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WATER FOR LONG-TERM GEOTHERMAL ENERGY PRODUCTION IN THE IMPERIAL VALLEY

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DISCLAIMER

FOREWORD

This report is part of a research effort at the Lawrence Livermore Laboratory known as the Imperial Valley Environmental Project. It is sponsored by the Assistant Secretary for Environment of the U.S. Department of Energy. The project is designed to ensure that the development of geothermal resources in the Imperial Valley proceeds on an environmentally sound basis. To carry out that objective, the project includes the following research groups: Air Quality, Ecosystem Quality, Water Quality, Subsidence and Seismicity, Health Effects, Socioeconomic Effects, and Integrated Assessment. Research on the water supply aspects of geothermal development was done under the auspices of the Integrated Assessment group with special research responsibilities that include the evaluation of relevant environmental impacts, data management, and the timely transfer of information to decision makers.

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ABSTRACT

The geothermal resources of California's Imperial Valley have the potential for the production of an estimated 3000 to 5000 MW/yr of electricity for 30 yr, provided that adequate cooling water is available for power plants. There are five possible sources of cooling water: irrigation water, waste waters from agriculture, steam condensate, ground water, and water from the Salton Sea. Technical, environmental, and regulatory constraints, however, could limit the availability of the water supplies. Of particular concern are the constraints that could be imposed if different water policies were implemented. To study how future policies could affect geothermal development, six combinations of various policies were defined to represent potential regulatory controls. A range of future water balances in the valley was also specified. The water balances plus the six policy combinations were used to determine whether deficits of cooling water would eventually constrain low, medium, or high levels of geothermal energy production. A companion analysis of changes in the elevation and salinity of the Salton Sea resulting from the use of agricultural waters for cooling was also made.

INTRODUCTION

The future use of water-dominated geothermal resources in the Imperial Valley to produce electricity will depend on the availability of cooling water for geothermal power plants. The primary geothermal resources are in the Heber, East Mesa, Brawley, and Salton Sea known geothermal resource areas (KGRAs) as shown in Fig. 1. Using these resource areas together, between 3000 and 5000 MW of electrical energy for 30 yr could be produced.[1,2] The Imperial Valley contains about 475,000 acres of farmland annually supported by approximately three million acre-feet (af) of water diverted from the Colorado River. Waste water from agricultural discharges plus imported irrigation water are possible sources of water for cooling geothermal power plants. Other cooling water supplies include steam condensate produced from power plants using flashed-steam energy conversion technologies, ground water underlying East Mesa, and water from the Salton Sea.

Despite the presence of multiple cooling water sources, the use of the different water supplies is complicated by problems involving quality, quantity, and distribution; the use and disposal of water; and various institutional, legal, and political constraints. As an example, a county planning policy has already restricted the consumption of irrigation water for cooling to demonstration facilities.[3] The use of agricultural waste waters and Salton Sea water poses problems of corrosion, scaling, and disposal of blowdown (blowdown is saline water discharged from a wet cooling tower to control the salinity of circulating water). If these and other water-related problems are not resolved, then only part of the Imperial Valley's geothermal energy potential will be developed.

The purposes of this report are to analyze the use of the various sources of water potentially available to support future geothermal energy production and to study the long-term consequences of implementing alternative cooling water policies. The report begins with a review of geothermal energy technologies and an analysis of the cooling-water requirements of power plants. Next, potential problems and constraints related to the consumption of the five water supplies are examined. Analyses of historic water balances in the Imperial Valley are then presented; and based on these analyses, future water balances are projected for alternative efficiencies of water use in irrigation.

