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ECONOMICS OF GROUND WATER RECHARGE
BY NUCLEAR AND CONVENTIONAL MEANS

Livermore, California

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NUCLEAR AND CONVENTIONAL MEANS*

by

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February 1964

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ABSTRACT

The Plowshare Program has been established to give technical direction and guidance to engineering applications of nuclear explosions. Massive excavation by explosions has been shown to cost between \$0.03 and \$5.00 per cubic yard, depending upon the size of the project. With the possible savings indicated here, it is logical to consider the use of nuclear explosives in the development of water resources, where a capital expenditure of about \$10 billion annually is involved, including earth and rock movement in the United States, alone.

This report compares the economics of a conventional earth-fill dam, reservoir, and spreading basins with a nuclear cratering project producing an equivalent storage volume. The comparison indicates that the costs are about equal for projects developing 6000 acre-feet of storage. The nuclear cratering method offers an economic advantage for projects developing more than 6000 acre-feet of storage and in areas involving high land costs.

SYNOPSIS

In 1957 the Plowshare Program of the Lawrence Radiation Laboratory was founded to give technical direction and guidance to engineering applications of nuclear explosives. Massive excavation by explosions was among the many early potential applications. Depending upon the size of the project, cost of excavation by nuclear explosives is in the range of \$0.03 to \$5.00 per cubic yard—a cost interval that brackets conventional techniques. With the possible savings associated with nuclear excavation, it is logical to consider the field of water resources development, involving movement of large volumes of earth and rock and a capital expenditure of about \$10 billion annually in the United States.

One possible application of nuclear explosives in the water resources field is construction of projects to artificially recharge ground water. Impermeable strata hindering movement of water into the underground could be fractured, and craters for water storage and recharge could be created.

A large crater located in permeable material and supplied with water forms an excellent structure for artificial recharge. Such a project would have multiple uses—

temporary water storage, recreation, and surface water supply. The blast creating a crater may improve the permeability of the surrounding formations, yielding higher recharge rates than could be obtained by conventional excavation. Craters for water storage have a flexibility in location not possible with the select topographic and geologic conditions required for a conventional dam and reservoir.

To determine the economic feasibility of such construction techniques this report summarizes benefits and alternatives to artificial recharge and reviews cost components of artificial recharge projects. Costs of existing artificial recharge projects, a majority of which are located in California, are summarized. Wherever possible quantitative cost data have been assembled.

An economic comparison is made of a cratering project involving storage and artificial recharge with a conventional project consisting of an earth dam, reservoir, and spreading basins for the same purpose. To make the comparison it was assumed that the storage volumes are equal (6000 acre-feet), the wetted areas for recharge are approximately equal (72 acres), rates of recharge are equal, and annual costs of operation and maintenance are equal. The comparison shows nuclear excavation would cost 9 percent more for land costs of \$100 per acre but would cost 9 percent less for land costs of \$1000 per acre. The analysis is illustrative only; other similar projects can be compared using the data and methodology described in the report. Greatest advantages for nuclear construction accrue in storage projects having volumes of about 6000 acre-feet or larger and for locations involving high land costs.

On the basis of the cost data and economic analyses presented in the report, it is concluded that:

- (1) In the southwestern United States the value of water for all purposes will continue to increase in the future in response to supply and demand, and therefore, water resources projects which provide storage and opportunity for management of water at low cost will become increasingly justified.
- (2) Artificial recharge projects have increased rapidly in recent years in the southwestern United States because they provide for conservation, storage, and the opportunity to manage available water resources, surface and sub-surface, for maximum beneficial use.
- (3) There are sufficient data available to ascertain costs of artificial recharge projects, particularly for the methods commonly practiced in California.
- (4) A comparison of cost estimates for equivalent artificial recharge projects constructed by conventional methods and by nuclear explosives indicates that nuclear construction is most advantageous for storage volumes approaching or exceeding 6000 acre-feet and for locations involving high land costs.

- (5) Cost comparisons of alternative construction methods for artificial recharge projects of various types and sizes can be made based upon the data and methodology presented in this report.
- (6) From an economic standpoint further study of cratering for construction of water resources projects appears to be fully warranted.

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ECONOMICS OF GROUND WATER RECHARGE BY NUCLEAR AND CONVENTIONAL MEANS*

David K. Todd

INTRODUCTION

Artificial recharge of ground water is a means for augmenting the natural recharge of ground water by some method of construction, spreading of water on the ground surface, or changing natural conditions ⁽¹⁹⁾.** In many localities the demand for ground water exceeds the natural underground supply draining downward from precipitation or surface water sources. Elsewhere surface storage facilities are inadequate to handle surplus or imported surface water so that temporary storage underground is both convenient and economical. Recognition of the advantages of artificial recharge for conservation, supplementing water supplies, storage, and even purification of water has stimulated the practice of artificial recharge in recent years ⁽²⁷⁾. California, because of its rapid growth in population in water-deficient areas, recharges more water underground than all other states combined ⁽²⁸⁾.

Water can be artificially recharged by several methods. Spreading it over the ground surface, releasing it into ditches, discharging it into pits, and injecting it into wells are the principal methods. The selection of a particular procedure depends to a large extent upon local conditions.

The Plowshare Division of the Lawrence Radiation Laboratory is interested in artificial recharge of ground water because of the possible application of nuclear explosives to assist in constructing artificial recharge projects. Nuclear explosives could prove useful in fracturing impermeable strata hindering the movement of water underground and in creating craters for water storage and recharge. Because such construction techniques must be shown to be economically feasible, this report has been prepared to (a) summarize benefits and alternatives to artificial recharge, (b) review cost components of artificial recharge projects, (c) summarize costs of existing artificial recharge projects and (d) indicate the economic feasibility of constructing artificial recharge projects by nuclear explosives.

* Prepared under contract to the University of California Ernest O. Lawrence Radiation Laboratory.

** Numbers in parentheses refer to references at the end of the report.

Cost data on artificial recharge have been obtained from a review of the literature and from visits and correspondence with state and county agencies having a direct interest in the technique. A majority of the data came from California, as could be anticipated, but no attempt has been made to apply a regional limitation. All available cost data on existing recharge works, whether the method employed might or might not be suitable for nuclear construction, have been included. Similarly, information on trends in construction costs and the value of water in the western United States form a part of the report because of their pertinence to the total economic picture.

METHODS OF RECHARGING GROUND WATER

Works for artificially recharging ground water are designed to increase infiltration rates, wetted area, and duration of infiltration over that occurring naturally. Most projects may be classified by method as follows: basins, modified stream bed, pits, ditches and furrows, flooding, and injection wells. Table I shows the distribution of projects and of amount of water recharged for the various methods in California.

Table I. Distribution of projects and of quantities of water recharged by method of artificial recharge in California, 1958 (23) .

Method	Percent of all projects	Percent of water spread, 1957-58*	Percent of water spread, 1912-58*
Basin	54	58.4	44.7
Modified stream bed	15	29.5	37.5
Ditch and furrows	8	9.4	16.8
Pit	7	1.3	0.3
Injection well	12	1.0	0.5
Flooding	4	0.4	0.2
	<u>100%</u>	<u>100.0%</u>	<u>100.0%</u>

*Data apply only to 63 projects where measurements were available out of 276 active projects in the State.

Basins

Artificial recharge through basins involves release of water into a series of basins formed by a network of low dikes. In general the basins are interconnected so that water may flow from one basin to another. The method is widely used because a maximum wetted area to gross area ratio can be obtained for recharging water, because irregular surfaces do not require special preparation, and because construction is inexpensive using local materials for construction of dikes with bulldozers. The size and shape of the basins can be tailored to fit the local topography and available land. Where basins parallel a stream channel, the upper

basins act as desilting basins, thereby permitting high infiltration rates in lower basins. Most basins need periodic cleaning by scraping of the surface when dry. Recharge rates vary with soil type and water quality and tend to decrease with time. Typical basin recharge rates in California fall in the range of 1 to 10 ft/day.

Modified Stream Beds

By modifying the natural contours in a stream channel, water can be spread over a large area to create an efficient and economical recharge operation. With upstream regulation of runoff, channels can be widened and leveled to increase the rate of flow of water underground. Temporary structures are often constructed to pond water in channels and yet allow for unrestricted flows of flood waters which may result on short notice. Small earthen check dams are excellent for this purpose. Structures of brush, wire, and riprap are also employed. In the Los Angeles River a rubber dam which can be inflated or deflated as required provides for storage or passage of water.

Pits

Abandoned sand and gravel pits are excellent for release of waters for artificial recharge. As these are often available at low cost, they can be operated economically if water can be brought to them without great expense. Pits can also be constructed specifically for recharging. Walls are usually planned to be steep so that silt will accumulate in the bottom leaving the sides for infiltration. Where shallow impermeable layers restrict the downward flow of water, pits are particularly advantageous over surface spreading methods. Periodic cleaning of pits is necessary to remove silt and restore recharge rates. Pits have proved to be effective recharge mechanisms in Los Angeles County and in Peoria, Illinois.

Ditches and Furrows

A series of shallow, flat-bottomed ditches, or furrows are useful for recharging in areas where irregular terrain precludes construction of basins. Ditch slopes should be sufficient to carry silt-laden water through the system into a lower collecting ditch and back to the stream channel. Various ditch patterns are in use; usually the ditches are designed to fit the configuration and slopes of an available area. As ditch recharge is much less efficient than basins because of the lower ratio of wetted area to gross area, the method is generally restricted to land which is relatively inexpensive.

Flooding

Flooding involves the release of water over land surface in a relatively thin sheet. Topography must be uniform and gently sloping without significant ridges or gullies. Highest infiltration rates are obtained where native vegetation and soil covering are undisturbed. Water is released at intervals over the upper end of the flooding area; peripheral dikes serve to contain the waters within the area, while a lower collecting ditch may return excess water to the stream channel.

Injection Wells

Water may be recharged underground through wells. The method is important where thick impermeable formations overlie the aquifer and where high land values, such as in urban areas, make other methods of recharge uneconomical. Recharge rates are generally less than pumping rates for similar wells in the same formation. Clogging, resulting from silt intake, entrapped air, bacterial growths, and chemical reactions, is often observed in recharge wells. Maximum recharge rates can be obtained by using clear, chlorinated, and chemically compatible water. Periodic redevelopment is essential for continued efficient operation. Recharge wells should be gravel packed and tightly sealed above the aquifer to avoid upward flow outside of the casings. Water should be injected at constant pressure and with a minimum of free fall to reduce air entrainment. Considerable experience on the successful operation of recharge wells has been gained on western Long Island, where industrial water pumped for cooling and air conditioning is recharged through wells, and on the west coast of Los Angeles County, where a line of recharge wells has halted sea water intrusion along a portion of the coast since 1953. At the latter location new recharge wells now under construction will eventually protect the entire exposed coast from intrusion.

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BENEFITS OF ARTIFICIAL RECHARGE PROJECTS

In assessing the benefits of artificial recharge consideration must be given to the importance of water to the total economy, to the value of water for various uses, as well as to the direct and intangible benefits which may accrue. Furthermore, because storage, underground distribution, and reuse of water are involved, the importance of the method as a technological necessity, as for the optimum development of California's water resources, needs to be assessed.

Importance of Water in the Total Economy

Water is an extremely low-cost item on a unit-cost basis, yet the large volumes consumed together with the increasing costs of its production make impressive totals in terms of expenditures involved. Recently in a worldwide review by Scientific American of technology and economic development, Roger Revelle (22) analyzed the role of water. The following excerpt is an excellent statement of the economic significance of water.

"Although it is usually not reckoned as such in economic statistics, water can be considered a new material. In the U.S. the production of raw materials has a minor role in the total economy, and water costs are small even when compared with those of other raw materials. The cost of all the water used by U.S. householders, industry and agriculture is around \$5 billion a year: only 1 percent of the gross national product. The less developed countries, where raw materials are a major component of the economy, cannot afford water prices that would be acceptable in the U.S.

"In the U.S. water costs \$10 to \$20 an acre-foot, compared with wholesale prices of \$22,000 an acre-foot for petroleum, \$100,000 an acre-foot for milk and \$1 million an acre-foot (not counting taxes) for bourbon whiskey. The largest tanker ever built can hold less than \$1000 worth of water. Yet Americans use so much water — about 1700 gallons a day per capita — that capital costs for water development are comparable to other kinds of investment. Although the water diverted from streams and pumped from the ground is equivalent to only about 7 percent of the rain and snow falling on the U.S., this is still an enormous quantity: 200 times more than the weight of any other material except air. The annual capital expenditure of water structures in the U.S. — dams, community and industrial water works, sewage-treatment plants, pipelines and drains, irrigation canals, river-control structures and hydroelectric works — is about \$10 billion.

"One of the most critical water problems in the U.S. is represented by the vast water-short region of the Southwest and the high Western plains. In some parts of the Southwest water stored underground is being mined at an alarmingly high rate, and new sources must soon be found to supply even the present population. The average annual supply of controllable water in the entire region is 76 million acre-feet. If agriculture continued to develop at the present rate, 98 to 131 million acre-feet would be required by the year 2000. Provided that the neighboring water-surplus regions could be persuaded to share their abundance, this deficit could be met by long-distance transportation of 22 to 55 million acre-feet per year. But the annual cost would be \$2 billion to \$4 billion, or \$60 to \$100 per acre-foot of water, including amortization of capital costs of \$30 billion to \$70 billion. The cost per acre-foot would be too high for most agriculture, although not too high for municipal, industrial and recreational needs.

"Nathaniel Wollman of the University of New Mexico and his colleagues have shown that the average value added to the economy of the Southwest through the use of water in irrigation is only \$44 to \$51 an acre-foot, whereas the value gained from recreational uses could be about \$250 an acre-foot and from industrial uses \$3000 to \$4000 an acre-foot. Because the quantities of water consumed by city-dwellers and their industries are much less than those in agriculture, the arid Western states would not require such a vast increase in future supply if they shifted from a predominantly agricultural to a predominantly industrial economic base."

In evaluating the economic feasibility of water management projects, it is important to recognize that in the future water will be in greater demand, will cost more to produce, and will be used differently than today. Table II shows water use and supply for 1954 and 2000 for regions of the Western United States. Note that three of the four regions will use more water than is available, necessitating expensive importations. Agricultural water demands will remain large but will decrease everywhere, whereas industrial, municipal and power demands will increase. Waste dilution, an insignificant factor at present, will become a major water use by 2000.

Value of Water in the Western United States

It is clear that analysis of the benefits of artificial recharging is dependent upon what value can be assigned to a unit volume of water. The price of water varies widely, being controlled by its source, use, quality, and the economic criteria of supply and demand. In general, water for municipal and industrial purposes is priced at many times that for agricultural purposes. It is also apparent that prices of water are rising

Table II. Water use and supply 1954, and projections for 2000 at medium population levels,
for four Western water-resource regions (In millions of gallons per day)

Use	South Pacific				Central Pacific			
	1954		2000		1954		2000	
	Gross	Depletions	Gross	Depletions	Gross	Depletions	Gross	Depletions
Agriculture	6,601	3,894	4,558	3,052	46,973	27,641	37,512	24,395
Mining and Manufacture	446	65	2,658	416	572	128	3,916	977
Thermal power	2,678	12	17,855	77	1,786	7	24,997	104
Municipal	1,104	221	3,420	684	733	147	2,715	543
Land treatment and structures	11	-	18	3	90	53	235	149
Fish and wildlife habitat	-	32	-	64	-	3,757	-	7,514
Waste dilution	-	-	11,400	-	-	-	9,900	-
Total requirement	-	-	-	15,664	-	-	-	39,771

Average flow prior to use	1,600	-	-	-	58,000	-	-	-

Use	Great Basin				Colorado River			
Agriculture	12,272	7,285	9,229	6,069	26,403	15,595	19,965	13,182
Mining and Manufacture	167	30	791	205	102	29	1,405	499
Thermal power	-	-	2,678	99	-	-	8,035	643
Municipal	172	34	579	116	187	37	647	129
Land treatment and structures	102	12	219	24	255	59	705	155
Fish and wildlife habitat	-	5,306	-	10,612	-	2,559	-	5,182
Waste dilution	-	-	1,700	-	-	-	4,513	-
Total requirement	-	-	-	13,507	-	-	-	21,685

Average flow prior to use	10,500	-	-	-	13,500	-	-	-

rapidly with the possible exception of agricultural water provided under Federal subsidy. Data presented in this section are indicative of water prices for different uses in the Western United States.

Renshaw ⁽²¹⁾ analyzed the value of water in terms of use. His data are summarized in Table III and illustrated by Fig. 1. Because water can be used for several purposes simultaneously, the aggregate value of water at any point is the sum of individual use values. In addition, water returned to a stream or reservoir may be used to generate values at other points of use.

Fig. 1. Value of water for various purposes, 1950⁽²⁾.

Table III. Value of water in the United States
for various purposes, 1950 (21).

Purpose	Maximum value, dollars/acre-foot	Mean value, dollars/acre-foot
Domestic water supply	\$235.66	\$100.19
Industrial water supply	163.35	40.73
Irrigation	27.04	1.67
Power	5.90	0.71
Waste Disposal	2.56	0.63
Inland Navigation	1.17	0.05
Commercial Fisheries	1.06	0.025

Values in Table III are gross values as other appurtenant costs are included. For municipal and industrial water, for example, costs of purification and distribution are included. Renshaw points out that the net worth of water is difficult to determine because there is not an active market in water rights; therefore, the best estimate of relative water values may be either distributions of market prices paid for water at points of use or distributions of actual costs incurred in putting water to work. Comparison of gross values is often inaccurate as an arbitrary decision to include or exclude a given cost element could have a significant effect. Although no attempt was made to assign monetary values to recreational and aesthetic attributes of water, it is apparent that these factors could become quite important for some water bodies.

Water rates for irrigation in the West are tabulated in Table IV. Note that prices are a fraction of estimates of repayment capacity. Regional differences in the value produced by irrigation water may be attributed to climate and type of crops grown.

Table IV. Charges for water delivered by irrigation supply systems
and estimates of repayment capacity (9).
(Dollars per acre-foot)

Water-resource region	Rates for irrigation supply systems, 1950		Estimates of maximum repayment capacity based on project plans by U.S. Bureau of Reclamation	Difference in irrigated and dryland values, 1954
	Mean	Upper quartile		
South Pacific	\$7.00	\$13.20	\$39.10-65.60	\$495.
Central Pacific	1.90	3.10	7.20-17.50	148.
Great Basin	0.60	1.00	2.30- 4.60	65.
Colorado River	1.60	3.70	2.10- 4.80	79.

The Bureau of Reclamation sells irrigation water to service area contractors for \$3.50 per acre-foot for firm (Class I) water and \$1.50 per acre-foot for variable occurrence (Class II) water, about 50 percent of which is useable for ground water recharge. By comparison the California Department of Water Resources proposed in 1961 to provide firm water from Northern California for irrigation in Kern County at an average price of \$20 per acre-foot.

Indications of the value of municipal and industrial water can be obtained from Table V showing water charges for public supply systems in the West.

Table V. Charges for water delivered by public supply systems, 1955.⁽⁹⁾
(Dollars per acre-foot)

Water-resource region	Small users	Bulk users
South Pacific	\$90.3-108.5	\$39.1-47.9
Central Pacific	100.0-143.1	20.9-67.8
Great Basin	78.2	52.1
Colorado River	87.0-138.2	36.2-56.0

The largest wholesaler of water in Southern California is The Metropolitan Water District of Southern California. Its water is transported from the Colorado River by aqueducts to markets in the coastal area from Los Angeles to San Diego. A majority of the District's income comes from an advalorem tax assessment, while a minor portion comes from water sales. The price schedule for Metropolitan Water District water is shown in Table VI from its first delivery in 1940 to 1966. In 1958 separate rates for domestic and municipal use and for agricultural use and ground water replenishment were established. The differential recognized the limited ability to pay of agricultural users. It was also designed to encourage agricultural use and artificial recharge of ground water reservoirs. This purpose has been served as can be seen by the sharp rise in annual volumes recharged (see Table VIII). In 1961-62 38.3 per cent of all imported Colorado River water was used for ground water replenishment.

Although the price of water is rising substantially, the discount for agricultural and recharge water is increasing: 20 percent in 1958 to 45 per cent in 1966 for untreated water. No changes in rates have been established for the

Table VI. Price of Colorado River water sold by the Metropolitan Water District of Southern California*
(Dollars per acre-foot)

Effective Date	Domestic and municipal use			Agricultural use and ground water replenishment		
	Softened and filtered	Softened	Untreated	Softened and filtered	Filtered	Untreated
12/20/40	\$15.00		\$ 8.00			
7/1/48	18.00		8.00			
7/1/50	20.00		10.00			
12/1/54	18.00		8.00			
5/1/55	22.00		10.00			
11/1/55	18.00		8.00			
12/1/55	20.00		10.00			
7/1/57	22.00		12.00			
7/1/58	25.00		15.00	\$22.00		\$12.00
7/1/60	23.00		15.00	20.00		12.00
1/1/61	25.00		17.00	20.75		12.75
1/1/62	27.00		19.00	21.50		13.50
1/1/63	29.00		21.00	22.25		14.25
1/1/64	32.00	\$29.00	24.00	23.00	\$20.00	15.00
7/1/64	34.00	30.00	25.00	24.25	20.25	15.25
7/1/65	37.00	33.00	28.00	25.00	21.00	16.00
7/1/66	40.00	36.00	31.00	26.00	22.00	17.00

*Data from Miller (16) and data furnished by the District.

period after July 1, 1966. One reason for the rapid rise in rates is the higher price that the District must pay for water from northern California in the future.

Reclamation of sewage represents a new source of fresh water which will be increasingly developed in the years ahead. This will be particularly true in water-short metropolitan areas where increasing costs of water make water reclamation economically justifiable. Public acceptance is also growing and can be accelerated by appropriate public relations campaigns. A study by the California Department of Water Resources ⁽¹¹⁾ revealed the cost of reclaiming sewage in the Los Angeles area. Data are summarized in Table VII and illustrated in Fig. 2. For prices in the range of \$18 to \$30 an acre-foot, reclamation appears to be feasible. Much of this water would be recharged for final purification and storage. Fig. 3 shows generalized curves of capital and annual costs of water reclamation plants.

Table VII. Economic comparison of potential water reclamation projects in the Los Angeles Metropolitan Area, 1960 ⁽¹¹⁾

Sewerage system and project	Annual plant yield, in acre-feet	Unit costs, in dollars per acre-foot		
		Treatment	Conveyance	Total
Los Angeles City				
Hyperion-Vernon	45,000	\$10.60	\$18.00	\$28.60
Hyperion-Torrance	17,000	10.60	9.20	19.80
Recharge of West Coast Basin	54,000	15.60	3.00	18.60
Griffith Park	3,000	41.00	5.00	46.00
Los Angeles County				
Whittier Narrows	72,000	18.80	4.30	23.10
South Whittier	4,400	18.80	22.50	41.30
Orange County				
Talbert Water District	2,800	0.50	5.35	5.85

Direct Benefits of Artificial Recharge

Evaluation of benefits received from operation of a surface water system can be measured by estimates of the revenue which will accrue as a result of the project. However, artificial recharge projects are generally not so

Fig. 2. Cost of reclaimed water from potential projects in the Los Angeles Metropolitan Area ⁽¹¹⁾ .

