundwater activities by local water districts, particularly groundwater recharge programs. Some districts are also given explicit groundwater management power. We summarized these in Table A.1.

Table A.1

GROUNDWATER MANAGEMENT POWERS

Type of District	Spread, Sink, or Replenish	Pump with District Wells	Monitor or Meter Wells	Tax Pumpage	Replenishment Assessment	No Specific Powers
Irrigation Districts	x					
County Water Districts	x					
Municipal Water Districts	x				x[a]	
County Waterworks Districts		x				
California Water Districts					x[b]	
Metropolitan Water Districts						x
Water Storage District				x		
Water Conservation Districts						
1931 Act	x	x	x	x	x	
1927 Act	x	x[c]				
Water Replenishment Districts	x				x	

[a]In special cases only.

[b]Only specified districts mentioned in Section 55335 of the California Water Code.

[c]They must have begun before October 1, 1953.

We have formed impressions, through our field surveys of water district operations, about the extent to which actual groundwater management activities are ongoing in California. We summarize these impressions here, with the caveat that they are not necessarily representative of what occurs in the state as a whole.

California has districts involved in varying levels of groundwater management and use. In districts where groundwater supplements or is supplemented by surface water, management ranges from complete noninvolvement through measurement of water table fluctuations to district ownership and pumping of wells.

Irrigation Districts. We observed a large number of districts intentionally recharging groundwater. One district owns and operates wells. We did not find irrigation districts metering private wells or implementing districtwide control of pumping.

County Water Districts. We found districts with sinking basins and groundwater recharge programs, with district-owned wells, and one district that sought and obtained in 1978 (A.B. 2513) special permission to levy a pump tax. Some districts finance groundwater programs through taxes, while others impose user charges or plan to use pump taxes.

Municipal Water Districts. A large portion of these districts were formed to contract for surface water delivery. Hence very few districts have recharge programs and pump assessments, although many purchase recharge water for other agencies to spread. We found a few municipal water districts that spread water themselves. However, most such services were financed by ad valorem taxes rather than pump assessments.

County Waterworks Districts. We did not observe any county waterworks districts with any form of groundwater management.

California Water Districts. We observed several districts with active groundwater recharge programs. We also found a district with plans to integrate ground and surface water operations using district-owned wells (in addition to private pumping). We also found California water districts with no groundwater programs.

Metropolitan Water Districts. There is only one such district in California, the water wholesaler—Metropolitan Water District of Southern California. While not directly involved in groundwater management, it sells replenishment water at a lower rate to encourage groundwater replenishment. In addition, the district collects revenue from ad valorem taxes, thus lowering its overall water rates, including its replenishment rate, below the average cost of development.

Water Storage Districts. We found several districts with very active conjunctive use programs. These districts own wells, which they use to supplement surface water deliveries in dry years. The districts also have spreading grounds for recharge in wet years. These districts did not meter private wells. Hence, district lands that rely on private wells for water are assessed acreage charges for groundwater operations. Unfortunately, none of these districts has complete control of a groundwater basin, hence outside pumpers receive free benefits from their conjunctive use operations.

Several other water storage districts have varying levels of recharge operations. However, we know of no water storage district using a pump tax.

Water Conservation Districts. Water conservation districts formed under the 1927 Act may replenish water but do not have the power to levy a pump tax, and they may not acquire groundwater. We found districts formed under the 1927 Act with active replenishment programs which they finance through ad valorem taxes. We also found districts formed under the 1931 Act with similar operations and financing even though they explicitly have the power to levy a pump tax.

Water Replenishment Districts. Only one district, the Central and West Basin Water Replenishment District, has been formed under this act. The district currently owns extensive recharge facilities. It purchases imported water (at $98 per acre-foot in 1978-1979) and reclaimed water (at $7 per acre-foot) for recharge. The district also purchases water for injection against salt water intrusion. The district's water costs are recovered through pump assessments (about $24 per acre-foot in 1978), and management and operation costs are covered by ad valorem taxes. In addition, the district has an in lieu replenishment program which reimburses pumpers for not pumping. Currently the Los Angeles County Flood Control District operates the district's recharge and well injection programs at no charge.

Water Districts—Special Act. Because special-act districts are unique, a discussion of the powers and actions of those involved in substantial groundwater activities is included in Appendix B on Existing Management.