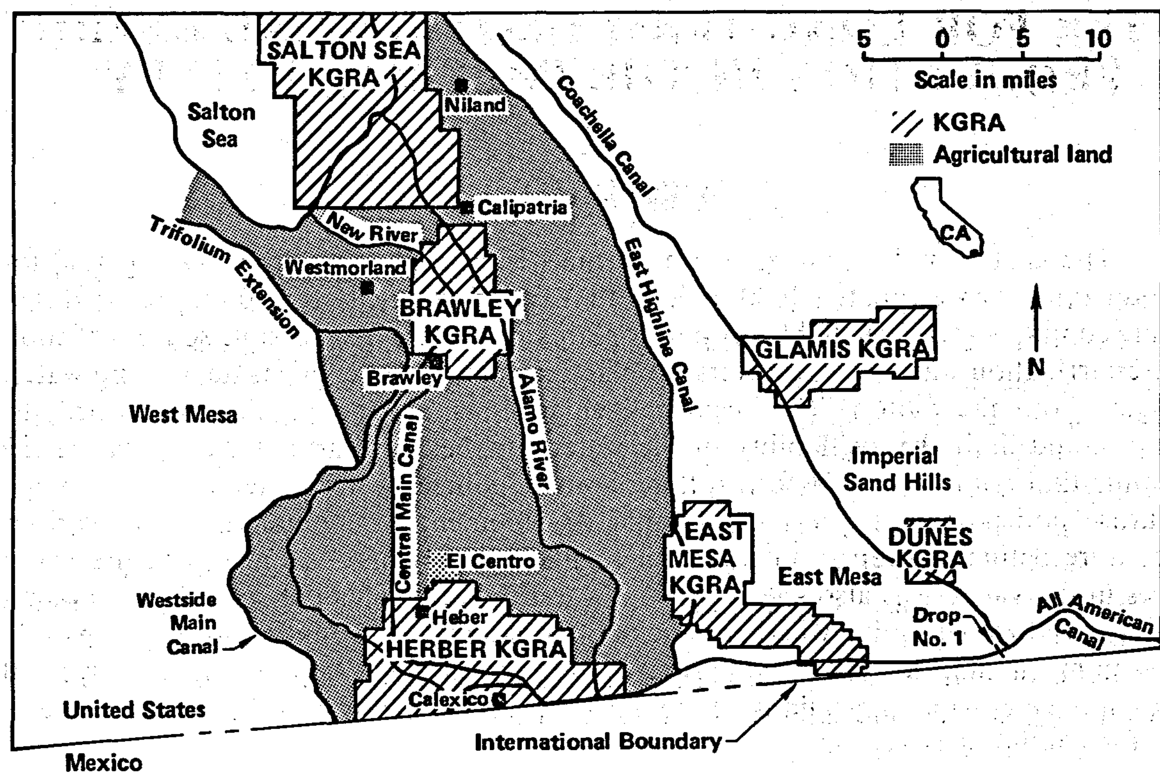


FIG. 1. The Imperial Valley, California, and its known geothermal resource areas (KGRAs). The only resource areas capable of supporting electrical energy production are the East Mesa, Heber, Brawley, and Salton Sea KGRAs.

These conditions form the basis for subsequent analyses of water supplies.

To determine whether constraints will develop and hinder geothermal energy growth, five water policies are identified representing possible regulatory controls on water supply selection. The policies are combined into six sets, and along with the projected water-balance conditions in the valley, are used to find out whether geothermal energy production will be constrained by deficits of water supply. To complete the study, changes in the Salton Sea's elevation and salinity resulting from the use of agricultural waste waters to support geothermal operations are then assessed.

GEOTHERMAL WATER REQUIREMENTS

How much water will individual geothermal power plants require for cooling purposes? The answer to that question will depend on such things as the types of conversion technologies implemented, the thermal efficiencies of the generating facilities, the cooling systems used, and the amount of blowdown needed to control the salinity of water circulating in cooling systems. In this section important factors influencing the use of cooling water are examined and estimates of cooling water consumption rates are provided for power plants that use either irrigation water, agricultural effluents, steam condensate, ground water or Salton Sea water.

GEOTHERMAL RESOURCES AND TECHNOLOGIES

The salinities, temperatures, and energy potentials of the Imperial Valley's geothermal resources vary from KGRA to KGRA. The Salton Sea resource area has the highest estimated potential for electrical energy production with 2787 MW per yr for 30 yr, followed by 973 MW at the Heber KGRA, 487 MW at the East Mesa KGRA, and the Brawley KGRA with 333 MW (Note: these estimates are subject to change as more reservoir information is obtained from new wells and analyses).[2] Resource temperatures in the Salton Sea geothermal field sometimes exceed 572°F,[4] while the geothermal fluids in other KGRAs are generally below 392°F.[5] Average salinities decrease from over 200,000 ppm total dissolved solids (TDS) in the Salton Sea area[6] to 76,000 ppm at Brawley,[7] 14,000 ppm at Heber,[7,8] and under 8000 ppm at East Mesa.[7]