Fig. 3. Estimated costs of water reclamation plants ⁽¹¹⁾.

susceptible of expression in explicit form. Organizations conducting recharging may receive only partial benefit, identification of recharged water is often impossible, and quality differences may complicate monetary evaluations. The basic benefits of artificial recharge of ground water can be classified under two categories: (a) relief of overdraft, and (b) use of ground water basins as cyclic storage and distribution systems.

By counteracting overdraft of a ground water basin, artificial recharge may provide the following specific benefits:

- (a) Lower operating costs for ground water supplies by lessening pumping lifts.
- (b) Eliminate capital expenditures for purpose of deepening wells.
- (c) Increase farm income as a result of augmented and dependable water supplies.
- (d) Reduce incidence of premature abandonment of wells.
- (e) Increased municipal expansion resulting from augmented subsurface water supplies.
- (f) Prevent sea water intrusion into coastal aquifers.
- (g) Prevent release of deep-seated connate brines into the aquifer.
- (h) Prevent dewatering of all or part of the underground reservoir.
- (i) Prevent land subsidence by sustaining ground water levels.

Use of underground reservoirs as storage and distribution systems is analogous to the operation of a surface reservoir and distribution system. The usable capacity of the ground water reservoir can be developed by planned extractions of ground water during periods of low precipitation, while subsequent replenishment can be made during periods of surplus surface supply. Such a conjunctive operation with surface and subsurface water supplies presupposes that there is sufficient ground water storage to meet requirements for regulation of local and imported water supplies, and that the aquifers possess sufficient transmissibility to permit movement of recharged water to the area of extraction. The basic difference between the usual surface water development with its associated ground water development and conjunctive operation of surface and ground water reservoirs is that the separate firm yields of the former may be replaced by a more economic joint yield in the latter (28).

The benefits of conjunctive operation of all water resources are several. These include:

- (a) Saving in cost of developing equivalent usable storage capacity in a surface storage reservoir.
- (b) Saving in cost of constructing an equivalent surface distribution system and with regard to peak requirements.

- (c) Increased total water supply available for use.
- (d) Small drainage system required in irrigated areas as wells aid in controlling the water table.
- (e) Reduced canal lining as seepage from canals becomes a benefit as artificial recharge.
- (f) Greater flood control as release of stored surface waters for artificial recharge reduces the flood control reservation.
- (g) Smaller evapotranspiration losses for water stored underground than above ground.
- (h) Improvement of power load and pumping plant use factors in areas served by either surface or ground water, as surface water can be released for irrigation during peak power demand periods to effect a saving in power costs.

Intangible Benefits of Artificial Recharge

Adequate storage of ground water supplies in a metropolitan area provides a high degree of protection of water supply and thus an important safety measure. Ground water supplies are much less susceptible to contamination as compared to surface reservoirs; similarly, their reduction from danger of destruction of reservoir structures and wide dispersion of outlet facilities make ground water basins of inestimable value as an emergency supply. Such considerations are of paramount importance in Los Angeles, for example, where widespread disasters such as dam failures, severed aqueducts, earthquakes, or atomic attacks could paralyze surface water facilities.

Importance of Artificial Recharge in California

Artificial recharge is a vital factor in carrying out the ultimate development of the California Water Plan to meet future water needs within the State ⁽²⁴⁾. With an estimated consumptive requirement of approximately 50,000,000 acre-feet per year, storage of more than 130,000,000 acre-feet will be required to conserve and regulate this water supply to a demand schedule. This storage volume is 110,000,000 acre-feet greater than all existing storage facilities.

In the Central Valley alone some 53,000,000 acre-feet will be needed. As surface storage for this purpose is not possible because of the nonavailability of economic reservoir sites, underground reservoirs must be utilized. Preliminary studies by the California Department of Water Resources indicate that this amount of conservation storage can be made up of 22,000,000 acre-feet of surface storage and 31,000,000 acre-feet of ground water storage used conjunctively. It is estimated that the underground storage would be divided as follows:

- (a) 4, 000, 000 acre-feet in Sacramento Valley,
- (b) 7, 000, 000 acre-feet in San Joaquin Valley north of Mendota Pool, and
- (c) 20, 000, 000 acre-feet in the Tulare Lake Basin.

These tremendous volumes can be readily stored underground because the useable ground water storage capacity (at depths between 20 and 200 feet) of Sacramento Valley amounts to 33, 700, 000 acre-feet, while that of San Joaquin Valley totals 93, 000, 000 acre-feet. Estimates show a need to recharge an average of 14, 000, 000 acre-feet per year in the San Joaquin Valley, or more than five times the existing recharge.

Artificial recharge is necessary in the San Francisco Bay area and in Southern California, primarily for seasonal regulation. Extensive studies are now in progress in both areas to determine the optimal operation of underground basins for storage of future imported water.

In 1959 the California Department of Water Resources reported that 276 artificial recharge projects were being operated in California by 54 agencies. Principal areas of recharge are in the eastern part of the San Joaquin Valley, the Santa Clara Valley in Santa Clara County, and the south coastal area of California. These areas share in common extensive exploitation and over-development of groundwater supplies together with extreme variability of runoff, scarcity of suitable surface storage, and adverse water problems such as sea water intrusion and salt balance. Interest in artificial recharge and volumes recharged have increased tremendously in California in the last 15 years.

The most concentrated efforts to recharge aquifers are being conducted in Los Angeles and Orange Counties. Table VIII shows the buildup in volumes of Colorado River water recharged in these two counties.

The following statement appeared in the 1961-62 annual report of The Metropolitan Water District of Southern California⁽¹⁶⁾ :

"There is a comprehensive and continuing program being carried out to replenish the dangerously overdrawn underground water basins in Los Angeles and Orange Counties. This program is one of the most important and, until recent years, one of the most neglected phases of water development projects designed to meet the requirements of a rapidly growing urban and suburban population and expanding industry.

"Beginning in 1949, Colorado River water was purchased to recharge the underground basin of the lower Santa Ana River Valley and since that time the Orange County Water

Table VIII. Colorado River water used for underground replenishment
in Los Angeles and Orange Counties, California
(Acre-feet)

Year	Los Angeles County Flood Control District		Orange County Water District	Total
	Zone I (Spread)	Zone II (Injected)	(Spread)	
1949-50			22,725.6	22,725.6
1950-51			22,183.1	22,183.1
1951-52			39,177.4	39,177.4
1952-53		413.4	27,956.1	28,369.5
1953-54		3,162.2	50,000.0	53,162.2
1954-55	54,796.0	2,989.7	67,789.1	125,574.8
1955-56	41,325.0	2,670.2	20,915.9	64,911.1
1956-57	63,244.0	3,344.5	82,954.8	149,543.3
1957-58	72,649.9	4,416.6	77,145.2	154,211.7
1958-59	81,327.5	4,549.9	81,710.0	167,587.4
1959-60	72,469.0	3,715.0	136,041.7	212,225.7
1960-61	143,185.4	4,491.7	166,278.7	313,955.8
1961-62	<u>179,150.9</u>	<u>4,436.5</u>	<u>173,149.0</u>	<u>356,736.4</u>
Total	708,147.7	34,189.7	968,026.6	1,710,364.0

District, with some early assistance from the Orange County Flood Control District, has applied a total of 968,026 acre-feet for ground water recharge up to June 30, 1962. Increasing amounts will be needed in the following years, so long as the supply is available from the Aqueduct.

"Since 1954, the Los Angeles County Flood Control District has been purchasing Colorado River water for spreading to the underground basins in Zone 1 south of Whittier Narrows in the San Gabriel River Valley and for injection to the underground aquifers in Zone 2 in the West Coast Basin area to form a fresh water barrier against salt water intrusion."

ALTERNATIVES TO ARTIFICIAL RECHARGE

Construction and operation of an artificial recharge project implies the desirability or necessity of either augmenting the existing water supply or utilizing the underground storage capacity for storage and distribution of local and imported water supplies. In order for a recharge project to be successful field conditions must be such as to provide for appropriate storage, movement, and utilization of recharge water. The California Department of Water Resources has enumerated the following physical requirements on recharging. These are arranged in the probable order of their significance:

- (a) Geology - The basin must be suitable from the standpoint of storage capacity and transmissibility of aquifers.
- (b) Water - Adequate water must be available for the purpose of controlled recharge.
- (c) Infiltration - Recharge rates must be maintained at adequate levels in spreading areas.
- (d) Drainage - Where a water table is near ground surface, adequate storage capacity in the basin for recharging must be provided.
- (e) Water Quality - Recharged water must be chemically compatible with existing ground water.
- (f) Recovery Efficiency - Pumping lifts must not be excessive, installed pumping capacity must be efficiently used, and quality of water recovered must be satisfactory.

If a limitation exists on one or more of the physical requirements for recharging, the only alternative is surface storage. Because the purpose of an artificial recharge project is to store and deliver an adequate water supply at a minimum cost, recharging must be considered in competition with the alternative of surface storage and distribution. Implied in this is that the cost of pumping recharged water must be included to deliver water to a point of use. Table IX shows a suggested basis for comparing costs of alternative projects having equal capacities.

In analysis of costs of a project storage and delivery costs should be considered as separate items, both in a capital expenditure and on an annual cost basis. The California Department of Water Resources estimates its capital recovery costs on an interest rate of 3 1/2 per cent. By California law the maximum permissible amortization period for water storage districts is 40 years. Depreciation periods vary according

to the nature and permanence of the recharge facility. They may range from one year for annual expendable dikes to 50 years for a major storage reservoir.

Although artificial recharge in particular situations may not be able to store and supply water at a lower cost than surface facilities, in total surface storage alone will be inadequate to meet ultimate water requirements of California. Furthermore, surface storage will become steadily more costly as the remaining combinations of good dam sites with surface reservoir sites of adequate storage capacity are exhausted. In general, capital expenditures for artificial recharge will be less than for equivalent surface storage facilities; however, the acquisition of land and rights of way in highly urbanized areas may present major economic problems.

Table IX. Comparison of storage and/or delivery costs for a given capacity unit*

Surface water			Recharged ground water		
Item	Storage costs	Delivery costs	Item	Storage costs	Delivery costs
I. Capital Costs			I. Capital Costs		
A. Reservoir structure			A. Spreading basin (or other)		
(a) Canal system			(a) Wells		
B. Land			B. Land		
(a) Rights of way					
C. Acquisition of water			C. Acquisition of water		
			(a) Pumping equipment		
D. Aqueduct system			D. Canal system		
E. Other			E. Other		
Total Capital Costs	\$ _____	\$ _____	Total Capital Costs	\$ _____	\$ _____
II. Annual Costs			II. Annual Costs		
A. Capital costs plus interest			A. Capital costs plus interest		
B. Depreciation			B. Depreciation		
(a) Reservoir			(a) Spreading basin		
(1) Canal system			(1) Wells		
(b) Aqueduct system			(b) Canal system		
(c) Other			(1) Pumping equipment		
C. Operation and maintenance			(c) Other		
(a) Reservoir			C. Operation and maintenance		
(1) Canal system			(a) Spreading basin		
(b) Aqueduct system			(1) Pumping plants		
(c) Administration			(b) Canal system		
(d) Other			(c) Administration		
Total Annual Costs	\$ _____	\$ _____	(d) Other		
			Total Annual Costs	\$ _____	\$ _____

* Furnished by California Department of Water Resources.

Table IX (Con't)

Surface water			Recharged ground water		
Item	Storage costs	Delivery costs	Item	Storage costs	Delivery costs
Adjusted Volume of Water Stored or Delivered (Assuming % efficiency)	AF	AF	Adjusted Volume of Water Spread (Assuming % efficiency)	AF	AF
Annual Cost/AF Stored or Delivered	\$_____	\$_____	Annual Cost/AF Stored or Delivered	\$_____	\$_____

INSTITUTIONAL AND FINANCIAL ARRANGEMENTS FOR ARTIFICIAL RECHARGE PROJECTS

Agencies Recharging Ground Water in California

In 1958 it was known that 276 artificial recharge projects were active in California. These were operated by 54 agencies, representing mostly various types of public water districts. A breakdown of the types of agencies is given in Table X.

Table X. Agencies in California having active artificial recharge projects in 1958 (23).

Type of agency	Number of agencies
Irrigation Districts	9
Water Conservation Districts	7
Flood Control Districts	7
Other Water Districts	7
Municipalities	4
Mutual Water Companies	10
Other Water Companies and Associations	6
Miscellaneous	4
	<hr/> 54

Projects were financed by (a) sale of general obligation bonds, (b) revenues from sales of water, power, property, water rights, leases, etc., and (c) direct assessments. Orange County Water District was the first organization to employ a replenishment assessment based upon volume of ground water pumped.

California Water Replenishment District Act

In 1955 the California legislature enacted a Water Replenishment District Act specifically designed to meet the assessment problems attending artificial recharge projects. Districts organized under this act are authorized to levy assessments in proportion to the amount of water pumped from underground supplies. This is of particular importance in making equitable assessments of those holding appropriate and prescriptive rights to use water on non-overlying land. The organization of water replenishment districts is presently limited to the counties of Santa Barbara, Ventura, Los Angeles, San Bernadino, Orange, Riverside, and San Diego.

The powers of a water replenishment district are very broad, as indicated by the following sections of the Water Code ⁽¹⁾ :

"60220. A district may do any act necessary to replenish the ground water of said district.

"60221. Without being limited to the following enumerations, a district may, among other things, but only for the purposes of replenishing the ground water supplies within the district:

- (a) Buy and sell water;
- (b) Exchange water;
- (c) Distribute water to persons in exchange for ceasing or reducing ground water extractions;
- (d) Spread, sink and inject water into the underground;
- (e) Store, transport, recapture, reclaim, purify, treat or otherwise manage and control water for the beneficial use of persons or property within the district;
- (f) Build the necessary works to achieve ground water replenishment.

"60222. A district may take any action necessary to protect or prevent interference with water, the quality thereof, or water rights of persons or property within the district, subject to the limitations contained in Section 60230.

"60223. For the purposes of replenishing the ground water supplies within the district, a district may do any act in order to put to beneficial use any water under its control or management. "

The powers of a district further include the right of eminent domain, the right to cause assessments and/or changes to be levied, and the right to carry on technical and other investigations. A district may borrow money, incur indebtedness, issue bonds, cause taxes to be levied, fix rates for services, and fix rates at which water shall be sold for replenishment purposes. It may also act jointly or cooperate with any entity, public or private, to the end that purposes and activities may be fully and economically performed.

Central and West Basin Replenishment District

The Central and West Basin Water Replenishment District was created by a favorable vote of the people in 1959. The district embraces the coastal plain of Los Angeles County South and West of the center of the City of Los Angeles. It has an area of 420 square miles and 29 incorporated cities are included in the area.

In its first year of operation the district levied a replenishment assessment, or pump tax, on all ground water pumped. The tax is revised annually to fit costs of purchasing Colorado River water for ground water recharge. Following are the annual charges levied by the district (3):

<u>Year</u>	<u>Pump Tax, Dollars/acre-foot</u>
1960-61	\$3.19
1961-62	5.75
1962-63	6.63
1963-64	6.58

The district purchases water from Metropolitan Water District at the replenishment rates shown in Table VI. It also buys at the same prices 10,000 acre-feet per year of reclaimed waste water produced at Whittier Narrows by Los Angeles County Sanitation District No. 2. Revenues from sale of reclaimed water are expected to cover operating costs of the reclamation plant and to repay the loan for the plant to Los Angeles County in 30 years.

Orange County Water District

In recent years Orange County Water District has recharged the largest volume of imported Colorado River water in Southern California. The district obtained its funds for the first purchases of imported water in 1949 from an ad valorem tax on real property that was then restricted to 15 cents per \$100 of assessed value. The tax, however, did not provide enough money to buy imported water in the quantities needed to offset annual overdrafts. To meet the need to raise additional water on an equitable basis, the Orange County Water District Act was amended in 1953 by the California legislature. The changes provided for a new source of revenue in the form of a replenishment assessment, or pump tax, on the production of ground water (6,7). The limit on the ad valorem tax was reduced from 15 cents to 8 cents per \$100 of assessed value, with funds from this source to be used to defray the administrative costs of the District and to buy enough water to replace in a 10-20 year period the long-time accumulated overdraft.

The pump tax has increased from \$3.50 per acre-foot of water pumped in 1953 to \$6.00 in 1962. In the first seven years of operation the assessment raised \$5,400,000, while in addition the ad valorem tax raised \$3,555,000. The District's act was amended in 1961 to permit levying an additional pump tax on the production of water for non-irrigation use. Thus, a two-rate pump tax was created favoring

agricultural interests using ground water. It also equalizes the purchase price of Colorado River water with the cost of ground water for cities connected to Metropolitan Water District lines and capable of securing imported water. Amendments also increased the ad valorem tax to purchase additional water to recharge the basin. The District expects to purchase and spread 210,000 acre-feet of water per year from Metropolitan Water District as long as such water is available.

Orange County Water District has pioneered in use of the pump tax to raise funds to purchase imported water for ground water recharge. The Interior Committee on Water of the California Assembly made the following statement ⁽²⁾ in this regard:

"The replenishment assessment in Orange County provides the only actual experience in California with this type of assessment. It has been judged by the committee to be a success both as a revenue-raising device and as a means of placing a positive emphasis on providing additional water supplies. In turn the emphasis on providing additional water supplies has de-emphasized conflicts and expensive litigation on water rights. Finally, it has been judged to be the most equitable means of assuring that those who pump from a common ground water supply will bear the proportionate cost of their pumping from that basin. The result is an economic incentive toward the wise and frugal use of water."

Kern County Water Agency

Kern County Water Agency, a recently established county-wide organization, signed a contract late in 1963 with the California Department of Water Resources for up to one million acre-feet of water annually beginning in 1968. The contract also provided for up to 300,000 acre-feet of water annually from surplus supplies available between 1968 and 1990. The water will be put to agricultural and ground water replenishment uses.

A graduated zone of benefit tax levy, beginning with 25 cents and increasing to 50 cents per \$100 assessed valuation, is planned for the service area to pay for the new water. After full development of the State Water Project in 1995, the rate would be decreased to 34 cents. Later, the same tax should produce sufficient funds to meet payments to the State because of increased valuation in the service area.

Under a provision of the contract, a surcharge of about \$2 per acre-foot would be applied to water for lands in excess of 160 acres in single ownership and 320 for husband and wife. The surcharge money would be used to reduce the water charge as much as \$2 per acre-foot for water users on lands within the 160 or 320-acre size classification.

Santa Clara Valley Water Conservation District

There is a trend within the State toward pump taxes to finance ground water replenishment. Santa Clara Valley Water Conservation District, for example, which recharges about 60,000 acre-feet of water annually, is shifting in 1964 from an ad valorem tax on undeveloped property to a pump tax to finance its purchase of imported water.

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COST COMPONENTS OF ARTIFICIAL RECHARGE PROJECTS

Costs of proposed artificial recharge projects must be ascertained to determine economic justification and financial feasibility. In this section the various cost components of artificial recharge projects, time variations in construction costs, costs of water wells and production of ground water, and costs of earth dams are summarized. In the following section costs of actual projects are presented.

Cost Components

The following discussion, published in a manual on ground water basin management⁽⁵⁾, points out the variety and variability of costs associated with artificial recharge projects:

"The cost of artificial recharge should be evaluated to determine the financial feasibility and economic justification of a proposed project. Financial feasibility refers to the ability of the project beneficiaries to repay the cost of the project. Economic justification, expressed in terms of a cost-benefit ratio, permits comparison of alternative projects to select the most economical project. Principles and techniques for economic studies have been developed and treated in other literature.

"Expenditures for land and easements, engineering and construction of facilities, water or rights to water, and operation and maintenance, generally make up the total cost of a project. An examination of the cost of existing projects has shown that these costs vary greatly with (1) purpose, (2) method of spreading, (3) quantity and quality of water and regimen of flow, (4) surface and subsurface conditions, (5) location of the artificial recharge project, and (6) standards and requirements of the agencies involved in spreading operations.

"The cost of land and easements usually forms a large proportion of the total cost of the project. It includes the cost of surveys, maps, title search, and acquisition. In some cases, legal and court fees are involved when public agencies must utilize condemnation procedures. Also, in urban areas, additional expense is often involved in rezoning a recharge site.

"The cost of the land varies with location and the time at which the land is purchased. As a result of the present trend of urbanization and inflation, cost of land increases considerably with time. As an example, the land at many existing projects

located in the populated areas of southern California was worth over \$3,000 an acre in 1958, as compared to the original cost of about \$200 an acre in 1930. Natural resources found on lands purchased for artificial recharge projects can be used to reduce the apparent total cost of the project. This is particularly evident when the sand and gravel found on many project sites in and near populated areas is sold to companies dealing in building materials.

"The largest portion of the total cost of a project is generally expended on the engineering design and construction of facilities to (1) divert water from streams, (2) convey water to and from the recharging area, (3) measure the amount of flow, (4) contain water within, and control flow through the recharging area, and (5) operate and maintain the facilities efficiently and safely. Costs of engineering include expenditures for preliminary studies, field surveys and maps, laboratory tests, designs, plans and specifications, and construction inspection and control. These costs are greatly affected by the standards and requirements generally dictated by the type of development in and around the project area. In urban areas, the need for levee compaction, fencing, and other protective measures has added significant costs to the total investment in spreading facilities.

"The cost in developing a spreading area is closely related to the efficiency with which the area is used. Thus, the cost per acre of development of a basin development, with an average area efficiency ratio of about 70% is considerably more than the cost of a ditch and furrow project with a ratio generally less than 10%.

"The total cost of a spreading project is affected by the type and size of appurtenances, such as structures for diversion, equipment for treatment of water and measurement of flow, and conduits for conveying the water from source to the spreading project and for returning unused water to the main stream. When costs of these appurtenances are large in proportion to the facilities in the spreading area, the cost per unit area is considerably higher than for projects in which cost of appurtenance is not a major item.

"Operation and maintenance costs include such items as rent, utilities, taxes, insurance, and legal fees. Variable operation and maintenance costs include cost of silt removal, operating personnel, patrolling, cleaning, and repair of facilities. Costs of operation and maintenance are frequently related to the amount of water spread during the operation period. As the amount of water spread increases, the cost per unit volume of water spread usually decreases. Thus, the cost for spreading a unit volume of water is expected to be less during wet periods than during dry

periods. However, variable costs may be great, even though a large amount of water was spread, due to inefficient use of personnel and spreading grounds. In general, high efficiency of operation is reached when the spreading project is operated at design capacity for a long period of time."

A check list of operation and maintenance costs and construction and engineering costs prepared by the California Department of Water Resources is shown in Table XI. Even though individual projects may vary greatly in size, design, and method of operation, most of these costs will arise in all recharge projects.

Table XI. Check list of operation and maintenance and construction and engineering costs for artificial recharge projects*

I. Operation and Maintenance

A. Field

1. Grading
2. Cleaning shoulders
3. Storm protection
4. Crushed rock or graveling (riprap)
5. Moving
6. Painting
7. Structure repair
8. Excavation (removing silt)
9. Miscellaneous
10. Equipment maintenance and fuels
11. Equipment rental
12. Spreading ground repairs - replacement
13. Discing
14. Weed control
15. Rodent control
16. Patrolling
17. Treatment of water
18. Injection well maintenance
19. Repair sides of basins due to washouts

B. Office

1. Supervision
2. Wages of personnel
3. Insurance liability (drowning)
4. Legal fees (Attorney)
5. Office expenses, such as stationery, telephone, etc.
6. Maintenance of office machines
7. Building expenses (rent, utilities, etc.)
8. Taxes
 - (a) Land
 - (b) Agency
9. Interest
10. Miscellaneous

II. Construction and Engineering

A. Structures

1. Conduit, closed-open, ditches
2. Recording devices
3. Control, structures
4. Operator's residence
5. Flood protection of grounds
6. Overflow drainline
7. Spreading ground
 - (a) Dikes
 - (b) Basins
 - (c) Roads
 - (d) Dams
 - (e) Diversion
 - (f) Equipment housing
 - (g) Pipe lines
 - (h) Intake structures
8. Fences
9. Trespassing signs
10. Lighting

B. Engineering

1. Surveys
2. Mapping
3. Design
4. Lab tests
5. Inspection
6. Consultation
7. Preliminary study

* Furnished by California Department of Water Resources

Operation and maintenance costs vary with the type and location of project, source of water for recharging, and water quality. Table XII summarizes the usual operation and maintenance problems encountered and possible corrective measures. In general, operation and maintenance costs are proportional to the amount of water spread on an annual basis, while the cost per acre-foot of water spread is inversely proportional.