Appendix B

EXISTING BASIN MANAGEMENT

Appendix A described the wide variety of groundwater related powers water agencies have and the diversity of agency actions directed at or resulting in some level of groundwater management. We do not wish to ignore the benefits of these many programs. However, we do want to stress the advantages of basinwide management. We focus now on the diversity and degree to which basinwide management exists in major California basins.

Basinwide or subbasin management is needed to solve the common pool problem and to maximize conjunctive use of groundwater. By basinwide management we mean that a water agency, group, or agencies, or delegated management group or agency, collectively have the powers (and exercise them) to meter wells, tax pumping, control extraction, buy water for recharge, and store water throughout the groundwater basin. In addition, the management entity should be able to sell water out of the basin, if it desires, and to use or distribute the gains therefrom.

WATER AGENCY BASIN MANAGEMENT

Several California water agencies do completely overlie a groundwater basin or a well-defined subbasin. In fact, these agencies were often created or modified to solve groundwater management problems. We next describe their current management operations.

Santa Clara Valley Water District

The Santa Clara Valley Water District currently overlies Santa Clara County. The district was created in 1968 pursuant to a special act of the Legislature (S.B. 5-10).

Groundwater supplies about 55 percent of water used within the area served by this district. This yield is maintained partly by district percolation of imported and local surface water.[1] Currently the district fully utilizes available percolation areas. Hence, increased groundwater replenishment would have to come from an in lieu pumping program.

South Santa Clara County relies on local water supplies, primarily groundwater. The area has no well metering and no pump tax. Thus the district has management powers over a large groundwater subbasin, but not the whole valley basin. Although the district may meter and tax groundwater pumping, it may not restrict pumping. The Santa Clara Valley Water District uses its pump tax authority to recover costs of importing water and recharge operations. In addition, the 1968 Act restricts the magnitude of the pump tax the district can impose. Consequently, the

[1] Santa Clara County's recharge program evolved to combat historical groundwater overdraft that resulted in drastically lowered water tables, extensive land subsidence, and localized salt water intrusion.

district relies on increased imported surface supplies and waste water reclamation to balance its overdraft problems.

Orange County Water District

The Orange County Water District overlies the lower alluvial fan of the Santa Ana River in Orange County. A special act of the legislature created the district in 1933 to protect and manage Orange County's groundwater basin, which was in overdraft from excessive pumping and diminished recharge (because of diversions by upstream users). In addition the basin suffered from localized salt water intrusion.

The district act was amended in 1953[2] to allow a replenishment assessment (pump tax) on each acre-foot of water pumped. The district uses this charge to finance replenishment of accumulated and annual groundwater overdraft.[3] This replenishment assessment led to district registration and metering of wells.

The Legislature amended the Orange County Water District act again in 1968 to provide for a basin equity assessment. Under the terms of the act, the district's Board of Directors determines a ratio of groundwater to supplemental water that best meets the management needs of the area. In its decision, the board considers the amount of water currently in groundwater storage, the availability of both replenishment and direct service water through the Metropolitan Water District, and the problems of distribution, water quality, and water supply availability. The board then establishes a groundwater production percentage (60 percent for 1976-1977) that allows water producers within the district to maximize the advantages of groundwater storage without danger of overdrafting the basin. This percentage is applied only to users of other than agricultural water pumping more than 25 acre-feet per year. The water producers are not bound to this percentage; however, the district levies a basin equity assessment ($23 per acre-foot for fiscal year 1976-1977) upon pumpers removing water from the groundwater basin in excess of the established ratio of groundwater produced to imported water directly supplied. These assessments are then used to subsidize those users who, at the request of the district, increase their purchases of Metropolitan Water District water, which costs more than water pumped from the basin. Monies from the basin equity assessment can only be used to equalize costs of water production.[4]

United Water Conservation District

The United Water Conservation District overlies seven serially connected groundwater basins along the Santa Clara River in Ventura County. Started initially as the Santa Clara Water Conservation District, the district was reorganized in 1950 under the 1931 Water Conservation District Act.[5]

[2] At this time the district was also expanded to its present boundaries, which include all lands overlying the basin.

[3] The assessment is determined to be the amount of money necessary to purchase sufficient water to replenish the five-year average annual overdraft (the amount of water extracted from the basin above the average recharge), plus an additional amount of water to eliminate the accumulated overdraft for a period of not less than ten nor more than twenty years. The district's 1976-1977 replenishment assessment rates were $12 per acre-foot for irrigation water and $25 per acre-foot for other uses.