Variations in the physical and chemical properties of the geothermal fluids will directly influence the selection of the energy conversion technologies used in the Imperial Valley. Three possible conversion methods are: (1) flashed-steam, (2) two-phase flow, and (3) confined flow. Of the three conversion technologies, the flashed-steam method is the only one that has been implemented on a commercial scale.[9] A simple one stage flash cycle is shown in Fig. 2a. Electricity is generated through the following process: (1) steam is separated from a liquid-steam mixture as it comes from a geothermal well or well field; (2) the separated steam is expanded through a turbine that runs a generator; (3) steam exhausted from the turbine is condensed by a direct contact or surface condenser; and (4) condensate is either sent to an evaporative cooling system (e.g., a wet cooling tower) as makeup water or is disposed of by injection along with the spent geothermal fluids.[10] A 75-MW flashed-steam power plant using fluids of around 20,000 ppm TDS is already operating to the south of the Imperial Valley in Cerro Prieto, Mexico.[11] The two-phase flow cycle depicted in Fig. 2b avoids the use of steam separators. A two-phase flow comprised of geothermal fluid and steam is sent directly through an expansion machine such as an impulse turbine.[11] After expansion, steam is condensed and residual fluids injected. Unfortunately the technical feasibility of expansion machines has not been fully proven. From the standpoint of a limited water supply, flashed-steam technologies are advantageous because they would be able to supply all, or nearly all, of their own cooling water from the condensate they produce.[10,12,13]

The confined flow process, unlike the previous conversion cycles, does not produce steam condensate because no flashing takes place. Consequently, power plants incorporating this conversion technology must rely on external supplies of water. A simple confined flow cycle is illustrated in Fig. 2c. A downhole pump sends geothermal fluids under pressure to a heat exchanger on the surface that transfers the heat of the fluids to a binary fluid driving a turbogenerator. After the geothermal fluids are passed through the heat exchanger, they are disposed of by injection. No noncondensible gases (e.g., H_2S) are released with this conversion system because the geothermal fluids are not allowed to flash to steam. Although downhole pumps were tested at the Heber and East Mesa KGRAs, it is not clear whether such pumps could withstand the more corrosive fluids associated with the Brawley and Salton Sea resource areas. A conversion facility testing the confined flow cycle is now being built at East Mesa.

Neglecting design differences between conversion cycles, the amount of heat rejected is primarily a function of resource temperature. More specifically, as the temperature of a geothermal resource rises, the conversion efficiency (i.e., the ratio of output power to the sum of condenser heat rejection, parasitic losses, and output power) increases. A higher conversion efficiency results in less rejected heat, and as a result, the amount of cooling water needed to reject waste heat decreases. Because the Salton Sea has the highest resource temperatures in the Imperial Valley, power plants using those resources will require less cooling water than facilities in the other KGRAs.

COOLING WATER CONSUMPTION

Waste heat from geothermal facilities will have to be rejected to the atmosphere through the use of either evaporative cooling systems, once-through cooling, dry cooling towers, or hybrid wet-dry towers. Evaporative systems applicable to the Imperial Valley consist of mechanical-draft, wet cooling towers and spray ponds. Wet cooling towers would be the favored method of cooling in the resource areas dominated by irrigated agriculture (i.e., the Heber, Brawley, and Salton Sea KGRAs) because they would displace less agricultural land than spray ponds. Either type of evaporative system could be implemented at the East Mesa KGRA since land-use problems are unlikely to occur there. Once-through cooling, using waste waters flowing in rivers or drains, is a remote possibility for two reasons. First, geothermal plants with their high heat rejection rates would need to withdraw large amounts of water. For example, a 100-MW plant using geothermal fluids of 482°F would require over 250×10^3 af/yr of water to pass through condensers