Table XII. Operation and maintenance problems
of artificial recharge projects⁽²³⁾

Problem	Manifestation	Corrective actions to be considered
Silt	Lodging of particles within interstices of soil near the surface area, reducing the infiltration rate.	(1) Desilt in retention reservoir and/or in uppermost series of basins. Feocculating agent such as "Separan" has been used with success. (2) Bypass water until concentration of silt will not be detrimental, with concentration depending upon soil condition. Ditches and furrows

Problem	Manifestation	Corrective actions to be considered
Silt (Cont'd)		generally can accept waters containing higher concentrations of silt if sufficient velocity is maintained through the project to carry silt back to the main canal. (3) Scrape, harrow, and/or disc after proper drying. Period of drying usually ranges from one to seven days depending upon soil and weather conditions. (4) Remove silt after drying. Silt may be used to build up levees of basins or bridges of ditches or furrows. (5) Sustain vegetative growth. (6) Sluice the silt out of ditches and furrows, and from channels, with due regard to erosion problems. (7) Pump injection well to loosen silt from interstices and remove silt from the well.
Weeds	Increases percolation rate and shortens drying period required for working an area or removing silt from the basin. There is a disadvantage in that vegetative growth may be a fire hazard.	(1) Control by chemical means and/or remove when weeds become a fire hazard, especially around structures. Consider use of hand labor instead of mechanical means in order to maintain infiltration rates. However, if possible, leave vegetation undisturbed in wetted area. (2) Prolonged deep submergence will kill vegetation. (3) The control of weeds is generally not considered a problem in the operation of pits and shafts, or injection wells.
Rodents	Leaks and failures of dikes and levees. Public nuisance near urban area.	(1) Set out poison about twice a year (2) Use of traps.
Public health and safety	Rodents and mosquito problem and possible injury to individuals. Potential problems of injury is greatest when depth of water is large in basins and pits.	(1) Enclose area with fence and gates with locks. (2) Patrol area with particular attention to children and structural failures, before and during operation, especially near inhabited area. (3) Vector control by use of mosquito fish, chemicals, and/or drying. (4) Rodent control by poisoning or traps. (5) Proper posting of signs when using chemical which is poisonous.
Maintaining of percolation rates	Reduction of percolation rates will decrease efficiency of system, increasing the unit cost of the amount of water actually recharged.	(1) Proper treatment of water. Desilt water to concentration desired. Use chlorine or copper sulfate for control of bacterial slime and algae. Use of chemicals to reduce the possibility of chemical incrustation, which is usually deposition of calcium carbonate. (2) Schedule intermittent drying periods to prevent problems due to swelling of soil particles. Permit growth of vegetation to decrease the drying

Problem	Manifestation	Corrective actions to be considered
		<p>period by removing the water in the root zone and loosening the soil. Studies have shown that bermuda grass has been successfully used to maintain rates, even under prolonged periods of deep submergence. (3) Prevent aeration of water, especially when operating recharge wells, pits, and shafts. (4) Increase head of water generally by increasing depth of water. (5) Use hand labor whenever possible to decrease the possibility of using heavy equipment which will cause surface compaction especially when soil is wet. (6) Scrape, harrow, and/or disc after proper drying. (7) Remove silt, chemical incrustation, and/or any material decreasing infiltration rates after proper drying period. (8) Maintain the design velocity to reduce silting to a minimum in use of ditches and furrows. (9) Recondition injection wells by use of dry ice, hydrochloric acid, and/or sulfuric acid. (10) Prevent freezing of water during winter by continuous spreading. (11) Check the possibility of base exchange reactions. (12) Soil can be reconditioned by using organic material such as cotton gin trash, or chemical agents, such as krilium.</p>
Maintenance to diversion structures	Breakdown of spreading operations.	<p>(1) Systematic and routine maintenance check as well as patrolling when in operation. Attention should be given to wooden structures since they deteriorate faster due to frequent wetting and drying cycles. Also attention should be given to settlement of structures thus changing flow condition. (2) Attention should be given to undercutting of structure particularly on the downstream and which preventive maintenance primarily in the form of riprapping. (3) Sluicing of channel to remove silt and debris which have accumulated near and at diversion structure.</p>

Time Variation in Construction Costs

It is apparent that with the relentless increase in construction costs in the United States during the last 30 years, direct comparison of costs of artificial recharge projects constructed at different times cannot be made. An adjustment to a common base to make such data compatible is necessary. The Engineering News-Record Construction Cost Index, published weekly by Engineering News-Record, is a convenient and well-recognized basis for comparing construction costs. Because the index is defined in terms of simple construction materials and common labor, it should be

a valid basis for comparing artificial recharge project costs, presented in the next section.

Semi-annual values of the index are tabulated in Table XIII and plotted graphically in Fig. 4. Note that construction costs have increased six-fold since the early 1930's.

The Engineering News-Record Construction Cost Index was established in 1921, based on price movements in structural steel, portland cement, lumber, and common labor.

Table XIII. Values of the Engineering News-Record
construction cost index, 1929-1963*

Date	Index	Date	Index	Date	Index	Date	Index
12/29	209	6/39	235	6/48	456	6/57	723
6/30	202	12/39	238	12/48	478	12/57	738
12/30	196	6/40	242	6/49	474	6/58	757
6/31	186	12/40	249	12/49	480	12/58	774
12/31	165	6/41	256	6/50	507	6/59	794
6/32	152	12/41	266	12/50	531	12/59	809
12/32	159	6/42	274	6/51	543	6/60	827
6/33	163	12/42	284	12/51	548	12/60	834
12/33	190	6/43	289	6/52	562	6/61	850
6/34	199	12/43	294	12/52	588	12/61	855
12/34	200	6/44	298	6/53	594	6/62	872
6/35	197	12/44	300	12/53	611	12/62	881
12/35	197	6/45	309	6/54	622	6/63	895
6/36	204	12/45	314	12/54	643	9/63	911
12/36	218	6/46	349	6/55	656		
6/37	236	12/46	369	12/55	673		
12/37	240	6/47	407	6/56	692		
6/38	235	12/47	441	12/56	705		
12/38	233						

*Source: Engineering News-Record

The index is based on 1913 = 100. The index reflects wage rate and material price trends. It does not adjust for labor or job efficiency, materials availability, competitive conditions, management, mechanization or other "intangibles" affecting construction costs.

A hypothetical block of construction requiring 6 bbls. of cement, 1.088 M ft. bm of lumber, 2500 lbs. of steel, and 200 hours of common labor is used in the Construction Cost Index to measure the trend of the cost of heavy construction. This simple structure was adopted to facilitate prompt reporting of changes due to price and wage movements, both as to direction and degree.

Fig. 4. Engineering News-Record construction cost index for the period 1930-1963.

The index has proved over the years infallible as to direction and in normal times accurate as to degree. Under abnormal conditions of increasing or decreasing job productivity, allowance for the "intangibles" listed above should be made in measuring the degree of change in overall completion costs, or in construction selling price trends.

Engineering News-Record also publishes a Building Cost Index (not shown), which uses the same materials as those in The Construction Cost Index but skilled labor instead of common labor.

Water Wells and Ground Water Production

Although the costs of water wells and production of ground water are not direct artificial recharge costs, they nevertheless must be considered in the total analysis of an artificial recharge project compared to an alternative surface storage and distribution project. The extraction and delivery of recharged water to a surface distribution point becomes a part of the overall project cost.

Water well costs are a function of the size, depth, type, and location of wells. Heavy production wells for irrigation or municipal water supply represent a major

capital investment. They are usually constructed with large diameters, corrosion-resistant casings, and gravel packs around the casings to insure high yields over a long life. The following paragraphs, summarizing actual costs of irrigation and municipal wells, are indicative of the costs involved in producing ground water.

An analysis of costs for producing ground water at one pumping plant was made by the City of Santa Ana, California, in 1960. The plant, containing two deep wells, produced water at a cost of \$13.53 per acre-foot. A breakdown of the costs is shown in Appendix I. It should be noted that the cost of water produced included costs of wells, power, reservoir, booster station, and well buildings.

Cost of producing ground water supplies by the City of Anaheim, California, during 1960 ranged from \$10.43 to \$22.77 per acre-foot among seven wells studied. The weighted average cost was \$13.62 per acre-foot. These costs include the Orange County Water District pump tax; without it, the weighted average cost would have been reduced to \$8.65 per acre-foot of water pumped. Details of the seven wells and their costs are given in Appendix II.

A detailed breakdown of costs for producing ground water for agricultural use in Orange County, California, was prepared in 1958 by Orange County Water District. This analysis, shown in Appendix III, gives capital, maintenance, and power costs for 11 irrigation wells located in representative agricultural areas of the District. The average cost per acre-foot of water pumped ranged from \$6.02 to \$25.95 among the 11 wells with a weighted average of \$9.21. All cost data were adjusted, as needed, to apply to the 1956-58 period. These data do not include any pump tax.

In 1957 a study was made of the cost of producing ground water for irrigation in Harmon County, Oklahoma⁽⁸⁾. Data were collected on some 25 wells irrigating about 100 acres each. It was found that capital costs (fixed costs) varied from \$2.38 to \$25.66 per acre-foot pumped and averaged \$7.20. In addition, operating costs ranged from \$1.45 to \$6.42 per acre-foot pumped and averaged \$3.11. Thus, the average total cost of the water was \$10.31 per acre-foot. Details of the study describing wells and pumps and the basis for the cost analysis are included in Appendix IV.

Studies by agricultural economists at the University of California, Davis, have provided valuable information on costs of ground water production for irrigation in the San Joaquin Valley, California^(10,18). Data were analyzed for some 11,000 wells in 16 sub-areas shown in Fig. 5. Pumping plants ranged from 5 horsepower motors lifting less the 100 gal/min. to 300 horsepower units discharging more than 2000 gal/min. The distance ground water must be lifted proved to be the most impor-

Fig. 5. Sub-areas of San Joaquin Valley, California, and modal pumping lifts, 1949-54 (10).

tant single factor in the cost. The investment and annual per acre-foot costs of pumping water at 1959 prices in the 16 sub-areas ranged from \$2.40 per acre-foot at the northern end of the valley (Area A) to \$22.63 per acre-foot on the west side of Fresno and Kings Counties (Area P). A breakdown of costs for each sub-area is listed in Table XIV. Details of the basis for computing the various costs are given in Appendix V.

Fig. 5 also shows the modal pump life for each sub-area. The distribution of wells by pump lift as well as pump characteristics are tabulated in Table XV. The median lift for the entire valley was 91.7 feet, but the extreme lifts in the Westside and in the Wheeler Ridge areas produced a mean of 118.1 feet.

For convenient reference two nomographs for determining pumping costs of wells are shown in Figs. 6 and 7. Fig. 6 enables the power cost of pumping 1000 gallons of water to be determined as a function of head, pump efficiency, and power rate. Fig. 7 evaluates the overhead cost of pumping water per 1000 gallons knowing the annual pumpage, total capital cost, and estimated well life. The charts were prepared by the Edward E. Johnson, Inc., of St. Paul, Minnesota.

Dams

Where dams are built to store water for subsequent artificial recharge, the cost of the dam becomes part of the total cost of an artificial recharge project. Often, however, a reservoir serves other purposes, as well - such as flood control, water supply, hydropower, and recreation. For multiple-purpose operation, costs must be prorated among the various benefits.

In Table XVI actual dollar costs of 17 dams constructed by Los Angeles County Flood Control District primarily for flood control and water conservation are tabulated. The cost of a dam is highly variable, depending on type of construction, its dimensions, foundation conditions, and location.

Information is available on costs of six rolled earth-fill dams constructed in 1935 and 1936 by Santa Clara Valley Water Conservation District. Details of the dams and their costs are listed in Table XVII. In the same District it was reported that low sausage dams (consisting of Page wire fencing held in place by steel fence posts driven into the creek bed) for modified stream channel spreading cost \$6.00 per lineal foot in 1936 and \$7.00 per lineal foot in 1938.

In recent years a good rule of thumb for estimating the cost of earth dams has been \$1 per cubicyard of compacted fill. Thus, in 1963 the contract price of the low bid for construction of Oroville Dam on the Feather River in California came in at \$1.03 per cubic yard.

Table XIV. Investment in wells and pumping plants and costs of
pumping water by hydrographic area, San Joaquin Valley⁽¹⁸⁾

Area	Well cost	Est. well life	Pump cost	Est. pump life	Total annual depreci- ation ¹	Insurance interest and tax	Cost due to lower water table ²
	\$	yrs.	\$	yrs.	\$	\$	\$
A	2,301	20	2,790	20	242.85	204.89	0
B	1,406	20	1,860	20	140.89	138.80	74.40
C	2,600	20	2,598	20	217.55	220.92	103.92
D	7,044	15	2,598	20	583.15	409.78	103.92
E	8,122	20	3,545	20	483.38	495.85	0
F	2,002	20	2,580	20	197.38	194.74	0
G	2,002	20	2,580	20	197.38	194.74	0
H	2,002	20	2,887	20	212.73	207.78	0
I	1,177	20	2,160	20	146.73	141.82	0
J	2,836	20	2,891	20	246.29	243.40	0
K	12,980	20	4,422	20	721.55	737.58	309.54
L	9,766	15	4,769	20	864.22	617.74	333.83
M	2,836	20	3,179	20	260.69	255.64	0
N	...	...	...	...	...	...	...
O ⁴	15,007	15	16,206	20	1,731.77	1,326.55	1,134.42
P	14,000	15	17,700	15	2,013.33	1,347.25	1,239.00

Table XIV. (Cont'd)

Area	Repair and Maintenance	Service (demand) charge	Total cost except energy	Energy Charge	Acre feet pumped ³	Total cost per acre foot
A	55.80	134.60	638.14	439.40	449.7	2.40
B	37.20	74.60	465.89	135.65	218.1	2.76
C	51.96	168.25	762.60	495.50	358.2	3.51
D	51.96	168.25	1,317.06	547.82	361.5	5.16
E	70.90	201.90	1,252.03	625.02	495.6	3.79
F	51.60	134.60	578.32	393.48	265.5	3.66
G	51.60	134.60	578.32	384.66	252.6	3.81
H	57.74	134.60	612.85	437.38	217.8	4.82
I	43.20	174.60	506.35	130.25	82.2	7.74
J	57.82	134.60	682.11	387.51	160.5	6.66
K	132.66	201.90	2,103.23	686.32	213.0	13.10
L	143.07	299.50	2,258.36	962.14	306.0	10.52
M	95.37	134.60	746.30	377.84	80.4	13.98
N	..	..	..	..	..	..
O ⁴	486.18	789.00	5,467.92	3,016.78	475.8	17.83
P	531.00	789.00	5,919.58	3,288.32	406.8	22.63

1 Salvage value of 40% of motor cost was credited to pump unit.

2 4% of new pump cost for areas B, C, and D; 7% for areas K, L, O, and P.

3 Thirty-six acre inches per acre of summer crops. This will understate the amount pumped in areas where winter crops are irrigated and will cause the cost per acre foot to be overstated for these same areas

4 Insufficient information.

Table XV. Number of wells in sample by total life and pump characteristics for
selected geographic areas, San Joaquin Valley, 1949-54

Feet of Lift	Area							
	A	B	C	D	E	F	G	H
0- 24.9	14	5			3	5		3
25- 49.9	187	877	30	34	35	182	14	22
50- 74.9	137	629	169	184	46	504	47	118
75- 99.9	54	62	79	70	31	434	21	184
100-124.9	9	10	39	48	17	92	3	48
125-149.9	3	5	26	73	15	9		9
150-174.9		4	21	48	18	5		2
175-199.9		4	9	28	20	1		
200-249.9		8	11	21	32	1		
250-299.9			3	3	23			
300-349.9			1	2	2			
350-399.9			3		2			
400-449.9					4			
450-499.9								
500 and above								
Total lift	39.8	40.9	60.8	62.7	62.3	62.2	62.3	87.1
Horsepower	22.2	11.3	23.9	26.2	32.6	18.4	17.8	20.8
Discharge								
G. P. M.	1344.5	654.1	1074.6	1084.6	1486.6	759.9	757.7	653.8
K. W. H. /								
acre foot	81.8	87.3	110.7	125.4	114.9	124.5	123.9	166.1
Plant								
Efficiency	52.4	50.0	58.0	52.9	60.5	53.6	54.6	55.2

Table XV (Con't)

	Area								
Feet of Lift	I	J	K	L	M	N	O	P	Total
0- 24.9	6	5	1		3				45
25- 49.9	99	278	0		19		2	1	1,780
50- 74.9	120	412	2	8	47	1	1	2	2,426
75- 99.9	167	680	17	20	43	1	2	3	1,867
100-124.9	93	504	96	44	64	0	5	5	1,078
125-149.9	17	285	171	51	84	1	4	4	756
150-174.9	5	214	145	43	104	3	14	10	634
175-199.9	4	111	111	30	82	14	20	7	430
200-249.9	3	83	212	36	139	9	58	30	648
250-299.9		19	174	24	105	4	69	37	466
300-349.9			121	15	30	0	74	49	298
350-399.9			67	3	7	1	48	61	191
400-449.9			40	1			27	83	152
450-499.9			20				7	75	102
500 and above			15				8	99	126
Total Lift	87.2	88.1	137.3	139.3	162.6	221.0	325.9	424.3	
Horsepower	9.9	17.2	32.2	46.8	17.2	21.4	147.8	163.8	
Discharge									
G. P. M.	246.2	481.7	638.6	917.9	241.0	197.6	1427.0	1220.7	
K. W. H. /									
acre foot	219.2	193.9	268.8	272.8	386.9	533.6	533.8	677.4	
Plant									
Efficiency	44.8	48.7	53.6	54.7	46.6	44.3	62.0	61.9

Fig. 6. This chart is used for determining the power cost of pumping water per thousand gallons when the total head, wire-to-water efficiency and power rate are known. In using this chart a ruler is placed from line A (Power Rate in Cents per Kilowatt Hour) to line B (% Wire-to-Water Pump Efficiency). A pin or pencil point is placed against the edge of the ruler on the Pivot Line and the ruler is then pivoted to the proper point on line D (Total Head in Feet). The Cost for Power per Thousand Gallons can then be read directly from line C at the left of the chart.

Fig. 7. This chart is used (for determining the overhead cost of pumping water per thousand gallons) when the following factors are known: (1) The number of gallons pumped per day on a yearly basis; (2) the total cost of the installation; and (3) a general knowledge of the normal lifetime of a good installation. In using this chart a ruler is placed from line A (Cost of Well and Pump Installation) to line B (gallons pumped per day). A pin or pencil point is placed against the edge of the ruler on the Pivot Line and the ruler is then pivoted to the proper Pivot number. Pivot No. 1 is used only where wells have exceptionally long lives, and No. 3 is used where wells last only about 10 years. No. 2 is an average. The Overhead Cost per thousand gallons can then be read from the line C at the left of the chart.

Table XVI. Cost of dams constructed by Los Angeles County
Flood Control District*

Name	Stream	Type	Approx Cost
Big Dalton	Big Dalton Creek	Mult. Arch	911,000.
Big Santa Anita	Trib. to Rio		
	Hondo	Conc. Arch	1,208,000.
Devil's Gate	Arroyo Sero	Conc. Grav.	464,350.
San Gabriel No. 2	W. Fk. San Gabriel		
	River	Rock fill	3,585,000.
Big Tujunga No. 1	Big Tujunga Crk.	Radius Arch	973,077.
Live Oak	Live Oak Crk.	Gravity-Curved	173,254.
Pacoima	Pacoima Crk.	Conc. Arch	2,524,013.
Puddingstone	Walnut Crk.	Earth	930,000.
San Dimas	San Dimas Crk.	Gravity-Curved	564,620.
Sawpit	Sawpit Creek	Radius Arch	638,000.
Sierra Madre	Little Santa Anita		
	Crk.	Radius Arch	108,320.
Thompson Creek	Thompson Creek	Earth	241,645.
Puddingstone Diversion	San Dimas Crk.	Earth	185,443.
Big Dalton Lower	Big Dalton Crk.	Gravity	118,430.
San Gabriel No. 1	San Gabriel River	Rock-Earth	15,746,251.
Eaton Wash	Eaton Wash	Earth	955,621
MWD-Morris	San Gabriel River	Gravity	4,807,142.

Table XVI. (Con't)

Name	Reservoir Area, acres	Max. Storage, acre-feet	Date
Big Dalton	26.0	953	1929
Big Santa Anita	17.1	728	1927
Devil's Gate	153.0	2,504	1920
San Gabriel No. 2	160.0	10,915	1935
Big Tujunga No. 1	---	4,236	1935
Live Oak	12.0	288	1922
Pacoima	68.0	4,714	1929
Puddingstone	490.0	17,190	1928
San Dimas	16.4	1,042	1922
Sawpit	9.0	322	1927
Sierra Madre	2.0	43	1928
Thompson Creek	345.0	612	1928
Puddingstone Diversion	16.0	112	1928
Big Dalton Lower	1.0	18	1926
San Gabriel No. 1	560.0	43,825	1938
Eaton Wash	54.0	661	1936
MWD-Morris	420.0	36,665	1935

* Data furnished by California Department of Water Resources.

Table XVII. Description and cost of six rolled earth-fill
dams constructed by Santa Clara County
Water Conservation District (a)

Dam	Year Constructed	Reservoir Capacity, acre-feet	Height of Crest above Stream bed, ft.	Fill yd. ³	Cost
Almaden	1935	1972	105	250,000	\$ 446,924. (b)
Calero	1935	9213	90	550,000	440,726. (b)
Coyote	1936	24,560	120	1,060,000	915,218. (c)
Guadalupe	1935	3460	129	520,000	361,565. (b)
Stevens Creek	1935	3966	120	530,000	441,329. (b)
Vasona	1935	750	30	70,000	197,757. (d)

- (a) Data furnished by the District.
(b) Including spillway and road.
(c) Including spillway.
(d) Including an estimated \$30,000. for Vasona Canal.

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COSTS OF EXISTING ARTIFICIAL RECHARGE PROJECTS

Generalized Cost Estimates

In Table XVIII is a listing of items to be considered in artificial recharge projects together with estimated costs or remarks. This information was furnished by the California Department of Water Resources and represents conditions as of 1957. The detailed check list of cost items shown as Table XI should also be consulted in this connection.