[4] OCWD *1976 Annual Report*, p. 39.

[5] The 1931 act provided better organization and financing.

The United Water Conservation District has a contract with Ventura County for 5000 acre-feet per year of SWP water. In addition, the district has two reservoirs, three spreading grounds,[6] a well field, and a pipeline and transmission facilities. To arrest salt water intrusion the well field of eleven wells provides surface water to the coastal plain in lieu of pumping.

The district finances its conservation and recharge program through a district-wide tax on all lands and improvements,[7] with users of pipelines and distribution facilities bearing the additional cost of those facilities. In the past the district did not meter wells or use a pump tax although it had the power to do so. Because pumping is not restricted, the district attempts to supply enough water to meet all demands. More recently California's property tax initiative has spurred the district to exercise its pump tax powers. The district hopes to use power records in lieu of costly water meters. Not surprisingly, area farmers are fighting the district's shift in revenue source.

Monterey County Flood Control and Water Conservation District

The Monterey County Flood Control and Water Conservation District overlies all of Monterey County, which includes the Salinas River Valley.

The district was created in 1947 by a special act of the Legislature primarily for flood control and water conservation. The district has two reservoirs that store flood waters for subsequent downstream groundwater recharge. All water used within the Salinas Valley is supplied from groundwater.

Although the district may spread or percolate waters, it does not have the power to levy a pump tax or meter wells. Thus, district operations are financed by ad valorem assessments on all property within the district. For taxing purposes the district has established zones of benefit with different rates.

Desert Water Agency and Coachella Valley County Water District

On July 1, 1976, the Desert Water Agency and the Coachella Valley County Water District entered into a water management agreement for the Whitewater River groundwater basin from Fingal Point to Point Happy. The agreement provides for monitoring of pumping, groundwater replenishment, and allocating the costs of purchasing and spreading recharge water. As a special-act district, the Desert Water Agency may replenish groundwater or deliver water in exchange for pumping reduction. The district may also require notices of intent to extract groundwater from persons drilling wells. (The Coachella Valley County Water District's groundwater powers were described previously under County Water District powers.)

Both agencies have amended their acts to levy replenishment assessments (pump tax). In addition, both agencies have contracts with the SWP for imported water. This water, currently exchanged by the Metropolitan Water District for Colorado River water, because of lack of transportation facilities, is jointly percolated into the underground reservoir. Each agency shares the costs of purchasing and spreading water in proportion to pumping within their boundaries.

[6] The district has been spreading water since 1928.

[7] This policy has led to cities within the United Water Conservation District bearing about 80 percent of water costs while using only 20 percent of the water.

San Benito County Water Conservation and Flood Control District

The San Benito County Water Conservation and Flood Control District is a special-act district that incorporates all of San Benito County and overlies the Gilroy-Hollister Valley Basin. The district may spread or percolate water and it may levy groundwater charges for production of groundwater in zones benefiting from recharge operations or imported water. The district act limits groundwater charges for agriculture and other water uses.[8]

Currently all water within the district is from unregulated groundwater pumping. Pursuant to receipt of Bureau of Reclamation water from the San Felipe Project, the district plans to meter wells and levy a groundwater pump tax of about $5 per acre-foot for agriculture and $29 per acre-foot for municipal and industrial users. The district will in turn annually use about 10,000 acre-feet of bureau water to recharge the basin.

BASIN MANAGEMENT BY ADJUDICATION

A number of groundwater basins in Southern California are currently managed through stipulated judgments of court adjudications. These adjudications were first initiated by local efforts to halt overdraft and control salt water intrusion. The management solutions to basin problems have evolved with time, experience, and knowledge to allow considerable flexibility in basin operation.[9]

MAJOR BASINS WITH PARTIAL MANAGEMENT

California's Central Valley has two extremely large groundwater basins that are not managed basinwide. These basins are the San Joaquin Valley Basin and the Sacramento Valley Basin. Each basin suffers to varying degrees from groundwater overdraft. The Sacramento Valley Basin has a relatively high water table; however, it averages about 0.1 MAF per year of localized overdraft. The San Joaquin Valley Basin, on the other hand, has a much lower water table (sometimes as much as 700 ft) and it averages about 2.3 MAF per year of overdraft with most occurring in the southern portion of the basin. The magnitude of each basin's estimated storage capacity (570 MAF for the San Joaquin and 113 MAF for the Sacramento) and their proximity to large surface water transportation and storage facilities have established them as prime candidates for basinwide groundwater management and conjunctive use. We have therefore included a discussion of existing localized management operations in each basin.