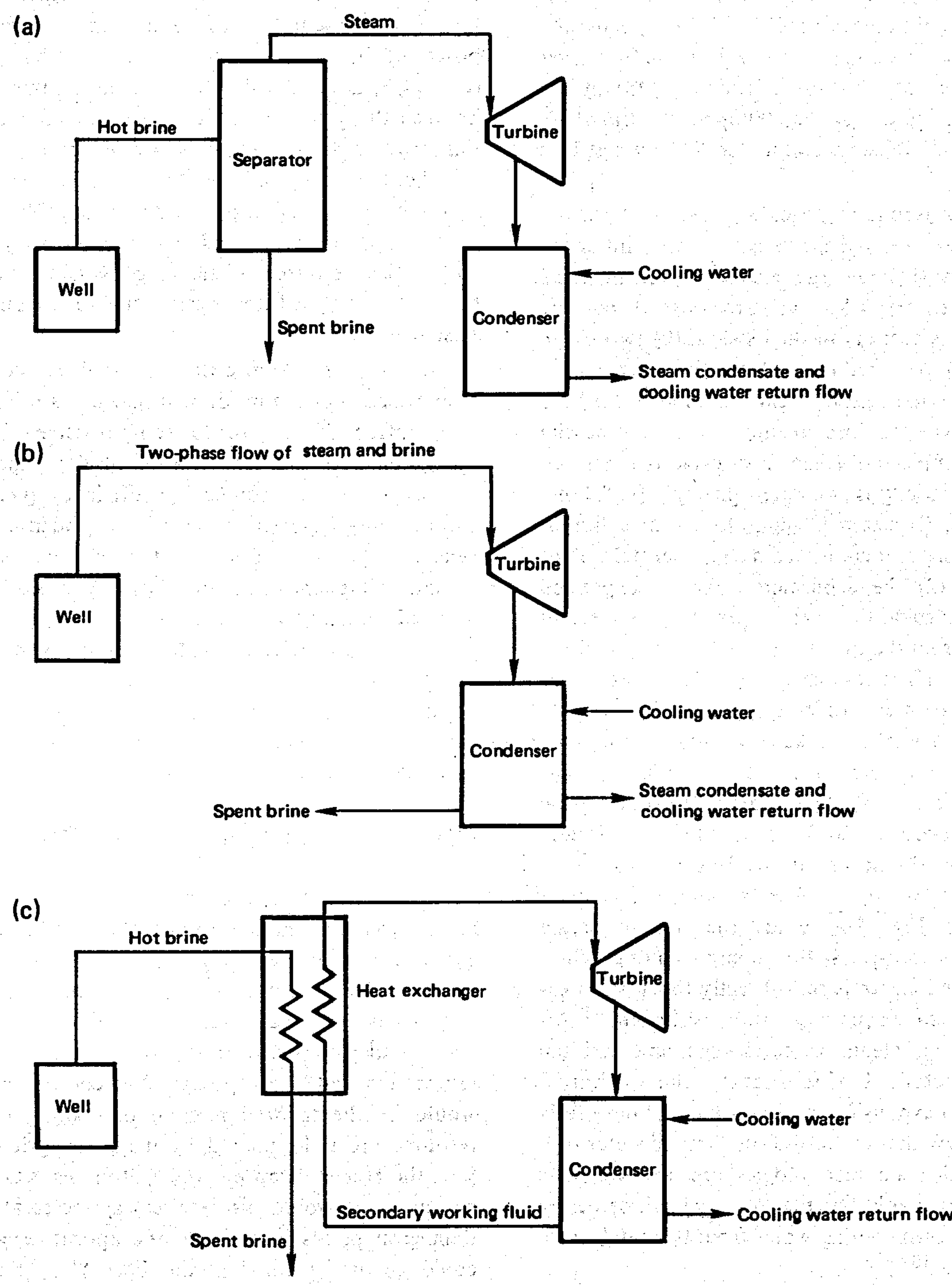


FIG. 2. **Simplified conversion cycles for the flashed-steam, two-phase-flow, and confined-flow systems. a. Single-stage, flashed-steam conversion cycle. b. Two-phase flow-conversion cycle. c. Confined-flow, binary-conversion cycle. The flashed-steam and two-phase-flow cycles can produce enough steam condensate to satisfy their cooling water requirements. The confined-flow method, on the other hand, does not produce condensate, and so external cooling water supplies are necessary.**

operating with a 20°F temperature rise.[12] Second, the corresponding thermal discharges to a drain, river, or the Salton Sea would be prohibited unless "such a practice will maintain the existing water quality and aquatic environment of the State's water resources."[14] Use of irrigation water for once-through cooling, however, would be an attractive option if positive benefits resulted from using the discharged warm water for irrigation. Further study is needed before this cooling alternative can be implemented because biocides and corrosion inhibitors introduced to a cooling system could make heated discharges unacceptable for agricultural uses.[15]

The use of dry cooling towers that do not consume water or hybrid wet-dry towers that significantly reduce water consumption is also improbable because these towers are much more expensive than other cooling systems.[16] Moreover, use of such towers would result in an efficiency penalty because of the higher temperatures at which waste heat is rejected.