Table XVIII. Estimated costs for components of artificial recharge
Projects in California, 1957*

Capital Costs Item	Estimated Cost
Land acquisition	\$10-100/acre; may be donated or leased.
Access rights-of-way	Generally same as land costs.
Buildings	Office space, maintenance yard, and shops; may be constructed, rented, or shared.
Reservoir site and clearing	\$50-250/acre
Leveling	\$30-100/acre
Dams	Cost may be shared by flood control.
Canals	\$0.30-1.50/yd ³
Diversion structures	\$500. and up.
Levees	\$0.35-1.50/yd ³
Roads	\$100 and up (should be gravel)
Measuring devices	Meters, weirs, Parshall flumes, \$50-500/unit.
Control valves	\$10-100/unit
Conduit	Concrete, metal, wood, earth.
Fences	\$0.25-1.50/ft.
<u>Annual Costs</u>	
Water	0-\$20/acre-ft.
Interest	0-6%
Loss of income from productive land	\$30-100/acre
Repayment	50-year period
Replacement	50-year period

* Data furnished by California Department of Water Resources.

Table XVIII. (Con't)

Capital Costs Item	Estimated Cost
Operation and maintenance	High variable: rodent control, flood damage, silt removal, vegetation control, algae control, wave action damage, structural repair.
General expenses	Administration, personnel, equipment, legal, engineering, office expenses.
Pumping costs to recover recharged water	\$2-8/acre/ft.
<u>Life of Works</u>	
Levees	50 years
Wood structures**	10 years
Buildings	30 years
Permanent works	50 years

** Also including structures buried in the ground or exposed to water.

Los Angeles County Flood Control District

Los Angeles County Flood Control District operates some 23 spreading grounds. Of these four basin grounds and three pit grounds were selected for cost analysis. The selection was made with the help of District personnel in an effort to obtain representative cost data for large and small as well as old and new spreading grounds. Costs per acre-foot of water recharge are listed in Tables XIX and XX. The following subsections contain brief descriptions of the individual grounds, and the final one describes the basis for ascertaining some of the cost figures. Year-by-year costs for capital outlay, rights-of-way, and operation and maintenance for the seven projects are tabulated in Appendix VI.

Wet and dry cycles will affect recharge costs, as well as whether the sources of water for spreading originates from uncontrolled runoff or from controlled dam releases. If imported water must be purchased, an additional cost must be included.

Rio Hondo Spreading Grounds

This is a large water spreading area consisting of shallow basins about five feet deep, occupying a gross area of 423 acres (in 1959-60), and having a wetted area of 370 acres. The basins are situated in a premium location, hydrologically speaking. The land was purchased by the District and purchase costs are regarded as average. About one-half of the water spread (88,000 AF) was storm water, which was stored upstream

Table XIX. Costs of selected spreading grounds operated by Los Angeles County Flood Control District ^(a)

	Rio Hondo Spreading Grounds	Sawpit Spreading Grounds	Pacoima Spreading Grounds	Santa Fe Reservoir Spreading Grounds
Operation and Maintenance ^(b)	\$ 3.50	\$13.00	\$ 3.40	\$ 1.25
Supervision of O & M	1.00	1.00	0.80	1.00
Office Engineering	0.30	1.00	0.25	0.04
Rights-of-Way ^(c,d)	3.25	4.00	0.75	0.00
Development	7.00	22.00	4.40	0.85
Clearing and Scarifying	1.50	5.00	1.10	0.09
Repairs	1.50	2.50	0.60	0.05
Total Cost per Acre-Foot	\$18.05	\$48.50	\$11.30	\$ 3.28
Total Water Spread, AF	172,000	2100	62,600	16,500
Period of Operation	1937-60	1946-60	1932-60	1954-60

a) All cost figures are in dollars per acre-foot of water spread, and are actual unadjusted costs.

b) Total operation and maintenance cost includes operation and maintenance, supervision of operation and maintenance, and office engineering.

c) Total capital investment includes development, clearing, and repairs.

d) Development consists of District engineering and surveys, basins, structures, fences, and buildings.

Table XX. Costs of selected recharge pits operated by Los Angeles
County Flood Control District ^(a)

	Peck Road Pit	Buena Vista Pit	Eaton Spreading Basin
Operation and Maintenance ^(b)	\$ 9.50	\$0.50	\$ 6.60
Supervision of O & M	8.00	0.80	0.80
Office Engineering	0.13	0.03	0.20
Rights-of-Way ^(c,d)	7.90	0.00	4.90
Development	15.00	0.70	3.70
Clearing and Scarifying	0.80	0.40	2.70
Repairs	3.70	1.25	0.60
Total Cost per Acre-Foot	\$45.03	\$3.68	\$19.50
Total Water Spread, AF	1000	6100	2500
Period of Operation	1959-60	1959-60	1956-60

- a) All cost figures are in dollars per acre-foot of water, recharged, and are actual unadjusted costs.
- b) Total operation and maintenance cost includes operation and maintenance, supervision of operation and maintenance, and office engineering.
- c) Total capital investment includes development, clearing, and repairs.
- d) Development consists of District engineering and surveys, basins and structures, and fences and buildings.

by reservoirs and released as needed. There was no charge for this water. The remaining water (84,000 AF) was purchased from the Metropolitan Water District for \$20.00/acre-foot. Funds came from ad valorem taxes of \$0.04 per \$100 assessed valuation in a local conservation district (Zone I).

Sawpit Spreading Grounds

This is a small group of shallow basins about three feet deep, having a gross area of 11.6 acres, and a wetted area of 3.8 acres. This is regarded as an excellent location in terms of efficiency of water spreading but costly in terms of land value. Only storm water is spread here. Costs tend to decrease with time as development is prorated over a longer period. Land costs are figured at 4 percent of initial cost annually throughout period of use. Office engineering is figured at 5 percent of development for an indefinite life. This project is considered to be a relatively expensive one for water spreading.

Pacoima Spreading Grounds

These are shallow spreading basins having a depth of five feet, occupying an area of 175 acres, and having a net area of 122 acres. The land was purchased by the District. Storm water is spread here; therefore, the degree of control depends upon the seasonal availability of water. This is the oldest spreading ground in the District and costs are stable.

Santa Fe Reservoir Spreading Grounds

As this land is part of the flood control basin of the Corps of Engineers, there is no land cost involved. These are shallow basins 3 to 5 feet deep, occupying a gross area of 193 acres, and having a wetted area of 133 acres. All water spread is storm water, part being stored and part being natural flood waters. Because of zero land and water costs, together with minimum operation and maintenance costs, this project gives the least cost for water spreading.

Peck Road Pit

This project consists of three pits approximately 60 feet deep excavated by a gravel company and subsequently condemned and purchased by the District. The gross area is 156 acres of which 85 acres are wetted. Only local storm water is spread. Part of the high cost of this project can be attributed to the fact that costs have been incurred since 1954, but no water was spread until 1959.

Buena Vista Pit

This is the smallest and least expensive pit operated by the District. The pit is an abandoned gravel pit purchased by the District. Its gross and wetted area is 10 acres. Storm water and excess irrigation water is recharged. There is no cost for land because the pit is figured as a flood control benefit. The actual purchase price of the land was \$4000 per acre.

Eaton Spreading Basin

This is a 60 foot deep abandoned gravel pit purchased by the District from a gravel company. The pit has a gross area of 16 acres and a wetted area of 10 acres. Only storm water is recharged and the pit is self-operating. This is considered by the District to be a typical pit in terms of size and developmental costs.

Method for Computing Costs

The cost of water varies with the availability of water. During a dry cycle spreading costs will slowly increase, while during a wet cycle costs will rapidly decrease. To compensate for this cyclic effect, the District adjusted costs for an average period of supply by using County rainfall indices. However, the economic consideration in this study is how much it costs to recharge water, thus only the actual cost instead of a computed cost for an average annual supply is given in this report.

In the following table is a summary of assumptions made in determining costs by the District.

Table XXI. Basis for cost evaluations of artificial recharge
project by Los Angeles County Flood Control District

A. Life of Items	
Land	Continuous at 4% interest
Land acquired by perpetual easement	50 years
Permanent structures and basins	50 years
R/W, Surveying, Mapping	50 years
Recorders	50 years
Shelter houses	30 years
Fences	30 years
Wood Structures	20 years
Temporary Structures	10 years
Maintenance and operation	1 year
Clearing and repairs	1 year
B. Annual Costs	
Interest on purchase price of land at 4 percent (When an area is rented or leased by the District to some outside agency for use until development, the income is subtracted from the annual interest).	
Interest and sinking fund for depreciation at 4 percent on all items with a limited life.	
Cost per year charges are entered the first year chargeable and each succeeding year for the life of the item.	

Imported Colorado River water is spread in Montebello Forebay (Zone I) by Los Angeles County Flood Control District. Quantities are listed in Table VIII. Total costs for operation of these facilities for 1954-1960 (6 years) and estimated total costs for 1960-1965 (5 years) appear in Table XXII. It can be seen that about 90 percent of the cost goes for purchase of water.

Table XXII. Water replenishment expenditures, Montebello Forebay
Recharge Project, Los Angeles, California (4)

1954-1960		1960-1965	
Spreading operation costs	\$ 551,400.	Zone I spreading operation	\$ 606,500.
Purchases of water by Zone I	<u>4,270,500.</u>	Central and West Basin replenishment District operation costs by Los Angeles County Flood Control District	612,300.
	\$4,821,900.	Purchases of water by Zone I	4,969,000.
		Purchases of water by Central & West Basin Replenishment District	<u>9,192,000.</u>
			\$15,379,800.

Recharge Wells, Los Angeles Coastal Plain

In the Los Angeles Coastal Plain sea water intrusion is contaminating aquifers on the western and southern sides as overpumping of the aquifers creates landward gradients which cause the sea water to advance underground into the formations. To control intrusion an experimental line of 9 recharge wells was constructed parallel to the coast and 2000 feet inland in 1953 at Manhattan Beach, California. By injecting filtered and softened Colorado River water through the wells into the confined aquifer, a pressure ridge formed a hydraulic barrier which effectively stopped the intruding sea water. The initial allocation for the construction and operation of the experimental well line was \$642,000 from the California Department of Water Resources to Los Angeles County Flood Control District.

Analysis indicated (14) that at Manhattan Beach the total capital outlay and annual operation costs per mile of recharge line would probably be \$186,000 and \$32,000, respectively, at 1954 prices exclusive of the cost of a recharge water supply. Considering cost of the project solely for replenishment to the basin as a source of water supply, costs would be as follows:

Water supply (3650 acre-feet at \$20/AF)	\$ 73,000 per mile
Annual cost of retirement (capital outlay)	14,900 per mile
Annual cost of O & M	<u>32,000 per mile</u>
Total annual costs per mile	\$119,900

Cost per acre-foot (recharged water)	\$32.80
Pumping costs	4.50
Cost per acre-foot (delivered to distribution system)	<u>\$37.50</u>

But, considering the value of the protection and assurance of the continued safe yield of the basin, estimated at 30,000 acre-feet per year, together with the import required to meet the entire estimated demand of the basin, the cost breakdown becomes:

Annual cost of protection for 11 miles of coastline (\$119,900 x 11)	\$1,318,900
Annual cost of additional water import (49,850 acre-feet at \$20/AF)	997,000
Pumping cost (70,150 acre-feet at \$4.50/AF)	<u>316,915</u>
Total cost	\$2,632,095

Total required supply - acre-feet

Injected supply	40,150
Safe yield	30,000
Required import	<u>49,850</u>
Total supply	120,000

Delivered cost per acre-foot	\$ 21.90
------------------------------	----------

This analysis still does not recognize the value of usable underground storage for fresh water. Assuming that the West Coast Basin area was supplied entirely by imported water at \$20 per acre-foot and that a storage of 10,000 acre-feet was required to balance peak demand and emergency storage against supply, then at a minimum figure of \$4000 per acre-foot of surface storage, the required investment would be \$40,000,000. Such a sum would have an annual amortization charge of approximately \$13 per acre-foot based on 120,000 acre-feet of annual use. Thus, the total cost of delivering imported water would be about \$33.00 per acre-foot, as compared to the above cost of \$21.90 per acre-foot.

The Manhattan Beach project, proven to be economically and technically feasible, is now being extended for 11 miles to protect the entire west side of the basin. This is the West Coast Basin Barrier Project. Total water replenishment expenditures for the period 1954-1960 (6 years) and estimated expenditures for 1960-1965 (5 years) are summarized in Table XXIII. Quantities of water injected through the wells are tabulated in Table VIII (Zone II).

Table XXIII. Water replenishment expenditures West Coast Basin
Barrier Project, Los Angeles, California⁽⁴⁾

1954-1960		1960-1965	
Construction and operation, Los Angeles County Flood Control District funds	\$ 641,600	Operation of basin facilities, Los Angeles County Flood Control District	\$1,000,000
Construction by Zone II	178,400	Construction, Los Angeles County Flood Control District	3,500,000
Engineering investigations and tests, Zone II	510,000	Construction by Zone II	3,000,000
Purchase of water, Zone II	426,000	Purchase of water by Central and West Basin Water Replenishment District	1,534,000
Total	\$1,756,100	Total	\$9,034,000

To control intrusion on the southern coast of the Los Angeles Coastal Basin, two new lines of recharge wells are now being started: Alamito Barrier, to be 4 miles long and constructed at a cost of \$3,000,000; and Dominguez Gap Barrier, to be 8 miles long and constructed at a cost of \$2,500,000. For comparison, the West Coast Basin Barrier Project will be 11 miles long and will cost \$6,250,000.

Recently Los Angeles County Flood Control District has published specifications for barrier and appurtenant wells for the three barrier projects. The estimated contract prices for various units of the work give valuable information on current well costs. Well descriptions and estimated contract prices are listed in Table XXIV.

Recharge wells will have 32-inch holes drilled by reverse-rotary method, 12-inch non-corrosive casings (either asbestos-cement or stainless steel) with gravel packs, and with regulating facilities either in vaults below ground surface or in enclosures above ground surface. Observation wells will have 16-inch holes drilled by hydraulic-rotary or reverse-rotary method (optional), and 4-inch or 2-inch non-corrosive casings (probably plastic) with gravel packs. Some of the wells will have 20-inch drill holes, equipped with 2 to 4 4-inch casings for monitoring multiple aquifers. Production wells (pumping wells on the Alamitos Barrier Project only for removal of a portion of the intruded sea water) will have 30-inch holes drilled by the reverse-rotary method, 12-inch non-corrosive casings (asbestos-cement for the blank portion and stainless steel for the perforated portion) with gravel packs, equipped with

vertical turbine pumps and motors up to 30 HP in capacity, and with regulatory facilities above ground in enclosures.

Orange County Water District

One of the largest water spreading projects in Southern California is conducted along the Santa Ana River in Orange County by the Orange County Water District. Quantities of Colorado River water spread are listed in Table VIII. Costs of spreading for the 9-year period 1953-1962 are summarized in Table XXV. Note that the total cost, exclusive of water purchase and land acquisition, for spreading more than one million acre-feet of water amounted to \$449,000, or only \$0.43 per acre-foot of water. This was distributed as follows: \$0.22 for salaries and administrative costs; \$0.19 for equipment, including gas, oil, and repairs; and \$0.02 for the prorated cost of capital investment on fixed assets, excluding land.

The District owns approximately 800 acres of land both within and outside of the Santa Ana River. The total purchase price of the land is approximately \$435,000; however, the district has received in excess of \$750,000 in royalties for sand and fill material which has been removed from these properties by permittees. For the 9-year period shown in Table XXV income from sale of sand and fill material totaled \$566,274, which considerably exceeds the total of all operating costs. And, incidentally, removal of this material has greatly improved the lands for spreading operations. Water is spread in the channel of the Santa Ana River and in adjoining basins and gravel pits.

Pomona Valley Protective Association

The Pomona Valley Protective Association has kept detailed cost data on operation of its San Antonio spreading grounds. Appendix VII shows costs for the 20-year period 1937-1957. Local water, obtained without charge, was spread except for the period 1951-1955, when water was purchased at \$5 per acre-foot from the San Antonio Water Company to augment the volume recharged. The average cost per acre-foot of water spread over the 20-year period amounts to \$0.66. This does not include the cost of land. Spreading takes place over an 1100-acre area; basin, ditch, and modified stream channel methods are employed.

Table XXIV. Estimated contract prices for barrier wells in Los Angeles County, California*

A. West Coast Basin barrier project

Type of well	Number of wells	Average depth, feet	Approximate contract amount	Cost per foot of well	Expected advertisement date
Recharge	19	400	\$480,000	\$ 62.20	1963
"	16	270	290,000	67.20	1964
"	14	460	390,000	60.60	1965
"	16	560	560,000	62.50	1963
Observation	13	400	90,000	17.30	1963
"	18	260	80,000	17.10	1964
"	6	370	40,000	18.00	1964
"	26	520	230,000	17.00	1963

B. Alamitos barrier project

23

Recharge	14	350	\$220,000	\$ 44.90	1964
"	4	100	70,000	17.50	1965
"	3	450	40,000	29.60	1964
Observation	14	370	90,000	17.40	1964
"	10	80	20,000	25.00	1963
"	15	80	30,000	25.00	1964
"	8	100	50,000	62.50	1965
"	10	400	90,000	22.50	1964
Production	3	95	40,000	140.00	1963
"	6	90	120,000	222.00	1964

C. Dominguez Gap barrier project

Recharge	8	140	\$100,000	\$ 89.40	1966-67
"	14	190	200,000	75.30	1966-67
Observation	20	160	90,000	28.10	1965-66
"	39	195	180,000	23.70	1965-66

* Data prepared by Los Angeles County Flood Control District.

Table XXV. Orange County water district water spreading costs
7/1/53 through 6/30/62* (9-Year period)

Salaries & administration		
Salaries, including administration	\$185,128	
Social Security	3,800	
Hospitalization	600	
Workmen's Compensation Insurance	4,680	
Mileage & miscellaneous expense	2,270	
Other overhead costs	<u>37,026</u>	
Sub-total		\$233,504
Maintenance & operation		
Utilities	1,974	
Gas, oil, repairs	37,332	
Field operations maintenance	20,240	
Equipment rental	1,460	
Expendable equipment:		
Small tools, pipe, etc.	30,481	
Tractors, autos, etc.	103,325	
Liability insurance	9,240	
Sub-total		204,052
Fixed assets - prorated for 9-year period		
Permanent structures:	Total cost	
Atwood connector	20,895	418
Crill delivery chute	43,898	878
Crill diversion gates	9,295	186
Fences	21,352	5,872
Buildings	19,850	4,042
Sub-total		11,396
Grand total all costs		\$448,952
Total water spread: Colorado River (MWD) 865,020 acre feet		
Other non-local	<u>182,655</u>	" "
Total	1,047,675	" "

$$\text{Cost of spreading per acre foot} = \frac{\$ 448,952}{\$1,047,675} = 42.9 \text{ cents}$$

* Data furnished by the District.

Los Angeles Department of Water and Power

The Department of Water and Power of the City of Los Angeles maintains a 30-acre spreading ground adjoining the Los Angeles River. A diversion dam diverts flood water into the grounds; usually only water containing 40-50 ppm of silt is spread to avoid costly cleaning of the basins.

In 1956 a treatment plant to remove silt was erected 2-1/2 miles above the diversion point. The plant provided for addition of Separan 2610, an organic polymer manufactured by Dow Chemical Company, to a maximum of 40 cfs of water. Separan is a flocculating agent and its addition to water removes suspended material in settling basins prior to spreading.

After the treatment plant was established, a 22-day test was run. An average of 12.8 cfs of water was treated and placed in the spreading grounds, amounting to 563 acre-feet. At the end of the test it was found that:

- (a) Water spread averaged 15 ppm turbidity, varying from 7 to 20 ppm;
- (b) Little silt accumulated in the basins;
- (c) The desilting operation was accomplished at a total cost of \$1.50 per acre-foot of water treated; and
- (d) Figuring water worth \$15 per acre-foot, the test resulted in a net gain of \$7300; water spread without treatment would have required a maintenance cleaning of about \$6500.

A new scraper was designed and built to clean the basins by removing the skin of algae and surface material. This machine cleaned the 30 acres for \$1300 as compared with the usual cost of \$6500.

North Kern Water Storage District

Spreading grounds of the North Kern Water Storage District in Kern County consist of basins constructed in 1952 and 1953 in four locations ranging in size from 210 to 610 acres and totalling 1600 acres. There are 1000 acres constructed with large borders, 2.5 feet high with a 12-foot top width and 600 acres constructed by dozing small contour borders. Individual ponds range in size from 1.5 to 14.5 acres.

The total cost of spreading includes operation and maintenance costs, pumping costs, and nonrecoverable losses. The rate of inflow is as much as 300 cfs for extended periods, and as much as 1100 acres are flooded at a given time. A total of 250,000 acre-feet of water was spread in 1957, 1958, and 1959. Prior to 1957 cost

records were inadequate to determine operation and maintenance costs. In 1957 the total cost was \$29,000; in 1958 it was \$32,000. These costs include all labor costs, supervision, materials, equipment, and taxes. The average cost per acre-foot of water spread in 1957 and 1958 was \$0.40. This figure represents only operation and maintenance; capital investment in land and construction is not included.

Santa Clara Valley Water Conservation District

Since the 1930's local water has been recharged in Santa Clara County by the Santa Clara Valley Water Conservation District. Originally, spreading was by the modified stream channel method; more recently, basins, or percolation ponds, have been constructed. Table XXVI shows the volume of water diverted to beneficial use (District personnel stated that more than 80 percent was recharged underground while less than 20 percent went for direct surface irrigation), total income, and cost per acre-foot (assuming all income was expended). Costs vary widely from year to year, primarily because of the variability of local water available for recharge. The average cost per acre-foot for the 10 years 1953-1963 amounts to \$17.60.

To obtain a better picture of the costs of artificial recharge in the District, data from four percolation ponds are tabulated in Appendix VIII. Included are descriptions of the works, and costs of rights of way, construction, and maintenance. Overhead administrative costs are not a part of the costs. The data yield maintenance costs per acre-foot listed in Table XXVII.

During the period 1958-1960, the District purchased stream bed land for \$1700 per acre, while off-stream land cost \$3575.

With concrete gunning machines 19.4 miles of canal were concrete-lined at a cost of \$0.42 per square foot. Hand clearing of aquatic weeds and algae in 20.5 miles of canals cost \$6820 in 1959. However, in 1960 using Aquilan, a new chemical herbicide from Shell Chemical Company, the cost was greatly reduced. It was estimated in 1961 that the cleaning with this chemical could be done for \$2180 on an annual basis.

Separan AP30, a new synthetic polymer designed as a flocculating chemical, was tested in 1959. Treatment consisted of adding the solution to a canal upstream from percolation ponds. With a concentration of 0.225 ppm of Separan in the water, turbidity was reduced from 618 ppm to 91 ppm on an 8-cfs flow for a cost of \$0.61 per acre-foot (25).

Table XXVI. Cost of water diverted to beneficial
use by Santa Clara Valley Water Conservation District,
1935-1963*

Year	Water diverted to beneficial use, acre-feet	Total income
1935-36	36,150	\$ 179,796.70
1936-37	60,410	216,817.71
1937-38	61,170	208,668.96
1938-39	6,670	190,345.41
1939-40	39,990	190,193.81
1940-41	38,260	203,587.17
1941-42	36,340	217,988.29
1942-43	38,270	210,410.70
1943-44	38,680	169,325.71
1944-45	39,710	203,200.21
1945-46	41,000	192,337.53
1946-47	6,200	196,722.70
1947-48	6,340	217,170.86
1948-49	22,170	363,697.72
1949-50	13,440	599,107.34
1950-51	57,380	553,054.00
1951-52	49,630	566,411.31
1952-53	55,080	596,051.87
1953-54	52,580	716,153.30
1954-55	44,960	776,623.89
1955-56	65,110	909,202.29
1956-57	63,090	1,020,225.44
1957-58	61,770	1,310,430.45
1958-59	87,450	1,449,762.43
1959-60	72,410	1,139,428.63
1960-61	23,222	1,242,213.31
1961-62	80,000 (est.)	1,311,662.64
1962-63	90,000 (est.)	1,388,382.76

Average cost (assuming income equals costs)
for 1935-63 period amounts to
\$12.84 per acre-foot.