San Joaquin Valley Basin

The San Joaquin Valley Basin is located in the southern two-thirds of California's vast Central Valley. The basin has two major subbasins, the San Joaquin and the Tulare. Although no one entity has management control over the entire basin

[8] Agricultural charges have a lower maximum rate than those for other uses.
[9] Lipson, op. cit., in a companion report, describes current basin management by adjudication.

or its subbasins, some thirty-five water agencies engage in intentional artificial recharge of the basin.[10]

The localized success of each agency's recharge operation depends on the location of the agency, its available water supply, and water use. For example, we found a water district with a recharge program and adequate water supplies to meet the needs of its service area. However, the district is surrounded by areas with insufficient water supplies. Hence, there is a net outflow of groundwater from beneath the agency service area in spite of the agency's recharging efforts. On the other hand, a similar district in a semi-isolated area of the basin has lost very little percolated waters to others.

Very few wells in the San Joaquin Valley basin are metered. Thus, most agencies finance recharge operations with property or land assessments. A few agencies own their own well fields or recharge facilities and they use these well fields to supplement surface supplies, particularly during dry years. However, most conjunctive use operations are at the individual pumper level, with farmers relying on groundwater when surface supplies are inadequate.

In Kern County in the Tulare Basin where overdraft is most significant, users have formed the Southern San Joaquin Ground Water Users Association. The stated objective of the association is the coordination and dissemination of information on groundwater management programs and cooperation with other bodies. The association reportedly supports solutions to the groundwater problem by importation of additional water, local control to the greatest extent possible, the avoidance of imposing burdensome restrictions and regulations unless the need is clearly indicated, and resorting to adjudication to solve problems in correlative use of groundwater only as a last resort.[11]

The Kern County Water Agency is the major water agency in the Tulare Basin. The agency overlies the basin area in Kern County and wholesales SWP water. The Kern County Water Agency has the power to store water, to meter wells, and to levy a pump tax in improvement districts. The agency has made limited use of these powers. Since most of the agency's water is obligated to agency contractors, very little has been available for recharge. Furthermore, the agency has metered wells only in a small urban area of Bakersfield. However, the agency has conducted extensive investigation and developed a groundwater model for much of its area. The Kern County Water Agency has taken the position that the most effective way to reduce groundwater overdraft is by importation of water rather than by adjudication.[12]

The history of water development in the San Joaquin Basin has been one of localized overdraft followed by surface water development which either relieved the overdraft problem or temporarily arrested it. Some of these surface water importation programs have stimulated successful localized conjunctive use programs. However, in many areas of the basin, overdraft continues. The likelihood that surface development will be sufficient to completely control the basin's overdraft problems is small given the high cost and environmental problems associated

[10] Department of Water Resources-San Joaquin District, *Artificial Recharge of Ground Water in the San Joaquin-Central Coastal Area*, May 1977.

[11] Stuart E. Pyle, "Ground Water Management in Kern County," *Proceedings of the Eleventh Biennial Conference on Ground Water*, California Water Resources Center, University of California at Davis, Report No. 41, November 1977, p. 17.

[12] Ibid.

with water development. Consequently, despite successful localized conjunctive use and management operations, the basin needs overall basinwide or subbasin management to solve its common pool problem and to take full advantage of its conjunctive use potential.

Sacramento Basin

The extent of overdraft in the Sacramento basin is much less than in the San Joaquin. In addition, the overdraft is more localized in nature. Many water users and agencies use the groundwater basin as their only source of water supply. We found no evidence of artificial recharge or management options like a pump tax or rights determination in the basin.[13] In addition, only a few individual groundwater users keep records of pumpage.

The Sacramento Basin, aside from being a major water supply for many local users, has statewide importance for its potential use in a conjunctive management program. Except for localized overdraft, much of the basin has relatively high water levels (small pump lifts). In addition, the basin is extremely close to the state's major river (the Sacramento) and surface storage facilities (Shasta and Oroville) Reservoirs).[14]

An agressive conjunctive use program for the Sacramento Basin would require basinwide management to adequately distribute the benefits and compensate local users for additional expenses.

[13] This probably occurs because surface water is relatively cheap and plentiful in many parts of the basin.

[14] Jaquette, op. cit., in a companion report, has demonstrated the basin's potential to enhance the state's water supply through conjunctive use.