Unless economic and technical circumstances change to favor other heat rejection methods, wet cooling towers will be the primary method of power plant heat rejection. Therefore, the water consumption estimates made in this study are based on that cooling technology. The quantity of water required by wet towers is equal to the total amount of water lost to evaporation, discharged as blowdown, and emitted to the atmosphere in the form of drift. Evaporative cooling losses associated with the operation of future geothermal plants were estimated by making the following two assumptions (see Ermak[17]): (1) energy facilities in the Salton Sea KGRA have an average conversion efficiency of 0.14—facilities in the other KGRAs have an efficiency of 0.10—and (2) evaporative losses are 1.5% of the condenser flow rate. The resulting evaporation rates are 50 af/MW-yr for plants in the Salton Sea KGRA and 75 af/MW-yr for plants in the other KGRAs. The blowdown rate is a function of the number of cycles the salinity of the source cooling water is increased by evaporation. As the number of cycles increases, discharges of blowdown decrease, and salinity increases. Stated mathematically,

$$B = \frac{\text{Tower evaporation rate}}{Z - 1} ,$$

where

B = blowdown discharge (af/MW-yr), and
Z = number of cycles source water is concentrated by evaporation.

Salinity of the blowdown is equal to the product of the concentration cycles and the salinity of the make-up water used in the cooling system.

Constraints involving water conservation, blowdown quality, and amounts of corrosion and scaling must be considered when selecting the number of cycles the original water used is to be concentrated. If a need to conserve water exists, the amount of blowdown discharged can be reduced by increasing the number of concentration cycles. But as the salinity of blowdown rises, disposal becomes more difficult. Blowdown discharged into one of the valley's rivers or drains, for instance, cannot exceed the water quality objective for those receiving waters, which is 4000 ppm TDS, annual average.[18] The quality of the blowdown discharged must also conform to new-source performance standards adopted under the Clean Water Act. It is stipulated that no detectable amounts of materials that inhibit corrosion—such as zinc, chromium, and phosphorus—be present.[19]

Irrigation water in the Imperial Valley normally varies between about 800 ppm TDS and 1000 ppm TDS.[20] It could be concentrated up to four times and still be discharged to a river or drain without exceeding the water quality objective. Similarly, steam condensate with a low salinity (less than 500 TDS) could be concentrated several times and the resulting blowdown would still meet the TDS limit. However, if toxic substances such as arsenic, mercury, and boron were present in blowdown derived from steam condensate, then either the number of concentration cycles would have to be adjusted or the blowdown would have to be treated prior to discharge. The actual controls necessary to reduce toxic substances will depend on the chemical composition of the condensate and on future effluent guidelines promulgated for toxic pollutants under the Clean Water Act.[21] Ground water on East Mesa that contains 1000 ppm TDS[22] or below could either be concentrated for disposal to surface waters or to evaporation ponds.

Agricultural waste waters concentrated more than twice (Z greater than 2) by evaporation in a cooling tower would exceed the salinity objective for surface waters because agricultural effluents

TABLE 1. Cooling water consumption rates for power plants using different geothermal resources and cooling waters.

		Cooling water requirements (af/MW-yr)					
		Salton Sea KGRA			Heber, Brawley, and E. Mesa KGRAs		
Cooling water source	Cycles of concentration	Evaporative	Blowdown	Total	Evaporative	Blowdown	Total
I. Irrigation water	4[a]	50	17	67	75	25	100
II. Ground water (East Mesa)	10[b]	50	5	55	75	8	83
III. Agricultural waste water	5[b]	50	12	62	75	19	94
IV. Steam condensate	10[c]	50	5	55	75	8	83
V. Salton Sea water	2[b]	50	50	100	75	75	150

[a]Assumes disposal to surface waters, provided that water quality objectives and effluent standards are met. Irrigation water use could be reduced with greater cycles of concentration, but then blowdown could not be discharged to surface waters.

[b]Assumes no return of blowdown to surface waters. Blowdown would be disposed of by subsurface injection, evaporation ponds, or at acceptable waste disposal sites.

[c]Blowdown may be discharged to surface waters or disposed of by subsurface injection or evaporation ponds depending on site location and blowdown quality.