*Data furnished by the District.

Table XXVII. Average maintenance costs of recharge,
Santa Clara Valley Water Conservation District

Area	Period	Maintenance costs, dollars per acre-foot
Coyote Percolation Ponds	1936-1961	\$0.13
Los Gatos Percolation Ponds	1959-1961	0.07
Penitencia Percolation Ponds	1938-1957	1.38
Penitencia Percolation Ponds	1957-1963	8.05
Main Avenue Percolation Ponds	1954-1962	1.37

During the period 1958-1960, the District purchased stream bed land for \$1700 per acre, while off-stream land cost \$3575.

With concrete gunning machines 19.4 miles of canal were concrete-lined at a cost of \$0.42 per square foot. Hand clearing of aquatic weeds and algae in 20.5 miles of canals cost \$6820 in 1959. However, in 1960 using Aquilan, a new chemical herbicide from Shell Chemical Company, the cost was greatly reduced. It was estimated in 1961 that the cleaning with this chemical could be done for \$2180 on an annual basis.

Separan AP30, a new synthetic polymer designed as a flocculating chemical, was tested in 1959. Treatment consisted of adding the solution to a canal upstream from percolation ponds. With a concentration of 0.225 ppm of Separan in the water, turbidity was reduced from 618 ppm to 91 ppm on an 8-cfs flow for a cost of \$0.61 per acre-foot ⁽²⁵⁾.

Miscellaneous Cost Data for California Projects

There are numerous individual quotations of costs of artificial recharge in the literature. However, unless these are carefully explained and documented, the values may have little meaning or, more seriously, could be misinterpreted. In general, cost figures should be carefully examined to determine exactly what the data do and do not include.

In 1952 Lavery ⁽¹²⁾ discussed costs of artificial recharge in southern California. He reported average spreading costs of \$2 - \$8 per acre-foot, depending upon cost of the land; cost of recharge wells for installation, redevelopment, injection, and treatment totalled \$15 - \$25 per acre-foot; and sewage reclamation costs, including treatment plants and spreading grounds, were estimated at \$12 - \$16 per acre-foot over a 40-50 year financing period.

Lavery also reported in 1954 ⁽¹³⁾ that capital investment and operating costs for spreading in San Gabriel Valley do not exceed \$8 per acre-foot of flood water conserved for areas exceeding 150 acres. If the development costs of the grounds are assigned to the initial purpose of floodwater conservation, then the total spreading cost for conservation of imported waters will not exceed \$3 to \$4 per acre-foot.

Table XXVIII contains a tabulation of land costs for artificial recharge projects in Southern California. Note that costs vary greatly depending upon location;

Table XXVIII. Land costs of artificial recharge
projects in Southern California*

Project	Year	Area purchased, areas	Cost of Land	Unit cost, dollars/acre-foot
Ojai	1951	5.	\$50. (annual rental)	\$10.
Saticoy	1947	202.4	7301. (annual rental)	36.
Coldwater Crk.	1890	400	1600.	4. ±
Day Canyon	1898	160 [±]	1000.	6.
East Ave.	1907	8	1227.	153.
Mayhew Wash.	1915	80	3200.	40. ±
Horsethief Crk.	1923	20 [±]	800.	40. ±
Indian Crk.	1890	100 [±]	4000.	40. ±
Rio Hondo Coastal	?	443 [±]	538,735.	1220.
San Gabriel Coastal	?	110	83,882.	763.
Pacoima	?	174.6	43,495.	249.
Tujunga	1931	183	43,000.	186.
Santa Ana River nr. Olive	1938-46	1000.	25,000.	25.
West Anaheim	1936	87	25,000.	288.
Sierra Madre	1914	34.1	20,460	600.
San Gabriel Canyon	1937	536	114,000.	214.
San Gorgonio River	1900 ±	8 sections	25,000.	5. ±
Piru	?	100.6	10,000. ±	100. ±
White Water River	1920	3100	Free	0.

*Data furnished by Calif. Dept. of Water Resources.

metropolitan areas produce costs of several hundred dollars per acre, whereas in rural areas costs may be only a few dollars per acre.

Table XXIX gives construction and engineering costs for several artificial recharge projects in Southern California. Cost data on construction and engineering as well as operation and maintenance for several recharge projects in the San Joaquin Valley are listed in Table XXX.

Lytle Creek, San Bernardino County

A total of \$665,606 was spent in the 1925-1937 period for a central channel, diversion weirs, and spreading grounds (ditches). There were 499.5 miles of spreading ditches completed, of which 455.3 were of 12-foot bottom width and 44.2 miles were 6 feet in width. These were excavated by hand at an average cost of \$0.151 to \$0.171/lineal foot. Cost of four weirs were \$11,547, \$17,431, \$26,490, and \$25,200. A fifth weir was to have been constructed at an estimated cost of \$22,000 (17).

Tujunga Wash, Los Angeles County

The completed cost per acre on the gross area under operation was \$1269, consisting of \$423 for land purchase, \$506 for pipe lines and valves, and \$340 for basin and road construction. This was built in about 1930 (17).

During 1932-33 season, the cost of spreading was \$0.66/acre-foot, consisting of \$0.16 for capital investment, \$0.12 for land investment, and \$0.38 for operation and maintenance. A total of 31,298 acre-feet of water were spread during that season.

Up to 1937 the average charges per acre-foot of storage on four surface reservoirs in San Fernando Valley were \$5.70 for the capital investment and \$3.23 for operation and maintenance, making a total of \$8.93. By comparison, assuming all water spread had to be pumped from the area with the greatest lift, the total annual charges for underground storage would have been only \$3.36.

Santa Clara River, Ventura County

Limited data on water spreading and annual operating costs are available for five units of the Santa Clara Water Conservation District in Ventura County. These data were published in 1937 (17) and are shown in Table XXXI.

Table XXIX. Construction and engineering cost
for artificial recharge projects in
Southern California*

Project	Method of recharge	Gross area, acres	Net area, acres	Years of construction	Total construction and engineering costs
Ventura County					
El Rio	Basin	125	111	1955	\$582,700.
Saticoy	Basin	Var.	Var.	Variable	310,805.
			39.8	1931-32	
Piru	Basin	63.9	43.2	1946-50	22,497.
Los Angeles County					
Rio Hondo Coastal	Basin	417	370	1937-52	282,442.
San Gabriel Coastal	Basin	127	96	1936-52	29,401.
Pacoima	Basin	179	122	1931-52	194,532.
Tujunga Wash.	Basin & Ditch	81	64.7	1931-32	68,526.
Sierra Madre	Basin	17	7	Var.	109,838.
San Bernardino County					
College Heights	Basin	28	21.3	1939-42	76,262.
				1939-42	
Eighth Street	Basin	32	20	1954-55	139,100.
Ely Street	Basin	32	20	1947-55	52,047.
Etiwanda	Basin	30	26	1954-57	9705.
Twenty-Ninth Street	Basin	8.8	6.4	1951-55	127,741.
Devil Canyon	Basin & Ditch	440	410	Var.	71,193.
Daley Canyon	Basin	30	21	1939-57	81,884.

* Data furnished by California Department of Water Resources.

Table XXIX. (Con't)

Project	Method of recharge	Gross area, acres	Net area, acres	Years of construction	Total construction and engineering costs
Thirteenth Street	Basin	2.6	2.1	1946-55	\$ 25,184.
San Gorgonio	Basin & Ditch	1725	1300	1900-10 1948-50	12,530.

Table XXX. Construction and engineering and operation and maintenance costs to 1958
for artificial recharge projects in San Joaquin Valley, California*

Project	Gross area, acres	Net area, acres	Year constructed	Total construction & engineering costs	Operation & maintenance cost to 1958	General & administrative costs to 1958	Total O & M to 1958
East San Joaquin Co. Water Cons. Dist.							
Belota Well	-	-	1957	\$ 4,000	-	-	-
Ivanhoe Irrig. Dist.							
Dist. Basin	8	7	1953	3,000	\$ 160	40	\$ 200
Kaweah-Delta Water Cons. Dist.							
Cairns Borrow Pit	-	-	1955	134	50	50 e	100
Belz Well	-	-	1951	376	50	50 e	100
Kibler Well	-	-	1950	1,733	50	50 e	100
Sinking Basin No. 10	160	-	1946	10,020	3200	800 e	4000
Sinking Basin No. 4	160	-	1941	23,994	3200	800 e	4000
Sinking Basin No. 3	160	-	1940	7,210	3200	800 e	4000
Sinking Basin No. 6	66	-	1942	18,007	1320	330 e	1650
Sinking Basin No. 13	34	-	1950	3,512	680	170 e	850
Sinking Basin No. 11	80	-	1950	6,592	1600	400 e	2000
Sinking Basin No. 2	20	-	1940	2,531	400	100 e	500
Sinking Basin No. 15	53	50	1954	2,030	1060	265 e	1325
Sinking Basin No. 8	120	-	1945	21,440	2400	600 e	3000
Sinking Basin No. 1	10	9	1940	839	200	50 e	250
Sinking Basin No. 7	1.5	1.5	1943	12	30	8 e	38
Sinking Basin No. 14	20	19	1953	178	400	100 e	500

* Data furnished by California Department of Water Resources.

e = Estimated

Table XXX. (Con't)

Project	Gross area, acres	Net area, acres	Year constructed	Total construction & engineering costs	Operation & maintenance costs to 1958	General & administrative costs to 1958	Total O & M to 1958
Lower Tule River Irrig. Dist.							
School House Basin	15	10	1952	\$ 3,500	\$ 300	\$ 75 e	\$ 375
Lapadula Pit	30	20	1952	1,080	600	150 e	750
Kern Co. Land Co. and North Kern Water Stor. Dist.							
Poso Basin	392	-	1951	39,200	7,840	1960	9,800
Switchfield Basin	212	-	1952	21,200	4,240	1060	5,300
Minter Basin	426	-	1937-38	42,600	8,520	2130	10,650
Rosedale Basin	582	-	1952	58,200	11,640	2910	14,550

e = Estimated

Table XXXI. Annual operating costs for the Santa Clara Water Conservation District for each unit and for each year since its organization to 1935 (17)

	Season	Amount spread, acre-feet	Operating cost	Cost per acre-foot
Camulos	1928-29	768	\$ 184.32	\$0.24
	1929-30	1,426	185.38	.13
	1930-31	32	-	-
	1931-32	903	132.74	.147
	1932-33	565	29.50	.052
	1933-34	-	-	-
	1934-35	-	-	-
Piru Creek	1928-29	-	-	-
	1929-30	588 ⁽¹⁾	202.86	0.345
	1930-31	424 ⁽¹⁾	129.32	.305
	1931-32	6,652	951.24	.143
	1932-33	3,100	480.52	.155
	1933-34	2,042	865.65 ⁽³⁾	.423 ⁽³⁾
	1934-35	7,336	1,065.89	.145
Santa Paula Creek	1928-29	-	-	-
	1929-30	135	-	-
	1930-31	271	146.34	0.54
	1931-32	2,191	475.45	.217
	1932-33	2,008	263.71	.131
	1933-34	1,709	346.25	.203
	1934-35	4,159	656.50	.158
Saticoy	1928-29	2,073	870.66	0.42
	1929-30	7,421	1,409.99	.19
	1930-31	6,373	1,089.78	.171
	1931-32	9,121	1,979.26	.217
	1932-33	10,254	983.47 ⁽²⁾	.096
	1933-34	6,819	1,742.44 ⁽⁴⁾	.255 ⁽⁴⁾
	1934-35	18,917	3,853.27	.203
River bed at Saticoy	1928-29	-	-	-
	1929-30	-	-	-
	1930-31	-	-	-
	1931-32	-	-	-
	1932-33	1,273	166.89	0.131
	1933-34	1,520 ⁽⁵⁾	178.00 ⁽⁵⁾	.117 ⁽⁵⁾
	1934-35	(5)	(5)	(5)

(1) Spreading in Santa Clara River bed below Torrey crossing.

(2) Includes cost of test-well records.

(3) Includes cost of cleaning grounds.

(4) Includes cost of test-well records, protection work, new pipe-line intake, and putting new spreading ground into operation.

(5) No measurement made - channel scarified twice, cost of which is included in Saticoy spreading grounds.

Yucaipa Valley, San Bernardino County

Data published in 1937 (17) on capital costs of water spreading for four projects in Yucaipa Valley are contained in Table XXXII.

Table XXXII. Description and capital costs of water spreading projects in Yucaipa Valley, San Bernardino County, Calif. (17)

Location	Method of spreading	Size of structures	Total capacity	Total cost
Wilson Creek	Contour ditches	6 ft. wide; 2 ft. deep; total length 17,000 ft.	cfs 20	\$20,700
Potato Creek	Canals with pipe outlets		15	7,500
Wildwood Creek	Contour ditches	6 ft. wide; 2 ft. deep; total length 6000 ft.	5	2,500
Atwood Lake	Lake		acre-feet 10	10,000*

* Diversion channel to lake.

Mill Creek (near Redlands)

Water is spread into ditches 3 ft. wide and 2 ft. deep from temporary diversion weirs (17). This is a one-man operation. Total cost of works existing in 1937 was estimated to be \$9500. A more permanent diversion was planned for an estimated cost of \$50,000. During 1922-34 period water was spread for \$0.12/acre-foot including cost of digging ditches and building the diversion weirs. Actual operating cost including labor, tools, and taxes on the land was approximately \$0.08/acre-foot. Cost of land was not included in either of these figures.

Day Canyon, San Bernardino County

These spreading grounds consist of a series of eight basins, each approximately 20 feet wide by 300 feet in length, and an average depth of 4 feet; and a contour ditch, 4 feet wide by 2 feet deep, with a total length of about 18,000 feet. Total cost of the works up to 1937 was \$20,000 (17).

Jacobsen Ranch, Tehachapi, California

A 12-acre spreading area was constructed in 1955 for \$4000, exclusive of land. It benefits 200 acres of downstream irrigated land. Maintenance costs are low, consisting of weed and rodent control and removal of silt in the first basin. During the first three years of operation (1956-1958), 420 acre-feet of water were spread; neglecting land and maintenance costs, this water cost \$9.50 per acre-foot (24).

Peoria, Illinois, Recharge Pits

In the last 10 years recharge pits were constructed adjoining the Illinois River at Peoria, Illinois, in an effort to combat the overdraft resulting from heavy industrial pumping (26). River water, chlorinated but unfiltered, was released into the pits continuously except in the summer months when river temperatures were high. The pits, located in highly permeable alluvium, accepted the water readily; cleaning was necessary only on an annual basis in most instances. The pits were constructed as an experiment by the Illinois State Water Survey, but their success has warranted their continued operation by the City of Peoria.

A summary of costs for one pit during 1954-56 and for two pits during 1956-1959 is presented in Table XXXIII. Note that the unit operating cost drops from \$8.83 per acre-foot for one pit to \$5.25 for two pits.

South Dakota Ranch Spreading

Ranchers in South Dakota spread rain water by ponding runoff in fields using bulldozers to construct earth dikes (15). In one area a rancher has moved 25,000 cubic yards of earth to build 7 miles of dikes. The cost at \$0.12/yard³ would be \$3000, or \$6.70/acre for the 450 acres covered. Maintenance and operation costs to 1956 were less than \$0.20/acre/year. Benefits include a hay crop and an alfalfa seed crop annually.

Table XXXIII. Cost of artificial recharge at Peoria, Illinois, pits (26)

CAPITAL INVESTMENT

Land and laboratory*	\$300,000	
Pit No. 1		
Observation wells		\$ 1,610
Sheet piling and intake		14,350
Control tower		
Structure	\$20,130	
Equipment	5,330	
Utilities	1,440	
	\$26,900	\$26,900
Pipe lines, piping		8,610
Pit excavation and sand		8,790
Fencing		3,040
Landscaping		100
Total		\$63,400
Pit No. 2		
Land**		\$15,000
Pump, motor, flow meter, and other equipment		5,600
Installation		4,730
Pit excavation, gravel, pipe line		12,760
Observation wells		4,460
Fencing		2,050
Miscellaneous		150
Total		\$44,750

OPERATING COSTS

	One pit		Two pits		
	1954-55	1955-56	1956-57	1957-58	1958-59
<u>Personal services</u>	\$ 6,600	\$ 7,500	\$ 9,920	\$ 9,425	\$ 8,705
<u>Contractual services</u>					
Water	300	410	500	465	900
Electricity	185	250	1,900	1,775	1,450
Gas (for heat)	130	135	100	105	100
Pit Cleaning	1,600	1,765	1,500	-----	-----
Miscellaneous	15	110	535	905	895
<u>Commodities</u>					
Chlorine	975	1,580	2,800	2,770	2,550
Copper sulfate	-----	-----	45	50	50
Miscellaneous	60	415	85	30	90
Equipment	-----	15	-----	10	-----
<u>Totals</u>	\$ 9,865	\$12,180	\$17,385	\$15,535	\$14,740
<u>Unit cost of operation</u>					
Recharge during season (million gallons)	365.02	423.63	1,079.86	966.78	915.32

* Includes cost of land Pit No. 1

** Cost of a grant of easement and not outright purchase of land.

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CONSTRUCTION OF ARTIFICIAL RECHARGE PROJECTS BY NUCLEAR EXPLOSIVES

Methods and Applications

The Plowshare Program of the Atomic Energy Commission is concerned with peaceful uses of nuclear explosives. Of many possible applications explored, one of the most promising is that of nuclear excavation, involving large-scale earth displacement at low cost.

By exploding a given charge a selected distance underground a crater can be produced at the earth's surface. Considerable cratering experience has been gained by the Atomic Energy Commission as a result of a series of underground shots for various purposes (20). Data now available provide good relations between charge size, depth of burst, crater radii, and crater depth.

As an example of what can be accomplished in cratering, Project Sedan, a 100-kiloton shot, was fired at the Nevada Test Site in July 1962. Fired in alluvium, the shot created a crater 1200 feet across and 320 feet deep. It moved 7.5 million cubic yards of material, equal to a volume of 4650 acre-feet.

Nordyke (20) has summarized relationships between crater radius and depth and depth of burst for any charge size. Thus, crater dimensions can be determined for specified shot conditions. Crater volumes can also be approximated from data assembled by Nordyke in the same reference.

A large crater, located in a permeable material and supplied with water, would constitute an excellent artificial recharge project. It could be compared to a combination of the conventional basin and pit projects, having the large contact area of a basin and the depth and storage characteristics of a pit. In terms of size and volumes of water which could be handled, a nuclear explosive crater would exceed any conventional individual project. This has the advantage from an economic standpoint of providing possible multiple uses not ordinarily considered in artificial recharge projects: temporary or emergency water storage, recreational uses, and simultaneous surface water supply and ground water recharge.

The blast creating a crater may also improve the permeability of the surrounding formation so that recharge rates are higher than would be obtained by conventional excavation. Proceeding radially outward from a crater, investigations have shown that a fall back zone, a rupture zone, a plastic zone, and an elastic zone exist in the

surrounding formations. The first three zones might be expected to have increased effective porosities and/or fractures in most media which would improve the hydraulic flow characteristics of the formations.

Nuclear explosives can be also employed to create underground cavities which could be employed for artificial recharge. However, as such projects have greatest application for disposal of wastes at great depths, they will not be considered further in this report.

Limitations

The use of nuclear explosives introduces problems and hazards not associated with conventional methods of excavation. Chief among these are (a) radiation fallout from the atmosphere, (b) radioactive contamination underground, (c) seismic disturbance, (d) air blast, and (e) deformation of media surrounding the shot point. Each of these problems has and is being intensively studied by the Atomic Energy Commission. Present indications are that none of these problems, except in metropolitan or other highly-populated areas, constitute a serious limitation to the use of nuclear explosives.

Charges

Charges for nuclear explosives for large-scale excavation are believed to be equal to or less than those for conventional excavation. A limited amount of charge data has been released by the Livermore Radiation Laboratory. These suggest that costs may vary from three cents to more than \$5.00 per cubic yard depending upon blast size. Conventional costs lie in between — never at the lower figure and only approaching the upper figure for very small projects. It has been estimated, for example, that a 1-megaton nuclear explosive system costing a total of about \$1.5 million would remove 50 million cubic yards of earth at a cost of 3.0 cents per cubic yard. Of course, yardage costs cannot be compared directly as nuclear explosives remove more material than would be blasted and dug by conventional methods.

The total cost of a nuclear explosive system involves many items, including exploratory drilling, weather observations, emplacement hole, surface facilities, pre- and post-shot surveys, road construction, control point and assembly area facilities, communications, engineering, a safety program, and miscellaneous items. Rough estimates of most of these costs can be made based upon AEC nuclear explosive test experiences in spite of the fact that most previous shots were experimental in

character and were for purposes other than those of interest here. Additional costs include land acquisition, completion costs after the nuclear explosion, and charge for the nuclear device itself.

Recently the Atomic Energy Commission revised its schedule of charge estimates, originally released in 1958, for nuclear explosives and related services, including safety studies. The revisions take into account technological advances in design, emplacement, and firing of thermonuclear explosives with very low fission yields. Costs of safety studies, which were included in the 1958 charges, can be accurately estimated only for each individual situation; therefore, these have been omitted from the 1964 charge estimates. The net result of the revisions is a substantial reduction in the charges for nuclear explosives for peaceful uses.

The revised charge estimates show charges nearly independent of device yield, ranging from \$350,000 for a nuclear explosive with a 10-kiloton yield to \$600,000 for one 200 times greater, a 2-megaton yield. Charges for yields between these limits may be read directly from Fig. 8. These charges include nuclear materials, fabrication and assembly, and arming and firing services; not included are safety studies, site preparation involving construction of holes, transportation and emplacement of the devices, and support. In accordance with AEC policy the user would be expected to pay full cost for any excluded services supplied by AEC. It should be noted that costs of these excluded related services depend significantly on the number of explosives detonated at one time.

Although the 1964 charge estimates for nuclear explosives are quite explicit, the AEC qualified these figures (a) in terms of their applicability for feasibility studies, and (b) for projects where new knowledge could be gained. These qualifications have practical importance in initial applications; consequently, the AEC policy statement in this connection is quoted in full in the following:

"These projected charges are released only for use in feasibility studies and evaluations and are based on a projection to a time when explosives will be produced in quantity for routine commercial utilization. Nevertheless, the Commission believes that these projected charges are sufficiently representative of the future situation to warrant their use in feasibility studies. At the present time, the Commission is not authorized to supply nuclear explosives and related services on a commercial basis, although the Commission may engage in research and development arrangements, including demonstrations of a particular peaceful application for nuclear explosives.

Fig. 8. Projected charges for thermonuclear explosives, published by AEC in 1964.

"The Commission believes that more research and development is needed before any routine commercial applications are practical. Therefore, the Commission will continue to work with other groups in studying the contribution their proposals for projects could make to the research and development program. It is expected that technical and economic information can be derived from such projects to help develop and demonstrate peaceful uses for nuclear explosives. In such projects it can be expected that the Commission will negotiate the charge to be made for the nuclear explosives and related services based upon a number of factors, including the nature of the contribution by the other party, the economic value of the project to the other party, and the value of information to be received by the Commission. Although the projected charges discussed above might be used as a basis for discussion of costs to be assumed by the AEC in such projects, it should be recognized that the costs to be assumed by the AEC as finally negotiated might be significantly different from the projected charges."