(both in drains and rivers) generally contain above 2000 ppm TDS.[20] But with Z values lower than 2, excessive quantities of blowdown would be discharged. The alternative is to increase Z beyond 2, thereby reducing the blowdown discharges, and dispose of the saline blowdown by subsurface injection or by evaporation at an acceptable waste disposal site. Higher cycles of concentration, however, will produce scaling and corrosion problems. Scaling of cooling tower components increases when the proportions of substances like calcium and silica rise as cooling water becomes more saline. Corrosion worsens as salt concentrations rise or when pH values of the circulating water are low.[23] Fouling of heat transfer surfaces with organisms is an additional problem to be dealt with because the nutrient-rich agricultural waste water is an excellent growth medium. Water taken from drains or rivers will therefore require extensive treatment to mitigate problems of corrosion, scaling, and fouling. Fortunately advanced treatment techniques are being developed that may resolve problems associated with the use of agricultural waste waters for power plant cooling.[24] Water from the Salton Sea would present even greater corrosion and scaling problems than agricultural drain waters. The sea's salinity is now approaching 39,000 ppm TDS, and a concentration factor of less than 2 would be needed to reduce corrosion of towers.[25] With such a low Z value, large quantities of blowdown would need to be discharged.

Table 1 summarizes the water consumption rates for power plants using different geothermal resources and cooling waters. Discharges of blowdown were calculated as a function of cooling tower evaporation from the cooling towers and the cycles of concentration likely to be used with alternative water supplies. The sum of the rates of blowdown and evaporation represents the annual water requirement, expressed in af/MW-yr. Losses through drift were assumed to be small (less than 0.01% of the circulating flow) and were not included in the rates of water use. Rates of cooling water consumption were assumed to be constant through time even though the temperature of geothermal fluids will decrease as a result of extraction. This will eventually result in higher rates of heat rejection and thus higher requirements for cooling water.

COOLING WATER SUPPLIES

There are no assured supplies of cooling water available for geothermal operations. Laws, regulations, environmental impacts, governmental policies, resource uncertainties, economics, and technical problems will all play a role in controlling the selection of cooling waters to support major geothermal energy production in the Imperial Valley.[26] The following discussions focus on the important ramifications of using irrigation water, steam condensate, agricultural effluents, ground water, and Salton Sea water to support geothermal operations.

IRRIGATION WATER

Irrigation water imported from the Colorado River by the Imperial Irrigation District (IID) is an attractive source of cooling water. It can be transported directly to each of the geothermal resource areas through existing irrigation canals; and its chemical quality is much better than water from either agricultural drainage or the Salton Sea, the alternative surface water supplies in the valley. Furthermore, blowdown produced by concentrating irrigation water three to four times can be disposed of into surface waters without exceeding present salinity standards. Water imported from the Colorado River cannot be used for power plants unless approval is obtained from the IID's board of directors. However, the board is unlikely to allocate substantial amounts of water for geothermal developments if that action limits the amount of water available to its primary constituents—the valley's farmers. Imperial County, by virtue of its authority to establish regulations controlling geothermal operations, is also in a position to control the use of irrigation water.

The county's present water policy, as expressed in the geothermal element in the county general plan, is to limit irrigation water to demonstration or experimental plants generating a maximum of 75 MW (net energy) in each "economic" geothermal anomaly for the first five years of operation. Consumption of irrigation water beyond the initial five years would only be permitted if it were demonstrated that "it is not economically and environmentally feasible to use alternative sources of water."[3] If the existing water policy of the county and the allocation preference of the IID toward agricultural water users remain unchanged, then future geothermal facilities will not be able to rely on irrigation water as a major source of cooling water.

The underlying concern of the water policy adopted by the county is that geothermal development should not compete with agriculture for fresh water supplies. Accordingly, just 75 MW can be generated in each KGRA using irrigation water for cooling. But, expanded use of irrigation water by geothermal facilities might be possible if a policy were adopted that allowed the use of excess irrigation water for cooling power plants. Surplus water conditions would occur if efforts to conserve water continue by the IID and the valley's irrigators, no new lands are brought into production, and use of water by crops (as determined by annual cropping patterns) is not unusually high. Excess water would be used as a supplemental source of cooling water for power plants using waste waters from irrigated agriculture. Use of irrigation water whenever it is available would be advantageous because its treatment and disposal costs would be lower than those for agricultural waste waters.

If surplus irrigation water is used to bring new lands into agricultural production, particularly arable lands on West Mesa, then little of any water would be available for geothermal facilities. At this point though, it is not clear whether such lands will be developed. The following discussion describes the circumstances that would allow irrigation water to be distributed to geothermal facilities, assuming that water surpluses do exist in the future.

The distribution of irrigation water to industrial users will be governed by the interpretation of existing state water laws and laws affecting the Colorado River. Important laws concerning appropriation of river water are summarized in Table 2. California water users receive a basic allotment of 4400×10^3 af/yr, and it is distributed to users by priorities established in the Seven-Party Agreement of 1931. The agreement includes an annual allocation of 3850×10^3 af according to the following priorities: Priority 1—the Palo Verde Irrigation District; Priority 2—the Yuma Project; and Priority 3—the Imperial Irrigation District and lands served by the All-American Canal in the Imperial and Coachella Valleys (some additional lands in the Palo Verde Irrigation District are also contained in the third priority).[27]

Net diversions (i.e., diversions minus return flow to the Colorado River) to the priority agricultural users in California for the years 1964 to 1976 are shown in Table 3. In several years the total diversions exceeded the basic allotment of 3850×10^3 af/yr but only because extra river water was available. At such time that the agricultural users are limited to 3850×10^3 af/yr (probably when the Central Arizona Project is completed), water will be allocated by priority; the Palo Verde Irrigation District and Yuma Project would withdraw water first, and the remaining water

TABLE 2. Summary of important laws dealing with the apportionment of Colorado River water.

A. Colorado River Compact (1922)

The Compact apportioned 7500 × 10^3 af annually to the Upper and Lower Basins of the Colorado River for their beneficial consumptive use. Unfortunately, the long-term, undepleted flow of the river at Lee Ferry (the dividing point between the two basins) is below 15000 × 10^3 af/yr. The Compact, therefore, apportioned more water between the Basins than is now available. Other important provisions in the Compact include: the right of the Lower Basin to increase its beneficial consumptive use by one million af/yr and the requirement that Mexico be supplied with surplus water first, and if that is inadequate, then the burden of the deficiency is to be equally borne by the Upper and Lower Basins.

B. Boulder Canyon Project Act (1928)

The Act authorized construction of the All American Canal and required that water delivery contracts be made with water users receiving Project water. The State of California was also required to pass an act limiting its annual consumptive use to no more than 4400 × 10^3 af out of the 7500 × 10^3 af apportioned to the Lower Basin by Article III(a) of the Colorado River Compact, "plus not more than one-half of an excess or surplus waters unapportioned by said compact (Colorado River Compact), such uses always to be subject to the terms of said compact."

C. Mexican Water Treaty (1944)

The Treaty guaranteed the annual delivery of 1500 × 10^3 af to Mexico except in times of severe shortage.

D. U.S. Supreme Court Decree in Arizona vs. California (1964)

The Decree stated that when adequate mainstream water was available, 2800 × 10^3 af of water was to be apportioned to Arizona, 4400 × 10^3 af to California, and 300 × 10^3 af to Nevada. In addition, California would receive half of any surplus flow. In times when insufficient water was available for the three states, the Court authorized the Secretary of the Interior to first provide for the "satisfaction of present perfected rights" and then to apportion the remaining water to other consumptive uses "as is consistent with the Boulder Canyon Project Act as interpreted by the opinion of this Court herein, and with other applicable federal statutes, but in no event shall more than 4,400,000 acre feet be apportioned for use in California including all present perfected rights."

E. Colorado River Basin Project Act (1968)

This Act authorized construction of the Central Arizona Project (CAP) along with several other projects in the Colorado River Basin. It also stipulated that when there was insufficient mainstream water to meet the consumptive use of 7500 × 10^3 af in Arizona, California, and Nevada, "diversions from the mainstream for the Central Arizona Project shall be so limited as to assure the availability of water in quantities sufficient to provide for the aggregate annual consumptive use by holders of present perfected rights, by other users in the State of California served under existing contracts with the United States by diversion works heretofore constructed, and by other existing Federal reservations in that State, of four million four hundred thousand acre feet of mainstream water, and by users of the same character in Arizona and Nevada."

would be left for the IID and the Coachella Valley County Water District (CVCWD). Assuming that the beneficial consumptive use of the first two priorities continues at the historic rate (i.e., 479 × 10^3 af/yr since the year 1964), then approximately 3370 × 10^3 af/yr would be available to lands served by the All American Canal in the Imperial and Coachella Valleys. The IID could conceivably divert all the available water because it is the senior appropriator to the CVCWD,[29] but that is improbable. Instead, IID diversions will probably remain near the historic rate of about 3000 × 10^3 af/yr. With that diversion rate, about 370 × 10^3 af/yr would remain for the CVCWD, considerably lower than the CVCWD's past withdrawal rate of 507 × 10^3 af/yr. Fortunately, the first 49 miles of the Coachella Canal (see Fig. 1) are going to be lined with concrete, saving nearly 132 × 10^3 af of water each year.[29] Therefore, when the IID withdraws 3000 × 10^3 af/yr and the other priority users consume 479 × 10^3 af/yr, the remaining 371 × 10^3 af would provide essentially the same amount of water within the CVCWD as did the previous diversion rate of 507 × 10^3 af/yr.