Actual costs of the Sedan cratering shot are summarized in Table XXXIV. This shot removed 7.5 million cubic yards of material at a cost of \$0.18 per cubic yard.

Table XXXIV. Costs of Sedan cratering
shot, Nevada Test Site, July 6, 1962*.

Program	Actual cost
Technical	\$ 452, 800
Operational Safety & Project Manager Programs	50, 600
Support	128, 900
Engineering and Construction	700, 400
Total	\$1, 332, 700

*Data from Livermore Radiation Laboratory

In order to study the economic feasibility of constructing artificial recharge projects from craters produced by nuclear explosives, the Lawrence Radiation Laboratory furnished at the author's request a cost estimate for a representative cratering shot for recharge purposes. The estimate was based on:

- (1) Emplacement in a 36" I. D. steel casing at a depth of 700 feet in alluvium.
- (2) Installation of standard surface emplacement facilities including power, hoist, cable, headframe, emplacement buildings and stemming material.
- (3) Three 6" exploratory holes each 1000' deep.
- (4) Pre- and post-shot ground and aerial surveys covering an area one mile in diameter.
- (5) Ten miles of new secondary road construction.
- (6) A trailer park control point area located eight miles from surface zero. This is to include space, power and receptacle for six trailers.
- (7) An isolated assembly compound. This to include fencing, stabilization, power and trailer receptacle for two trailers.
- (8) T. V. monitor at the C. P. viewing surface zero.
- (9) On-site U.S. Weather Bureau monitoring.
- (10) Miscellaneous on-site support and radio and telephone communications.
- (11) A reasonable on-site safety program to include:
 - (a) A limited hydrological program in the exploratory holes.
 - (b) Seismic and air blast monitors.
 - (c) Instrumentation of existing wells.
 - (d) Remote area monitors.

- (e) USPHS monitors.
- (f) Evacuation and claims.
- (g) Observers assembly area.

The breakdown of costs is given in Table XXXV. To this total cost must be added costs for land, the nuclear device (see Fig. 8), and post-shot completion work.

Table XXXV. Cost estimate of a representative
nuclear explosion to create a crater for
artificial recharge purposes. *

Description	Unit	Quantity	Price	Sub total	Total
(1) Exploratory holes					
Mobilization	Ea.	1	5,000	5,000	
Drilling 3 at 1000'	L. F.	3000	25.00	75,000	
Move	Ea.	2	1,000	2,000	
Demobilization	Ea.	1	5,000	5,000	
					87,000
(2) U.S. Weather Bureau					
4 mo. on site observations	L. S.				25,000
(3) Emplacement Hole 1 at 700'					
Mobilization	Ea.	1	10,000	10,000	
Surface casing	L. S.	1	2,000	2,000	
Drilling	Day	30	1,200	36,000	
36" casing	L. F.	700	35.00	24,500	
Install casing	Day	2	1,200	2,400	
Cement casing	C. F.	3780	2.00	7,600	
Wait on cement	Day	3	1,200	3,600	
Survey hole	L. S.	1	1,000	1,000	
Log hole	L. S.	1	2,000	2,000	
Tools, bits & mud	L. S.	1	15,000	15,000	
Demobilization	L. S.	1	10,000	10,000	
Lost circulation contingency				20,000	
					134,000
(4) Surface plant					
Device bldg. 12x30	S. F.	360	10.00	3,600	
T & F bldg. 8x8	S. F.	64	10.00	640	
Emplacement crane					
(rental)	Day	10	200.00	2,000	
Collar pad	L. S.		2,000	2,000	
Cable rack	L. S.		1,000	1,000	
Wire rope	L. F.	1500	1.00	1,500	
Generator (rental)	Day	30	100.00	3,000	
Power distribution	L. S.		10,000	10,000	
Stemming material	C. F.	4900	1.00	4,900	
Down hole cables					
(Average)	L. F.	5000	1.00	5,000	
					33,600

*Data from Lawrence Radiation Laboratory.

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COMPARISON OF ALTERNATIVE METHODS OF CONSTRUCTION

In order to make an economic comparison of costs of alternative artificial recharge projects constructed by conventional methods and by nuclear explosives, it is necessary to ascertain what type of projects can be compared. Recharge by flooding, ditch and furrow, and modified stream bed methods are not in general comparable because these involve only minor or temporary construction works. Similarly, most pit recharge projects make use of existing pits, such as gravel pits, and therefore they are unique in that their singularity of location was not planned for the purpose of recharge. Injection wells have been employed for recharge only in metropolitan areas where land is limiting or for control of sea water intrusion, neither of which could be accomplished by nuclear explosives.

But a cratering project involving storage and artificial recharge can be compared with a reservoir and basin project for the same purposes. Such a project might be visualized in the San Joaquin Valley where imported water from northern California might be stored for (a) seasonal regulation, (b) local water supply, (c) peak water requirements, and (d) controlled releases for artificial recharge. In a conventional project the reservoir-plus-basins would be located near each other, whereas in a crater project the storage and recharge functions would be superposed.

To compare the two projects, the following assumptions will be made:

- (a) The volume of the storage reservoir and the volume of the crater will be equal.
- (b) The wetted area of the crater approximates the wetted area of the basins.
- (c) Rates of recharge in the basins and in the crater are equal.
- (d) Annual costs of the two projects, including water purchase and treatment, operation and maintenance, depreciation, interest, administrative expenses, and pumping costs, are equal.
- (e) Topographic and geologic conditions are suitable for construction by either method.
- (f) An imported water supply is available nearby to where water is required for for underground storage.
- (g) The surface reservoir requires no excavation and has no leakage.

Cost estimates of the two alternatives are given in Table XXXVI. In all instances costs are intended to be representative current values and are based upon costs tabulated in this report.

Table XXXVI shows that construction by nuclear excavation would cost \$142,600 or 9 percent more than by conventional construction.

Table XXXVI. Comparative cost estimates for equivalent artificial recharge projects constructed by conventional methods and by nuclear explosives.

A. Conventional construction method

Item	Unit	Quantity	Price	Total
Earth dam (60 ft. high, 2500 ft. long, top width 20 ft., side slopes 2.5:1), construction	yd ³	945,000	\$ 1.	\$945,000.
Reservoir (6000 acre-ft. volume, average depth 20 ft., net area 300 acres, gross area 300 acres),				
site clearing	acre	300	50.	15,000.
Basins (wetted area 72 acres, gross area 90 acres)				
leveling	acre	90	50.	4500.
dike construction	acre	90	100.	9000.
Canals	ft.	5000	15	75,000.
Observation wells (10 at 500 ft. depth)	ft.	5000	20.	100,000.
Appurtenances				
Control valves and gates	Ea.	10	1000.	10,000.
Diversion structures in canal	Ea.	4	500.	2000.
Measuring devices	Ea.	10	250.	2500.
Building and misc. structures	L.S.			25,000.
Road construction	mile	10	2500.	25,000.
Fences	ft.	10,000	2.	20,000.
Subtotal				\$1,233,000.
Engineering (12 percent of construction)				148,000.
Subtotal				\$1,381,000.
Contingency (at 10 percent)				138,000.
Land	acre	420	100.	42,000.
Total				\$1,561,000.

B. Nuclear explosives construction method

Item	Unit	Quantity	Price	Total
Crater (radius 685 ft., depth 354 ft., volume 6000 acre-feet, area 34 acres)	L.S.			\$875,800.
construction	L.S.			480,000.
158 kiloton nuclear device	L.S.			5000.
Grading, post-shot	L.S.			50,000.
Crater inflow chute	ft.	5000	15	75,000.
Canals	ft.	5000	20	100,000.
Observation wells (19 at 500 ft. depth)				
Appurtenances				
Control valves and gates	Ea.	5	1000.	5000.
Diversion structure in canal	Ea.	2	500.	1000.
Measuring devices	Ea.	4	250.	1000.
Buildings and misc. structures	L.S.			25,000.
Road construction (included in crater construction)				
Fences	ft.	10,000	2.	20,000.
Subtotal				\$1,637,800.
Engineering (12 percent of all construction except crater and nuclear device)				28,000.
Subtotal				\$1,665,800.
Contingency (at 10 percent), less crater construction and nuclear device)				31,000.
Land (twice crater area)	acres	68	100	6800.
Total				\$1,703,600.

Land costs can prove to be a highly variable item. If instead of \$100 per acre, as shown in Table XXXVI, a value of \$1000 per acre is assumed, conventional construction costs total \$1,939,000 while the nuclear method totals \$1,764,800. This represents a savings of \$174,200, or 9 per cent, using nuclear explosive construction. Thus, the smaller area associated with the crater design makes this project increasingly advantageous as land costs increase.

From an operational standpoint the crater would have approximately the same water contact area as the basin (the 72 acre area is the horizontally projected area in each case). Because of the higher hydraulic head, recharge rates might be expected to exceed those of the basins. For removal of silt deposits, basins could be cleaned more easily and economically. But experience in the Peoria pit has shown that the steep sides of a pit (or crater) serve as the major recharge zone and silt collects largely in the bottom portion.

Water costs on an acre-foot basis cannot be assessed without evaluating annual costs; however, the benefits suggested by the projects described should prove to be economically feasible. Assuming a recharge rate of only one foot per day yields an annual volume of 26,200 acre-feet - more than four times the reservoir or crater storage capacity.

The cost comparison shown in Table XXXVI must be regarded as purely hypothetical in that it is assumed that the choice of method of construction is governed entirely by relative costs. In practice limitations may be imposed by geology, topography, social factors, and multipurpose aspects of the operation of the project. Each item listed in Table XXXVI is subject to considerable variation; the particular design of a specific project could influence markedly many of the values. Yet, with all of these qualifications the cost data taken in ensemble are believed to be both reasonable and representative.

The foregoing analysis is illustrative only; many other similar projects differing in site and/or design can be compared using the data and methodology described in this report. What emerges from Table XXXVI is that construction by nuclear explosives of selected artificial recharge projects are not only economically competitive with conventional construction methods but can show definite economic advantages. The greatest advantages accrue for larger projects approaching or exceeding 6,000 acre-feet in volume as the total charges for nuclear explosives are essentially independent of magnitude of the explosive yield and for locations involving high land costs,

since craters are more efficient structures for storage and recharge of water than are conventional reservoirs and spreading basins.

A large crater located in permeable material and supplied with water forms an excellent structure for artificial recharge. But craters also have other important applications in the water resources field--for flood control, drainage, recreation, temporary storage, and terminal storage. Craters for water storage have a flexibility in location not possible with the select topographic and geologic conditions required for a conventional dam and reservoir. For example, a terminal storage reservoir could be created for an irrigation district receiving water in the San Joaquin Valley, where water surface storage by conventional methods would not be possible. Certainly, with these potential benefits in mind and the foregoing economic analysis, further study of cratering for construction of water resources projects appears to be warranted.

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CONCLUSIONS

On the basis of the cost data and economic analyses of projects to artificially recharge ground water presented in this report, it is concluded that:

- (1) In the southwestern United States the value of water for all purposes will continue to increase in the future in response to supply and demand, and therefore, water resources projects which provide storage and opportunity for management of water at low cost will become increasingly justified.
- (2) Artificial recharge projects have increased rapidly in recent years in the southwestern United States because they provide for conservation, storage, and the opportunity to manage available water resources, surface and sub-surface, for maximum beneficial use.
- (3) There are sufficient data available to ascertain costs of artificial recharge projects, particularly for the methods commonly practiced in California.
- (4) A comparison of cost estimates for equivalent artificial recharge projects constructed by conventional methods and by nuclear explosives indicates that nuclear construction is most advantageous for storage volumes approaching or exceeding 6,000 acre-feet and for locations involving high land costs.
- (5) Cost comparisons of alternative construction methods for artificial recharge projects of various types and sizes can be made based upon the data and methodology presented in this report.
- (6) From an economic standpoint further study of cratering for construction of water resources projects appears to be fully warranted.

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APPENDIX I

COST OF PRODUCING GROUND WATER FOR MUNICIPAL USE AT THE NORTH BRISTOL STREET PUMP PLANT, SANTA ANA, CALIFORNIA, 1960

A. Description And Capital Cost Of Facilities

	<u>Cost Adjusted to 1960 Base</u>
<u>Reservoir 1954 (50 Year Life)</u>	
Capacity 6,000,000 Gal. (Approx.) Size 166' x 359' x 20'	
Total Cost of Construction	\$ 69,358.83
<u>Reservoir Roof 1954 (50 Year Life)</u>	
Structual Steel Frame, Aluminum Sheeting Roof	
Total Cost of Construction	\$ 63,315.00
<u>Booster Station 1965 (20 Year Life)</u>	
2 Each 2,650 G.P.M. Pumping Units, 150 ft. Total Design Head with 150 Horsepower Motors, 24" Discharge Line	
Total Cost of Installation	\$103,312.21
<u>Well #18 - 1956 (20 Year Life)</u>	
Depth of Well 654 feet	
Size of Casing 18" - #8 Gauge 654 ft. 2 Stage Bowls, Depth 200 Feet.	
150 H.P. 1,768 R.P.M. Motor	
Total Cost of Construction and Equipment	\$ 35,534.09
<u>Well #14 - 1927 (20 Year Life)</u>	
Depth of Well 1,050. feet	
Size of Casing 20" - #10 Gauge 180 ft., 16" - #10 Gauge 400 ft., 12" - #10 Gauge 470 ft.	

4 Stage Bowls, Depth 173 feet.

100 H. P. 1, 180 R. P. M. Motor

Estimated Total Cost Including Construction
and Equipment

\$ 26,000.00

Well Buildings 1927 & 1956 (20 Year Life)

Estimated Total Cost of Construction

\$ 3,000.00

Total

\$300,520.13

B. Pumping Requirements And Operation

1. Ground Surface Elevation	(Approx.)	121 feet
2. Ground-Water Elevation	(Approx.)	-4 feet
3. Depth to Ground-Water Level	(Approx.)	125 feet
4. Average Pumping Head		
Well #14		144.4 ft.
Well #18		160.0 ft.
5. Average Rate of Production		3,800 G. P. M.
6. Average Efficiency of Well Pumps and Motors		65%
7. Annual Production of Both Wells		3,412 A. F.
8. Storage of Reservoir		6,000,000 Gal.
9. Capacity of Booster Pumps		5,300 G. P. M.

C. Capital And Maintenance Cost Per Year

	<u>Capital Cost/Year*</u>	<u>Maintenance Cost/Year</u>	<u>Total Cost/year</u>
Reservoir	\$ 8,411.52	\$ 305.00	\$ 8,716.52
Booster Station	8,998.49	693.00	9,691.49
Well #18	3,095.02	706.50	3,801.52
Well #14	2,264.60	745.88	3,010.48
Total	\$22,769.63	\$ 2,450.38	\$25,220.01
Power Cost of all Units			\$20,950.00
		Total	\$46,170.01
Cost per Acre Foot			\$ 13.53

*These figures reflect amortization at 6% interest based on life shown on attached sheet.

APPENDIX II
COST OF PRODUCING GROUND WATER FOR THE
CITY OF ANAHEIM, CALIFORNIA, FROM
SEVEN WELLS, 1960

Well #10

Depth 389' Size of casing 12" I.D. Date of drilling Before 1940

Water & Ground Elevation Characteristics

Ground surface elevation above sea level	113,302'
Ground water elevation	11.34'
Center line of pump discharge to water	124,643'
Draw-down when pumping	17'10"
Total pumping head	318'
Rate of production	1,230 G. P. M.
Total production for year	212.1 A. F.

Pumping Equipment

Make of pump	Johnson	Date of installation 8-21-56
Column diameter	8"	
Column length	200'	
Bowl size	9-1/2" O.D.	
Number of stages	11	
Make of motor	U.S. Motor	125 H. P.

Rate of Depreciation & Costs

	Original Cost \$4,900.00
Well casing depreciated on a 40 year basis	\$ 122.50
Equipment & appurtenances depreciated 25 year basis	263.27
Orig cost \$ 6,581.68	
Total depreciated cost	385.77
Total cost of well & equipment new \$11,481.68	
50% depreciation of original cost of well & equipment \$5,740.84	
Interest 6% per annum	344.45

Production Costs

Repairs, maintenance & energy	\$2,984.71
Pump tax 1-1-60 to 6-30-60 43.2 A. F. x \$4.30	185.76
Pump tax 7-1-60 to 12-31-60 168.9 A. F. x \$5.50	928.95

Total Operating Cost Plus Annual Depreciation

Total cost for year	\$4,829.64
Total cost per acre ft.	22.77

Well #14

Depth 450' Size of casing 16 I. D. Date of drilling Dec. 17, 1956

Water & Ground Elevation Characteristics

Ground surface elevation above sea level	142, 477'
Ground water elevation	4, 144'
Center line of pump discharge to water	138, 333'
Draw-down when pumping	13'. 5"
Total pumping head	184'
Rate of production	2, 275 G. P. M.
Total production for year	1, 761. 1 A. F.

Pumping Equipment

Make of pump	Peerless	Date of installation 1957
Column diameter	10" I. D.	
Column length	220'	
Bowl size	10" O. D.	
Number of stages	4	
Make of motor	U. S. 150 H. P.	

Rate of Depreciation & Costs

Booster pump, wet well and reservoir depreciated on 75 year basis	Original cost \$90, 000. 00	1, 200. 00
Well casing depreciated on a 40 year basis	Original cost 10, 068. 39	251. 71
Equipment & appurtenances depreciated 25 year basis	Original cost 9, 220. 00	368. 80
Total depreciated cost		\$ 1, 820. 51
Total cost of well & equipment new		109, 288. 30
50% depreciation of original cost of well & equipment		54, 644. 20
Interest 6% per annum		3, 278. 65

Production Costs

Repairs, Maintenance & energy Wet well in reservoir	5, 511. 88
Repairs, maintenance & energy	8, 544. 70
Pump Tax 1-1-60 to 6-30-60 737. 3 A. F. x \$4. 30	3, 170. 39
Pump Tax 7-1-60 to 12-31-60 1, 023 A. F. x \$5. 50	5, 630. 90

Total Operating Cost Plus Annual Depreciation

Total cost for one year	27, 957. 03
Total cost per acre ft.	15. 87

Well #15

Depth 638' Size of casing 16" I.D. Date of drilling 7-1-56

Water & Ground Elevation Characteristics

Ground surface elevation above sea level	170.566'
Ground water elevation	27.566'
Center line of pump discharge to water	143.000'
Draw-down when pumping	19'
Total pumping head	326'
Rate of production	1,180 G. P. M.
Total production for year	1638.9 A. F.

Pumping Equipment

Make of pump	Peerless	Date of installation 6-21-57
Column diameter	8"	
Column length	240'	
Bowl size	11-1/2" O.D.	
Number of stages	8	
Make of motor	125 H. P. U.S.	

Rate of Depreciation & Costs

Well casing depreciated on a 40 year basis	
Original cost \$12,458.39	\$ 311.46
Equipment & appurtenances depreciated 25 year	
basis Original cost \$8,233.00	329.32
Total depreciated cost	640.78
Total cost of well & equipment new	20,691.39
50% depreciation of original cost of well & equipment	10,345.70
Interest 6% per annum	620.74

Production Costs

Repairs, maintenance & energy		7,943.36
Pump Tax 1-1-60 to 6-30-60	936.2 A. F. x \$4.30	4,025.66
Pump Tax 7-1-60 to 12-31-60	702.7 A. F. x \$5.50	3,864.85

Total Operating Cost Plus Annual Depreciation

Total cost for year	17,095.39
Total cost per acre ft.	10.43

Well #17

Depth 576' Size of casing 16" I.D. Date of drilling Prior 1930

Water & Ground Elevation Characteristics

Ground surface elevation above sea level	176.405'
Ground water elevation	47.739'

Center line of pump discharge to water	128.666'
Draw-down when pumping	10'
Total pumping head	290'
Rate of production	855 G. P. M.
Total production for year	1050.3 A. F.

Pumping Equipment

Make of pump	Winthroath	Date of installation 1960
Column diameter	8"	
Column length	210'	
Bowl size	10" I. D.	
Number of stages	6	
Make of motor	U.S. 75 H. P. Sub.	

Rate of Depreciation & Costs

Well casing depreciated on a 40 year basis	
Orig. cost \$5,000.00	125.00
Equipment & appurtenances depreciated 25 year basis	
Orig. cost \$7,884.00	315.36
Total depreciated cost	440.36
Total cost of well & equipment new	12,884.00
50% depreciation of original cost of well & equipment	6,442.00
Interest 6% per annum	386.52

Production Costs

Repairs, maintenance & energy		6,497.18
Pump Tax 1-1-60 to 6-30-60	394.5 A. F. x \$4.30	1,696.35
Pump Tax 7-1-60 to 12-31-60	655.8 A. F. x \$5.50	3,606.90

Total Operating Cost Plus Annual Depreciation

Total cost for year	12,627.31
Total cost per acre ft.	12.02

Well #19

Depth 351' Size of casing 16" I. D. Date of drilling Before 1930

Water & Ground Elevation Characteristics

Ground surface elevation above sea level	143.685'
Ground water elevation	27.019'
Center line of pump discharge to water	116.666'
Draw-down when pumping	16'
Total pumping head	361'
Rate of production	1200 G. P. M.
Total production for year	587.7 A. F.

Pumping Equipment

Make of pump	Wintroath	Date of installation June 1959
Column diameter	8"	
Column length	210'	
Bowl size	11-5/8"	
Number of stages	7	
Make of motor	U.S. 125 H. P. Sub	

Rate of Depreciation & Costs

Well casing depreciated on a 40 year basis	
Orig. cost \$1200.00	30.00
Equipment & appurtenances depreciated 25 yr. basis Orig. Cost \$13,064.46	482.58
Total depreciated cost	512.58
Total cost of well & equipment new \$12,264.46	
50% depreciation of original cost of well & equipment \$6,632.23	
Interest 6% per annum	397.93

Production Costs

Repairs, maintenance & energy		5,127.09
Pump Tax 1-1-60 to 6-30-60	262.5 A. F. x \$4.30	1,128.75
Pump Tax 7-1-60 to 12-31-60	225.2 A. F. x \$5.50	1,788.60

Total Operating Cost Plus Annual Depreciation

Total cost for year	8,954.95
Total cost per acre ft.	15.24

Well #22

Depth 446' Size of casing 16 I.D. Date of drilling May 22, 1958

Water & Ground Elevation Characteristics

Ground surface elevation above sea level	158.648'
Ground water elevation	22.648'
Center line of pump discharge to water	136.000'
Draw-down when pumping	9'-11"
Total pumping head	301'
Rate of production	1197 G. P. M.
Total production for year	806.1 A. F.

Pumping Equipment

Make of pump	Johnston	Date of installation 7-31-58
Column diameter	8"	
Column length	220'	
Bowl size	11-3/8"	
Number of stages	8"	
Make of motor	U.S. 125 H. P.	

Rate of Depreciation & Costs

Well casing depreciated on a 40 year basis	
Orig. cost \$9,486.85	\$ 237.17
Equipment & appurtenances depreciated 25 year basis Orig. cost \$7,938.12	317.52
Total depreciated cost	554.69
Total cost of well & equipment new	17,424.97
50% depreciation of original cost of well & equipment	8,712.49
Interest 6% per annum	522.75

Production Costs

Repairs, maintenance & energy		6,004.75
Pump Tax 1-1-60 to 6-30-60	345.4 A.F. x \$4.30	1,485.22
Pump Tax 7-1-60 to 12-31-60	460.7 A.F. x \$5.50	2,533.85

Total Operating Cost Plus Annual Depreciation

Total cost for year	11,101.26
Total cost per acre ft.	13.77

Well #26

Depth 411' Size of casing 20 I.D. Date of drilling 1926

Water & Ground Elevation Characteristics

Ground surface elevation above sea level	192.448'
Ground water elevation	47.115
Center line of pump discharge to water	145.333
Draw-down when pumping	10' -6"
Total pumping head	311' -6"
Rate of production	2500 G. P. M.
Total production for year	1278.3 A. F.

Pumping Equipment

Make of pump	Pomona Sub	Date of installation 1960
Column diameter	10"	
Column length	220'	
Bowl size	14" I.D.	
Number of stages	7	
Make of motor	U.S. 250 H. P.	

Rate of Depreciation & Costs

Well casing depreciated on a 40 year basis	
Orig. cost \$15,000.00	375.00
Equipment & appurtenances depreciated 25 year basis	
Orig. cost \$14,622.04	584.00
Total depreciated cost	959.88

Total cost of well & equipment	29,622.04
50% depreciation of original cost of well & equipment	14,811.02
Interest 6% per annum	888.66

Production Costs

Repairs, maintenance & energy	9,104.57
Pump Tax 1-1-60 to 6-30-60 571.6 A. F. x \$4.30	2,457.88
Pump Tax 7-1-60 to 12-31-60 706.7 A. F. x \$5.50	3,886.85

Total Operating Cost Plus Annual Depreciation

Total cost for year	17,297.84
Total cost per acre ft.	13.53

Summary Sheet

	<u>Total Aver. Annual Cost</u>	<u>Aver. Production Used in Analysis</u>	<u>Aver. Cost per Acre Ft. of Water Produced</u>
Well #10	\$ 4,829.64	212.1	\$ 22.77
Well #14	27,957.03	1,761.1	15.87
Well #15	17,095.30	1,638.9	10.43
Well #17	12,627.31	1,050.3	12.02
Well #19	8,954.95	587.7	15.24
Well #22	11,101.26	806.1	13.77
Well #26	17,297.84	1,278.3	13.53
	<u>\$99,863.42</u>	<u>7,334.5</u>	

Weighted average cost per acre
foot of water produced from all 7 subject wells = \$13.62

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APPENDIX III

COST OF PRODUCING GROUND WATER FOR AGRICULTURAL USE IN ORANGE COUNTY, CALIFORNIA, 1958

Well No. 1

Ground surface elevation	(approx.)	+238 ft.
Ground-water elevation on 11-1-56	(approx.)	+ 22 ft.
Depth to ground-water level on 11-1-56	(approx.)	216 ft.
Total pumping head		237 ft.
Rate of production		1000 g.p.m.
Maximum overall plant efficiency		73 %
Average efficiency - 18 yrs		64 %
Average production for 5 largest producing agricultural wells in area for period July 1, 1956 to June 30, 1957		381.3 ac. ft.

Capital And Maintenance Requirements

Well: 600' deep, 16" ID double 10 ga. casing			\$9600.00
Pumping equipment: 4 stages 14" bowls set at 250', 10" column, 2-1/2" tubing, 1-13/16" shaft, 100 HP direct connected electric motor complete with necessary wiring and switches			6700.00
	Rate of Depreciation	Cost	Depreciation per year
Well & casing	20 yrs.	\$9600.00	\$480.00
Pumping equipment	18 yrs.	6700.00	372.22
Total cost \$16,300.00 - 1/2 total cost \$8,150.00			
Interest and taxes at 6% per annum			489.00
Lubrication - Repairs - Maintenance 381.3 ac. ft. production at 25 Cents per ac. ft.			95,32 \$1436.54

Power Requirements

Service charge at \$5.50 per HP per yr. for 100 HP		550.00
380 KWH required for each ac. ft. production 380 x 381.3 = 144,894 KWH		
First 100,000 at 1.2 Cents = \$1200.00		
44,894 at .75 Cents = \$ 336.70	1536.70	2086.70
Total average annual cost		\$3523.24
Average cost per ac. ft. production		\$ 9.24

Well No. 2

Ground surface elevation	(approx.)	185 ft.
Ground-water elevation on 11-1-56	(approx.)	-2 ft.
Depth to ground-water level on 11-1-56	(approx.)	187 ft.
Total pumping head		221 ft.
Rate of production		900 g. p. m.
Maximum overall plant efficiency		72 %
Average efficiency - 18 yrs.		63 %
Average production for 7 largest producing agricultural wells in area for period July 1, 1956 to June 30, 1957		221.7 ac. ft.

Capital And Maintenance Requirements

Well: 322' deep, 16" ID double 10 ga. casing		\$5152.00	
Pumping equipment: 5 stages 12" bowls set at 253', 10" column, 3" tubing, 2-11/16" shaft, 75 HP direct connected electric motor complete with necessary wiring and switches		6750.00	
	Rate of Depreciation	Cost	Depreciation per year
Well & casing	20 yrs.	\$5152.00	\$257.60
Pumping equipment	18 yrs.	6750.00	375.00
			632.60
Total cost \$11,902.00 - 1/2 total cost \$5,951.00			
Interest and taxes at 6% per annum			357.06
Lubrication - Repairs - Maintenance 221.7 ac. ft. production at 25 Cents per ac. ft.			55.42
			\$1045.08

Power Requirements

Service charge at \$6.00 per HP per yr. for 75HP		450.00	
360 KWH required for each ac. ft. production 360 x 221.7 = 79,812 KWH			
First 75,000 at 1.3 Cents = 975.00 4,812 at .75 Cents = 36.09		1011.09	\$1461.09
Total average annual cost			\$2506.17
Average cost per ac. ft. production			\$ 11.30

Well No. 3

Ground surface elevation	(approx.)	107 ft.
Ground-water elevation on 11-1-56	(approx.)	-14 ft.
Depth to ground-water level on 11-1-56	(approx.)	121 ft.
Total pumping head		141 ft.
Rate of production		500 g. p. m.
Maximum overall plant efficiency		67 %
Average efficiency - 18 yrs.		58 %
Average production for two largest producing agricultural wells in area for period July 1, 1956 to June 30, 1957		96.6 ac. ft.

Capital And Maintenance Requirements

Well: 168' deep, 12" ID double 12 ga. casing \$1760.00

Pumping equipment: 5 stages 10" bowls set at 150',
8" column, 2" tubing, 1-3/16" shaft, 25 HP direct
connected electric motor complete with necessary
wiring and switches 3010.00

	Rate of Depreciation	Cost	Depreciation per year	
Well & casing	20 yrs.	\$1760.00	\$ 88.00	
Pumping equipment	18 yrs.	3010.00	167.22	255.22
Total cost \$4,770.00 - 1/2 total cost \$2,385.00				
Interest and taxes at 6% per annum				143.10
Lubrication - Repairs - Maintenance				
96.6 ac. ft. production at 25 Cents per ac. ft.			24.15	\$ 422.47

Power Requirements

Service charge at \$6.50 per HP per yr. for 25 HP	162.50	
250 KWH required for each ac. ft. production		
250 x 96.6 = 24, 150 KWH		
24,150 at 1.4 Cents = \$338.10	338.10	500.60
Total average annual cost		\$ 923.07
Average cost per ac. ft. production		\$ 9.56

Well No. 4

Ground surface elevation	(approx.)	52 ft.
Ground-water elevation on 11-1-56	(approx.)	-29 ft.
Depth to ground-water level on 11-1-56	(approx.)	81 ft.
Total pumping head		99 ft.
Rate of production		1000 g.p.m.
Maximum overall plant efficiency		73 %
Average efficiency - 18 yrs.		64 %
Production from largest producing agricultural well in area for period July 1, 1956 to June 30, 1957		61.3 ac. ft.

Capital And Maintenance Requirements

Well: 983' deep, 12" ID double 10 ga. casing \$9830.00

Pumping equipment: 3 stages No. 12 medium bowls set
at 150', 8" column, no tubing, 1-1/2" shaft, 40 HP
direct connected electric motor complete with
necessary wiring and switches 4575.00

	Rate of Depreciation	Cost	Depreciation per year		
Well & casing	20 yrs.	\$9830.00	\$491.50		
Pumping equipment	18 yrs.	4575.00	254.17	745.67	
Total cost \$14,405.00 - 1/2 total cost \$7202.50					
Interest and taxes at 6% per annum				432.15	
Lubrication - Repairs - Maintenance					
61.3 ac. ft. production at 25 Cents per ac. ft.				15.32	\$1193.14

Power Requirements

Service charge at \$6.50 per HP per yr. for 40 HP	260.00	
160 KWH required for each ac. ft. production		
160 x 61.3 = 9,808 KWH		
9,808 at 1.4 Cents	137.31	397.31
Total average annual cost		\$1590.45
Average cost per ac. ft. production		\$ 25.95

Well No. 5

Ground surface elevation	(approx.)	28 ft.
Ground-water elevation on 11-1-56	(approx.)	-28 ft.
Depth to ground-water level on 11-1-56	(approx.)	56 ft.
Total pumping head		68 ft.
Rate of production		1200 g. p. m.
Maximum overall plant efficiency		74-1/2 %
Average efficiency - 18 yrs.		65-1/2 %
Average production for 7 largest producing agricultural wells in area for period July 1, 1956 to June 30, 1957		128.7 ac. ft.

Capital And Maintenance Requirements

Well: 724' deep, 12" ID double 10 ga. casing				\$7800.00	
Pumping equipment: 3 stages No. 12 medium bowls set at 120', 8" column, no tubing, 1-1/2" shaft, 40 HP direct connected electric motor complete with necessary wiring and switches				4173.13	
	Rate of Depreciation	Cost	Depreciation per year		
Well & casing	20 yrs.	\$7800.00	\$390.00		
Pumping equipment	18 yrs.	4173.13	231.84	621.84	
Total cost \$11,973.13 - 1/2 total cost \$5986.56					
Interest and taxes at 6% per annum				359.19	
Lubrication - Repairs - Maintenance					
128.7 ac. ft. production at 25 Cents per ac. ft.				32.17	\$1013.20

Power Requirements

Service charge at \$6.50 per HP per yr. for 40 HP	260.00	
105 KWH required for each ac. ft. production		
105 x 128.7 = 13,513 KWH		
13,513 at 1.4 Cents	189.18	\$ 449.18
Total average annual cost		\$1462.38
Average cost per ac. ft. production		\$ 11.36

Well No. 6

Ground surface elevation	(approx.)	31 ft.
Ground-water elevation on 11-1-56	(approx.)	-23 ft.
Depth to ground-water level on 11-1-56	(approx.)	54 ft.
Total pumping head		59 ft.
Rate of production		800 g. p. m.
Maximum overall plant efficiency		71 %
Average efficiency - 18 yrs.		62 %
Average production for 4 largest producing agricultural wells in area for period July 1, 1956 to June 30, 1957		86.7 ac. ft.

Capital And Maintenance Requirements

Well: 165' deep, 12" ID double 12 ga. casing	\$2178.00	
Pumping equipment: 3 stages 10" bowls set at 100', 6" column, no tubing, 1" shaft, 20 HP direct connected electric motor complete with necessary wiring and switches	2300.00	
	Rate of	Depreciation
	Depreciation	Cost
Well & casing	20 yrs.	\$2178.00
Pumping equipment	18 yrs.	2300.00
		per year
		\$108.90
		127.78
		236.68
Total cost \$4,478.00 - 1/2 total cost \$2,239.00		
Interest and taxes at 6% per annum		134.34
Lubrication - Repairs - Maintenance		
86.7 ac. ft. production at 25 Cents per ac. ft.	21.67	\$ 392.69

Power Requirements

Service charge at \$6.50 per HP per yr. for 20 HP	130.00	
100 KWH required for each ac. ft. production		
100 x 86.7 = 8,670 KWH		
8,670 at 1.4 Cents	121.38	251.38
Total average annual cost		\$ 644.07
Average cost per ac. ft. production		\$ 7.43

Ground surface elevation	(approx.)	96 ft.
Ground-water elevation on 11-1-56	(approx.)	-10 ft.
Depth to ground-water level on 11-1-56	(approx.)	106 ft.
Total pumping head		116 ft.
Rate of production		650 g. p. m.
Maximum overall plant efficiency		69 %
Average efficiency - 18 yrs.		60 %
Average production 2 largest producing agricultural wells in area for period July 1, 1956 to June 30, 1957		82.4 ac. ft.

Capital And Maintenance Requirements

Well: 400' deep, 12" ID double 12 ga. casing		\$4400.00	
Pumping equipment: 5 stages 10" bowls, set at 140', 8" column, no tubing, 1-3/16" shaft, 25 HP direct connected electric motor complete with necessary wiring and switches		3000.00	
	Rate of Depreciation	Cost	Depreciation per year
Well & casing	20 yrs.	\$4400.00	\$220.00
Pumping equipment	18 yrs.	3000.00	166.67
			386.67
Total cost \$7400.00 - 1/2 total cost \$3700.00			
Interest and taxes at 6% per annum			222.00
Lubrication - Repairs - Maintenance			
82.4 ac. ft. production at 25 Cents per ac. ft.			20.60 \$ 629.27

Power Requirements

Service charge at \$6.50 per HP per yr. for 25 HP		162.50	
200 KWH required for each ac. ft. production			
200 x 82.4 = 16,480 KWH			
16,480 at 1.4 Cents		230.72	\$ 393.22
Total average annual cost			\$1022.49
Average cost per ac. ft. production			\$ 12.41

Well No. 8

Ground surface elevation	(approx.)	34 ft.
Ground-water elevation on 11-1-56	(approx.)	-37 ft.
Depth to ground-water level on 11-1-56	(approx.)	71 ft.
Total pumping head		83 ft.
Rate of production		1000 g. p. m.
Maximum overall plant efficiency		73 %
Average efficiency - 18 yrs.		64%
Average production 9 largest producing agricultural wells in area for period July 1, 1956 to June 30, 1957		188.2 ac. ft.

Capital And Maintenance Requirements

Well: 540' deep, 12" ID by 1/4" single casing \$6538.82

Pumping equipment: 4 stages 10" bowls set at 120',
8" column, 2" tubing, 1-3/16" shaft, 40 HP direct
connected electric motor complete with necessary
wiring and switches 4307.00

	Rate of Depreciation	Cost	Depreciation per year	
Well & casing	20 yrs.	\$6538.82	\$326.94	
Pumping equipment	18 yrs.	4307.00	239.28	566.22

Total cost \$10,845.82 - 1/2 total cost \$5422.91.

Interest and taxes at 6% per annum 325.37

Lubrication - Repairs - Maintenance

188.2 ac. ft. production at 25 Cents per ac. ft. 47.05 \$ 938.64

Power Requirements

Service charge at \$6.50 per HP per yr. for 40 HP 260.00

135 KWH required for each ac. ft. production

135 x 188.2 = 25,407 KWH

25,407 at 1.4 Cents 355.70 \$ 615.70

Total average annual cost \$1554.34

Average cost per ac. ft. production \$ 8.26

Well No. 9

Ground surface elevation	(approx.)	162 ft.
Ground-water elevation on 11-1-56	(approx.)	-15 ft.
Depth to ground-water level on 11-1-56	(approx.)	177 ft.
Total pumping head		213 ft.
Rate of production		1000 g. p. m.
Maximum overall plant efficiency		73 %
Average efficiency - 18 yrs.		64 %
Average production 3 largest producing agricultural wells in area for period July 1, 1956 to June 30, 1957		290.5 ac. ft.

Capital And Maintenance Requirements

Well: 715' deep, 14" ID x 1/4" single casing \$10,010.00

Pumping equipment: 7 stages 12" bowls with 8" ID
standard drop pipe, 75 HP submersible pump
with electric motor complete with necessary
wiring and switches 6522.00

	Rate of Depreciation	Cost	Depreciation per year	
Well & casing	20 yrs.	\$10,010.00	\$500.50	
Pumping equipment	18 yrs.	6,522.00	362.33	862.83
Total cost \$16,532.00 - 1/2 total cost \$8266.00				
Interest and taxes at 6% per annum				495.96
Lubrication - Repairs - Maintenance				
290.5 ac. ft. production at 25 Cents per ac. ft.			72.62	\$1431.41

Power Requirements

Service charge at \$6.00 per HP per yr. for 75 HP		450.00	
340 KWH required for each ac. ft. production			
340 x 290.5 = 98,770 KWH			
First 75,000 at 1.3 Cents = \$975.00			
23,770 at .75 Cents = 178.27	1153.27		\$1603.27
Total average annual cost			\$3034.68
Average cost per ac. ft. production			\$ 10.45

Well No. 10

Ground surface elevation	(approx.)	68 ft.
Ground-water elevation on 11-1-56	(approx.)	70 ft.
Depth to ground-water level on 11-1-56	(approx.)	138 ft.
Total pumping head		162 ft.
Rate of production		950 g. p. m.
Maximum overall plant efficiency		72-1/2 %
Average efficiency - 18 yrs.		63-1/2 %
Average production 8 largest producing agricultural wells in area for period July 1, 1956 to June 30, 1957		595.9 ac. ft.

Capital And Maintenance Requirements

Well: 1315' deep, 12" ID x 1/4" single casing	\$15,780.00
Pumping equipment: 7 stages 10" bowls set at 200', 8" column, 2-1/2" tubing, 1-1/2" shaft, 50 HP direct connected electric motor complete with necessary wiring and switches	6091.00

	Rate of Depreciation	Cost	Depreciation per year	
Well & casing	20 yrs.	\$15,780.00	\$789.00	
Pumping equipment	18 yrs.	6,091.00	338.39	1127.39
Total cost \$21,871.00 - 1/2 total cost \$10,935.50				
Interest and taxes at 6% per annum				656.13
Lubrication - Repairs - Maintenance				
595.9 ac. ft. production at 25 Cents per ac. ft.			148.97	\$1932.49

Power Requirements

Service charge at \$6.00 per HP per yr. for 50 HP	300.00	
265 KWH required for each ac. ft. production		
265 x 595.9 = 157,913 KWH		
First 50,000 at 1.3 Cents = \$650.00		
2nd 50,000 at .75 Cents = 375.00		
57,913 at .57 Cents = 330.10	1355.10	<u>\$1655.10</u>
Total average annual cost		\$3587.59
Average cost per ac. ft. production		\$ 6.02

Well No. 11

Ground surface elevation	(approx.)	158 ft.
Ground-water elevation on 11-1-56	(approx.)	-22 ft.
Depth to ground-water level on 11-1-56	(approx.)	180 ft.
Total pumping head		202 ft.
Rate of production		750 g.p.m.
Maximum overall plant efficiency		70-1/2 %
Average efficiency - 18 yrs.		61-1/2 %
Average production 5 largest producing agricultural wells in area for period July 1, 1956 to June 30, 1957		380.1 ac. ft.

Capital And Maintenance Requirements

Well: 1133' deep, 12" ID by 1/4" casing			\$13,814.52	
Pumping equipment: 10 stages 10" bowls set 230', 8" column, 2-1/2" tubing, 1-1/2" shaft, 50 HP direct connected electric motor complete with necessary wiring and switches			7031.00	
	Rate of Depreciation	Cost	Depreciation per year	
Well & casing	20 yrs.	\$13,814.52	\$690.73	
Pumping equipment	18 yrs.	7,031.00	390.61	1081.34
Total cost \$20,845.52 - 1/2 total cost \$10,422.76				
Interest and taxes at 6% per annum			625.37	
Lubrication - Repairs - Maintenance				
380.1 ac. ft. production at 25 Cents per ac. ft.			95.02	\$1801.73

Power Requirements

Service charge at \$6.00 per HP per yr. for 50 HP	300.00	
340 KWH required for each ac. ft. production		
340 x 380.1 = 129, 234 KWH		
First 50,000 at 1.3 Cents = \$650.00		
2nd 50,000 at .75 Cents = 375.00		
29,234 at .57 Cents = 166.63	1191.63	<u>\$1491.63</u>
Total average annual cost		\$3293.36
Average cost per ac. ft. production		\$ 8.66

Summary Sheet

Well No.	<u>Total Average Annual Cost</u>	<u>Average Production Used in Analysis</u>	<u>Average Cost Per Acre Foot of Water Produced</u>
1	\$3,523.24	381.3	\$ 9.24
2	2,506.17	221.7	11.30
3	923.07	96.6	9.56
4	1,590.65	61.3	25.95
5	1,462.38	128.7	11.36
6	644.07	86.7	7.27
7	1,022.49	82.4	12.41
8	1,554.34	188.2	8.26
9	3,034.68	290.5	10.45
10	3,587.59	595.9	6.02
11	3,293.36	380.1	8.66
	<u>\$23,142.04</u>	<u>2,513.4</u>	

Weighted average cost per acre foot of water produced
from all eleven subject wells \$ 9.21

APPENDIX IV

COST OF IRRIGATION WELLS, HARMON COUNTY, OKLAHOMA, 1957⁽⁸⁾

The total cash outlay or investment of each of the systems was allocated on an annual basis by spreading the investment over an eight-year period to give an "annual fixed cost." The "annual fixed cost" was then divided by the acre feet of water pumped to give the fixed cost per acre foot of water.

Total annual operating costs include cost of fuel, cost of oil, repair of motor and repair of pump. No charge was made for attendants. The "operating cost per acre foot" of water was determined by dividing the total annual operating costs by the estimated number of acre feet of water pumped.

To locate the supply of water and determine the amount of water available, four-inch test holes were usually drilled. The most desirable location, in terms of land utilization and water distribution, was tested. If unsuccessful, a move was made to less desirable locations in the field. Costs of drilling these test wells varied but were usually from 60 cents to \$1 per foot. Cost of the test hole selected for development was applied against the cost of the well.

The test hole selected as showing the greatest possibilities was reamed to 20 or 32 inches in diameter. It was usually considered essential to case the well to a solid formation. In the Harmon County area this generally meant casing the well the entire depth in an unconsolidated aquifer. Many drillers improvised by slitting the lower section of steel well casing with an acetylene torch. In most instances this was a part of the contractual services provided by drillers.

The casing and screen installed were usually 12 to 16 inches in diameter, depending on the capacity of the aquifer, size of pump and diameter of bowls installed. After the casing and screen were centered in the hole, washed pea gravel was packed around the casing. After the casing was set properly, wells were tested to determine well capacity and size of pump to be installed. The driller usually had a test pump to use in making the test. An additional charge, which was seldom less than \$50, was made for this service.

Deep-well, turbine pumps were used exclusively in the wells studied. The average total cost of pump and gearhead was about \$25 per foot of setting for these wells.

The type of power plant used depended somewhat on the type of energy available. Three general classifications of motors were used by the Harmon County farmers:

electric, automotive, and industrial. Electric motors had a cheaper first cost and were more convenient to operate but the cost of energy was generally considered higher than for liquid gas or diesel motors. Automotive type motors had a lower first cost than industrial motors. Cost of overhauling was about the same, but the automotive type motor did not run as long between overhaul jobs.

Of the 25 plants studied, 11 were using automotive motors; 13, industrial motors; and 1, electric motor. The 13 plants powered by industrial type motors had costs which ranged from \$850 to \$1400 for an average cost per plant of \$1,001.23. The 11 plants powered by automotive motors had an average cost of \$694.09, ranging from a low of \$250 to a high of \$1,050. Since two of these were not bought as new motors, the first costs were much higher.

Cost of fuel was 9 cents per hour for the motors on natural gas and 32 cents per hour for those on propane. Operating cost records on the electric motor were considered inadequate to make an estimate.

Fixed costs consisted of annual investment charges (depreciation), interest on investment, and taxes.

Table A-1. Average cost of installation
of irrigation wells in Harmon County, Oklahoma

Depth of well, feet	No. of wells	Av. no. of acres irri- gated per well	Primary Development cost	
			Per well	Per acre irrigated in 1955
50-149	16	96.4	\$3,992.59	\$41.41
150-199	3	93.9	4,692.16	49.88
200-400	6	105.3	5,270.16	50.03
Average			\$4,361.53	\$44.62

For purposes of this study, an annual investment charge was calculated at 12-1/2 percent of the total investment. It was realized that some of the installation should be depreciated at a greater rate and some at a lesser rate, but this corresponded to the rate used for income tax purposes by the local certified public accountant.

Interest on investment was calculated at 5 percent on one-half the total initial investment.

Irrigation wells were assessed in Harmon County according to the size of the pump. A 10-inch added \$800 to the value of the personal property of the operator and did not change the assessed valuation of the land on which it was located. An 8-inch pump added \$600, a 6-inch pump added \$400, and a 4-inch pump added \$200 to the value of personal property. The amount taxes on each irrigation installation reflected the tax levy for the school district in which the well was located.

Although fixed costs must be recovered in the long-run, they were not considered in deciding whether to apply water in a season. Only the operating or variable costs were considered in making this decision. In this study the fixed costs were attributed to the major crops, such as wheat or cotton. These had a relatively high cash income. Grain sorghums and alfalfa were considered supplementary crops and carried only variable costs. Fixed costs per acre foot of water pumped for the major crops ranged from a low of \$2.38 to a high of \$25.66 and averaged \$7.20.

Operating cost per acre foot of water was found by dividing the annual operating cost (cost of fuel plus cost of repairs) by the number of acre feet of water pumped. This cost ranged from \$1.45 to \$6.42 or an average of \$3.11 per acre foot. This did not represent an actual outlay for operating for the particular year because the expense of future repairs was estimated and prorated.

The average lift for the 25 wells was 79 feet. The cost per acre foot per foot of lift was 3.9 cents. This was obtained by dividing the average operating cost per acre foot of water (\$3.11) by the average lift of the 25 wells or 79 feet.

Table A-11. Estimated fixed cost of irrigation wells of different capacities
and to different depths in Harmon County, Oklahoma

Pump size	Feet of lift									
	50	60	70	80	90	100	110	120	135	180
8-inch pump 650 to 1000 GPM										
Total investment	\$ 4, 475	4, 975	5, 275	5, 475	5, 975	6, 475	6, 675	6, 775	6, 975	7, 475
Annual fixed cost*	687	762	807	837	913	987	1, 017	1, 032	1, 062	1, 137
10-inch pump 1, 000 to 1, 500 GPM										
Total investment	\$ 5, 775	5, 975	6, 275	6, 575	6, 875	7, 175	7, 275	7, 475	7, 975	
Annual fixed cost*	890	920	965	1, 010	1, 055	1, 100	1, 115	1, 145	1, 220	

*Annual fixed cost represents 5 percent interest on one-half of the total investment, plus the annual depreciation (12-1/2 percent of the total investment), plus taxes (\$6.00 on 4 inch wells, \$10.00 on 6 inch wells, \$16.00 on 8 inch wells and \$24.00 on 10 inch wells.)

APPENDIX V
BASIS FOR COST ANALYSIS OF GROUND WATER PRODUCTION
IN SAN JOAQUIN VALLEY, CALIFORNIA ⁽¹⁸⁾.

Investments in pumps and accessories were determined from current list prices supplied by manufacturers. Costs of pumping plant equipment have risen rapidly in the past few years. Therefore, the prices used in this study overstate the cost of pumping plants installed at earlier dates. The amount of such overstatement is reflected by the wholesale price index for electrical machinery and equipment, which has increased from 96.1 in 1947 to 154.5 in 1959 on the base period of 1947-49 as 100%.

Pump discharge, plant efficiency and electric energy-in kilowatt hours-per acre-foot were adjusted for the seasonal drawdown of the pumping level in the wells. The total energy bill was determined by assuming one-fourth of the water was pumped in the spring when the water table was high, one-half from a lift midway between the seasonal high and seasonal low, and one-fourth in the late summer and early fall when the water table was low.

How costs were determined is illustrated by area D, where the total pump lift is 62.7' with a discharge of 1,084 gallons per minute at the midpoint during the pumping season. The seasonal draw-down is 20'; in the spring the total lift is 52.7' and late in the season the lift is 72.7'. That change in head gave a spring discharge of 1,284 gallons per minute and a fall discharge of 885 gallons per minute. To determine the number of acre-feet pumped it was assumed that the pump had a service area equal to one acre for each nine gallons per minute of discharge at midseason and the area irrigated with 31 acre-inches of water under a farm irrigation efficiency of 86% or 36 acre-inches of water per acre pumped. The assumption was for the irrigation of summer crops only.

In areas such as the Westside--Fresno and Kings counties--where a large share of the land is in winter barley, the total acre-feet pumped would be as much as one-third greater. The greater volume would have a marked effect upon the unit cost of pumping water by spreading the heavy fixed charges over more units. For example, if the acre-feet pumped on the west side were increased by one-third, the cost per acre-foot would drop to \$18.38 compared to the \$22.63 shown in the table. Area D experiences ground water overdraft at the rate of about 3' per year. Therefore, an additional average annual cost equal to 4% of the new pump cost was charged to cover lowering of bowls and other capital improvements associated with the lower water table.

For area D, the well life was estimated at 15 years and the pump life at 20 years. Total annual depreciation was calculated by summing the two initial costs, less salvage value of the motor, and dividing by the estimated life. Interest was calculated at 6% of mid-value and insurance and taxes at 2.5% of mid-value. Repair costs were estimated at 2% of new pump costs for areas with a pump lift of less than 100' and 3% for areas with lifts of more than 100'.

APPENDIX VI
ANNUAL COSTS OF SEVEN SELECTED SPREADING
GROUNDS OPERATED BY LOS ANGELES
COUNTY FLOOD CONTROL DISTRICT

A. Rio Hondo-East Side Spreading Ground

<u>Years</u>	<u>Capital Outlay</u>	<u>Right-of-Way</u>	<u>Operation & Maintenance</u>	<u>Total Outlay</u>
1937-38	\$ 9,229.78	\$ 0.00	\$ 53.80	\$ 9,283.58
1938-39	37,899.09	80,425.27	916.29	119,230.55
1939-40	14,331.71	39,780.18	4,972.02	59,083.91
1940-41	3,925.67	22,704.55	12,525.41	39,155.63
1941-42	19,298.85	0.00	16,285.74	35,575.59
1942-43	1,561.95	10,845.12	7,516.05	19,923.12
1943-44	4,003.16	0.00	11,120.64	15,123.80
1944-45	1,555.47	0.00	12,190.89	12,346.36
1945-46	16,809.20	0.00	22,146.99	38,956.19
1946-47	24,617.93	0.00	39,350.45	63,968.38
1947-48	93,868.11	44,139.80	42,435.97	180,433.88
1948-49	96,249.52	253,440.76	25,655.84	375,346.12
1949-50	22,920.67	3,242.62	24,053.28	50,216.57
1950-51	8,256.62	23.80	17,200.43	25,480.85
1951-52	9,864.47	0.00	22,092.35	31,956.82
1952-53	59,288.31	0.00	36,490.62	95,778.93
1953-54	98,782.19	7,397.50	42,235.82	148,415.51
1954-55	33,292.03	0.00	30,473.73	63,765.76
1955-56	593,899.49	0.00	53,628.94	647,528.43
1956-57	4,671.63	5.09	64,858.16	69,534.88
1957-58	0.00	0.00	48,188.68	48,188.68
1958-59	45,815.02	0.00	58,362.15	104,177.17
1959-60	57,771.38	0.00	54,556.97	112,328.35

B. Sawpit Spreading Ground

1946-47	7,376.20	0.00	53.19	7,429.39
1947-48	16,661.36	15,933.26	71.01	32,665.63
1948-49	25,126.52	0.00	1,121.78	26,248.30
1949-50	1,925.20	0.00	3,298.19	5,223.39
1950-51	326.58	0.00	1,598.75	1,925.33
1951-52	318.82	0.00	5,542.21	5,861.03
1952-53	20.57	0.00	2,414.40	2,434.97
1953-54	12.44	0.00	863.99	876.43
1954-55	2,911.28	0.00	2,071.11	4,982.39
1955-56	16,823.99	433.06	7,088.08	24,345.13
1956-57	0.00	0.00	2,918.90	2,918.90
1957-58	0.00	0.00	10,384.76	10,384.76
1958-59	106.34	0.00	5,679.16	5,785.50
1959-60	8.66	0.00	4,970.79	4,979.45

C. Pacoima Spreading Ground

<u>Years</u>	<u>Capital Outlay</u>	<u>Right-of-Way</u>	<u>Operation & Maintenance</u>	<u>Total Outlay</u>
1931-32	\$ 9,403.26	\$28,310.26	\$ 35.39	\$ 37,748.91
1932-33	36,777.02	9,613.01	186.96	46,576.99
1933-34	518.59	49.82	809.83	1,378.24
1934-35	218.02	358.71	1,167.87	1,744.60
1935-36	3,964.55	0.00	1,820.80	5,785.35
1936-37	1,145.51	0.00	2,250.43	3,395.94
1937-38	179.86	0.00	2,051.08	2,230.94
1938-39	244.39	0.00	1,283.30	1,527.69
1939-40	25,767.11	0.00	3,212.00	28,979.11
1940-41	1,597.71	561.60	8,410.97	10,570.28
1941-42	4,175.70	0.00	4,787.47	8,963.17
1942-43	26,093.55	0.00	10,849.63	36,943.18
1943-44	19,763.54	0.00	23,812.58	43,549.12
1944-45	3,721.08	0.00	18,479.17	22,200.25
1945-46	19,684.18	0.00	5,317.48	25,001.66
1946-47	13,932.63	0.00	13,237.22	27,169.85
1947-48	1,271.23	0.00	9,234.30	10,505.53
1948-49	0.00	0.00	9,291.61	9,291.61
1949-50	200.00	0.00	12,372.84	12,572.84
1950-51	1,270.87	0.00	8,351.57	9,622.44
1951-52	25,779.51	0.00	34,009.40	59,788.91
1952-53	32,996.99	0.00	18,987.13	51,984.12
1953-54	156,654.68	2,651.27	24,035.09	183,341.04
1954-55	21,610.98	0.00	23,254.00	44,864.98
1955-56	11,768.21	0.00	21,061.77	32,829.98
1956-57	21,095.78	0.00	22,910.57	44,006.35
1957-58	14,651.94	0.00	55,104.10	69,756.04
1958-59	18,808.85	0.00	25,770.02	44,578.87
1959-60	8,840.98	0.00	21,368.62	30,209.60

D. Santa Fe Reservoir Spreading Ground

1954-55	15,665.78	0.00	2,394.85	18,060.63
1955-56	24,456.98	0.00	1,700.43	26,157.41
1956-57	630.57	0.00	4,728.41	5,358.98
1957-58	500.00	0.00	22,929.69	23,429.69
1958-59	0.00	0.00	2,242.09	2,242.09
1959-60	17,317.39	0.00	5,751.31	23,068.70

E. Peck Road Spreading Ground

1954-55	439.42	0.00	1.02	440.44
1955-56	1,991.99	0.00	5.66	1,997.65
1956-57	9,229.84	3,047.71	1,315.06	13,592.61
1957-58	0.00	0.00	1,095.64	1,095.64
1958-59	93,025.68	0.00	1,341.80	94,367.48
1959-60	46,888.47	182,102.63	18,097.10	247,088.20

F. Buena Vista Spreading Ground

<u>Years</u>	<u>Capital Outlay</u>	<u>Right-of-Way</u>	<u>Operation & Maintenance</u>	<u>Total Outlay</u>
1954-55	0.00	0.00	237.20	237.20
1955-56	4,157.70	0.00	699.43	4,857.13
1956-57	721.99	0.00	1,714.28	2,436.27
1957-58	1,720.61	0.00	7,889.21	9,609.82
1958-59	22,818.29	0.00	2,546.64	25,364.93
1959-60	0.00	0.00	3,354.44	3,354.44

G. Eaton Spreading Basin

1954-55	662.33	0.00	1.54	623.87
1955-56	28,404.52	77,615.43	70.52	106,090.47
1956-57	8,814.51	268.15	4,927.19	14,009.85
1957-58	971.41	13,214.38cr	10,140.63	2,102.34cr
1958-59	72,531.46	0.00	2,655.30	75,186.76
1959-60	2,977.49	0.00	7,051.23	10,028.72

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APPENDIX VII
COSTS OF OPERATION OF WATER SPREADING AT SAN ANTONIO
SPREADING GROUNDS, POMONA, CALIFORNIA
1937 - 1957.*

	1937-38	1938-39	1939-40	1940-41	1941-42	1942-43
Operation & Maintenance						
Labor	\$ 3,419.67	\$ 1,819.96	\$ 1,851.27	\$ 2,205.51	\$1,649.24	\$ 2,283.36
Materials	289.27	416.31	368.57			34.73
Truck Exp.	772.72					268.37
Construction	482.69	64.46	142.51	598.40	122.12	61.41
General						
Salaries	900.00	900.00	900.00	900.00	900.00	900.00
Taxes R. E.	459.87	323.93	218.48	214.40	192.51	215.02
Franchise						
Payroll	132.23	124.05	60.10	56.02	45.88	59.38
Ins. Liability						
Compensation				63.53	51.00	51.00
Utilities						48.11
Audit				10.00		
Legal					25.00	
Engineer	118.97					
Office Exp.				314.45	253.59	210.56
Interest						
Misc.						375.00
Totals	6,575.42	3,648.71	3,540.93	4,362.31	3,239.34	4,508.94
Acre Ft. of Water Spread	15,632.	1,438.	2,840.	28,899.	85.	30,350.

	1943-44	1944-45	1945-46	1946-47	1947-48	1948-49
Operation & Maintenance						
Labor	\$ 2,073.52	\$ 2,112.90	\$ 2,775.70	\$ 2,656.88	\$ 2,210.00	\$ 2,600.30
Materials	224.24	79.88	96.54	39.65	67.46	20.41
Truck Exp.	461.43	391.99	346.13	306.68	381.59	472.77
Construction General	233.97	201.11	537.00	157.50	120.00	180.00
Salaries	900.00	900.00	900.00	900.00	900.00	900.00
Taxes R. E.	235.39	185.31	205.91	243.14	231.16	242.14
Franchise		21.50	25.00	21.50	25.00	25.00
Payroll	67.10	89.40	89.94	129.89	125.38	118.13
Ins. Liability						
Compensation	68.76	77.92	54.27	56.18	54.81	57.24
Utilities	40.99	39.82	37.50	38.27	41.25	41.51
Audit		12.50	40.91			
Legal	184.91					
Engineering						
Office Exp.	229.72	215.95	20.43	9.90		18.03
Interest						
Misc.	38.92		127.64	25.00		41.08
Totals	4,758.95	4,328.28	5,256.97	4,584.49	4,156.65	4,716.61
Acre Ft. of Water Spread	10,317	None	3,359	5,838	6	8

	1945-50	1950-51	1951-52	1952-53	1953-54	1954-55
Operation & Maintenance						
Labor	\$ 1,738.75	\$	\$ 1,311.95	\$ 60.00	\$ 466.63	\$ 6.00
Materials	54.24	29.50				
Truck Exp.	348.73	317.60	339.01	166.01	24.59	340.00
Construction						
General						
Salaries	900.00	1,200.00	1,200.00	1,200.00	1,200.00	1,200.00
Taxes R. E.	254.22	272.90	308.54	299.27	337.97	347.99
Franchise	25.00	25.00	25.00	25.00	25.00	25.00
Payroll	162.88	36.00	59.91	24.39	30.46	24.00
Ins. Liability				124.66	125.66	131.78
Compensation	65.48	64.00	33.80	15.00	15.00	15.00
Utilities	35.09	48.31	65.00	64.74	54.98	51.16
Audit		60.00	35.00	35.00	35.00	35.00
Legal		300.00	300.00	300.00	300.00	300.00
Engineering		2,000.00	50.00			
Office Exp.			81.36			
Interest				28.06		
Misc.	10.28	4.07		31.12	41.80	10.99
Totals	3,594.67	4,357.38	3,809.57	2,373.25	2,655.09	2,180.92
Water purchased for spreading			4,289.34	6,945.07	6,519.52	5,270.82
Acre Ft. of Water Spread	59.	3	11,712	1,014	6,105	51

	1955-56	1956-57	20 year totals	20 year average
Operation & Maintenance				
Labor	148.00		31,389.64	1,569.48
Materials			1,720.80	86.04
Truck Exp.	24.00	81.05	4,736.67	236.83
Construction			2,901.17	145.06
General				
Salaries	1,200.00	1,200.00	20,100.00	1,005.00
Taxes R. E.	368.52	364.06	5,518.63	275.93
Franchise	25.00	25.00	318.00	15.90
Payroll	26.96	25.00	1,487.10	74.36
Ins. Liability	173.37	55.01	610.48	30.52
Compensation	15.00	15.00	772.99	38.65
Utilities	54.99	54.11	715.83	35.79
Audit	35.00	35.00	383.42	18.69
Legal	300.00	300.00	2,309.91	115.49
Engineering	63.22		2,232.19	111.61
Office Exp.			1,353.99	67.69
Interest			28.06	1.40
Misc.	46.52	60.40	812.82	40.64
Totals	2,480.58	2,214.63	77,341.20	3,867.06
Acre Ft. of Water spread	none	none	117,716	5,886 ac./Ft.

*Data furnished by California Dept. of Water Resources.

APPENDIX VIII
COST AND RECHARGE DATA FOR FOUR PERCOLATION
PONDS OPERATED BY SANTA CLARA VALLEY
WATER CONSERVATION DISTRICT

A. Coyote Percolation Ponds

Total acreage: 61

On stream percolation ponds. Located on Coyote Creek with water spread by means of dam consisting of removeable wood sections. Water is untreated since these ponds are not used during the winter months. Water is spread on 20 acres of District land while the District has flooding rights on remaining 41 acres used. Ponds require cleaning every 2 or 3 years. Constructed sometime prior to 1935. Ponds are not fenced.

Capital costs:

1935	Rights of way	Construction	Total
	\$ 8,220.55	\$ 40,085.87	\$ 48,306.42

<u>Year</u>	<u>Maintenance costs</u>	<u>Percolation, acre-feet</u>
1935-36	367.69	-
36-37	705.87	11,652
37-38	1,420.75	9,059
38-39	930.81	6,093
39-40	387.32	7,243
40-41	378.80	7,715
41-42	383.38	99
42-43	116.50	1,341
43-44	636.26	5,928
44-45	212.33	7,219
45-46	415.65	7,134
46-47	178.00	0
47-48	-	0
48-49	276.13	0
49-50	253.61	3,746
50-51	155.65	20,796
51-52	2,493.55	10,207
52-53	1,010.30	12,504
53-54	781.28	10,198
54-55	83.32	7,651
55-56	2,372.38	5,288
56-57	4,782.60	8,688
57-58	1,365.94	9,597
58-59	899.28	13,216
59-60	1,372.80	10,217
60-61	1,131.84	3,838
61-62	4,946.54	-

B. Los Gatos Creek Percolation PondsTotal acreage: 44

First gravel spreading dams were constructed in the channel of Los Gatos Creek in 1958 after securing permission from land owners. Some land has been purchased while the remainder is under negotiation. The dams are removed during periods of time when heavy storm runoff is anticipated. The dams consist of gravel placed by dozer equipment and a spillway consisting of either a pipe or wood chute. These areas are not fenced. There has been some problem from swimming and acts of vandalism.

Capital costs:

1957 to date	Rights of way \$ 28,447.69	Construction \$ 1,204.19	Total \$ 19,651.88
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<u>Year</u>	<u>Maintenance costs</u>	<u>Percolation, acre-feet</u>
1959-60	467.83	2,999
60-61	2.58	4,204
61-62	3,047.74	---
62-63	3,605.17	---

C. Penitencia Percolation PondsTotal acreage: 23

Offstream percolation ponds. Original ponds consist of use of old San Jose Peninsular Railway right of way forming a long chain of ponds. The new ponds, under development at present, are of rectangular shape and are located adjacent to original ponds. Water is diverted from Penitencia Creek at times when it is certain this water would waste to San Francisco Bay. The District does not have an impounding reservoir in Penitencia watershed. When diverted water is of high turbidity it is treated with flocculating chemicals to insure clean water enters the perc ponds. All acreage has been acquired.

Capital costs:

	Right of way	Construction	Total
1935	\$ 7,839.85	\$ 23,765.79	\$ 31,605.64
1957 to date	<u>146,715.18</u>	<u>20,872.30</u>	<u>167,587.48</u>
	\$ 154,555.03	\$ 44,638.09	199,193.12

<u>Year</u>	<u>Maintenance costs</u>	<u>Percolation, acre-feet</u>
1935-36	453.89	----
36-37	551.65	----
37-38	806.26	----
38-39	279.96	155
39-40	638.71	1,190
40-41	605.90	2,020
41-42	486.75	1,649
42-43	768.14	1,320

<u>Year</u>	<u>Maintenance costs</u>	<u>Percolation, acre-feet</u>
1943-44	844.46	925
44-45	755.48	1,660
45-46	588.58	627
46-47	640.94	0
47-48	516.00	3
48-49	430.74	289
49-50	544.88	292
50-51	2,100.61	2,230
51-52	2,853.52	2,034
52-53	1,340.55	491
53-54	1,284.40	106
54-55	986.33	192
55-56	3,700.06	1,260
56-57	3,744.84	356
57-58	3,863.89	1,299
58-59	4,306.15	145
59-60	3,625.11	117
60-61	4,322.00	0
61-62	3,955.96	460
62-63	2,267.11	755

D. Main Avenue Percolation Ponds

Total acreage: 10

Offstream percolation ponds. Water diverted from Anderson Dam outfall pipe through pipeline and open ditch. Bottom and sides of ponds contain a clayey gravel such that wave action causes some of the clay to go into suspension. To prevent this, additional maintenance is required to maintain log booms along the perimeter of the ponds.

Ponds are not fenced. Flocculating chemicals are used when water has high turbidity.

Ponds are used on a year around basis when water is available. Ponds must be cleaned at least once a year.

<u>Capital costs</u>	<u>Rights of way</u>	<u>Construction</u>	<u>Total</u>
1955	\$ 10,000.00	\$ 38,450.19	\$ 48,450.19
1960		4,246.68	4,246.68
	<u>\$ 10,000.00</u>	<u>\$ 42,696.87</u>	<u>\$ 52,696.87</u>

<u>Year</u>	<u>Maintenance costs</u>	<u>Percolation, acre-feet</u>
1954-55	726.54	1,345
55-56	2,708.47	1,622
56-57	4,957.45	1,508
57-58	1,502.37	1,711
58-59	584.87	2,519
59-60	3,645.72	1,502
60-61	1,289.52	1,227
61-62	1,327.41	846
62-63	1,202.22	----