Under those water supply and use conditions, surplus water would exist whenever the IID's diversions were below 3000 × 10^3 af/yr. But the allocation of that water to geothermal facilities could be subject to a compromise agreement reached between the IID and the CVCWD in the year 1934, which clarified water right priorities in the Seven Party Agreement of 1931. The compromise states

> "Imperial Irrigation District shall have the prior right for irrigation and potable purposes only and exclusively for use in the Imperial service area as herein after defined or here under modified to all water

TABLE 3. Net diversions of Colorado River water by priority agricultural users in California 1964–1976 (in acre-feet).[28]

Year	Palo Verde Irrigation District	Yuma project	Imperial Irrigation District	CVCWD[a]	Total diversions
1964	397,780	72,625	2,891,155	526,417	3,887,981
1965	350,760	63,433	2,741,309	524,686	3,680,188
1966	404,550	68,947	2,944,495	489,429	3,907,421
1967	363,480	67,463	2,819,724	464,053	3,714,720
1968	393,520	74,219	2,895,541	478,583	3,841,863
1969	393,650	64,966	2,766,924	495,082	3,720,622
1970	410,110	66,573	2,848,565	449,263	3,774,511
1971	458,570	63,341	2,967,907	470,683	3,960,501
1972	439,640	62,039	2,965,910	511,476	3,979,065
1973	465,250	63,863	3,047,899	522,356	4,099,368
1974	458,400	60,492	3,171,977	558,864	4,249,733
1975	449,486	62,186	3,070,974	570,987	4,153,633
1976	392,320	64,797	2,876,984	524,801	3,858,902
Averages	413,655	65,765	2,923,797	506,668	3,909,885

[a]Coachella Valley County Water District.

> apportioned to said Imperial Irrigation District and other lands under or that will be served from the All-American Canal in Imperial and Coachella Valley as provided in the Third and Sixth Priorities....'[29]

Emphasis on "irrigation and potable purposes" implies that those uses have priority over industrial uses. If interpreted that way, water used for irrigation purposes in the Coachella Valley would have priority over that used for geothermal purposes. Surplus water would then become available for geothermal operations when irrigation water consumption of the agricultural water users in the first three priorities was below 3850×10^3 af/yr.

Under extreme water shortage conditions, when California's allotment of 4400×10^3 af/yr could not be satisfied, surplus water would be nonexistent. The IID would then depend on a "present perfected" water right, defined in the Arizona vs California Supreme Court Decree as a right existing before the Boulder Canyon Project Act became effective on June 25, 1929. The IID has claimed a present perfected right of 2600×10^3 af/yr.[30]

The IID is authorized to distribute water that is determined to be surplus by Section 22259 of California State Water Code. It states

> "If its board deems it to be for the best interests of the district, a district may enter into a contract for the lease or sale of any surplus water not then necessary for use within the district, for use either within or without the district."[31]

The "best interests of the district" implies that such a contract would have the prior support of the valley's farm community; and support would undoubtedly require assurances that sufficient surpluses did indeed exist, and agricultural and domestic users would not be cut back. Even with the necessary assurances that existing water users would not be affected, resistance to the delivery of irrigation water to power plants would remain. The California Farm Bureau Federation, for example, opposes the use of water of irrigation quality for power plant cooling[32] and could not be expected to support the consumption of Colorado River water by geothermal facilities. To alleviate fears that continued use of surplus irrigation water by geothermal plants would pre-empt agricultural water uses, any contracts for such water would have to be short term—perhaps one year in duration. Contracts longer than three years must have the approval of the California Districts Securities Commission.[33]

One other mechanism for obtaining imported water from the Colorado River to cool power plants is to implement the Lanterman Act.[34,35] Under the provisions of that act, the Metropolitan Water District (MWD) of Southern California would be able to provide water (including up to 100×10^3 af/yr of Colorado River water) to power plants located outside of its service boundaries. It is stipulated in the act that most of the power generated from plants receiving water must be used "directly or indirectly through exchange, within the district, or for pumping, producing, treating, or reclaiming water for use in the district." Furthermore, the act requires that low quality water (i.e., agricultural waste waters and brackish ground waters) be used for cooling to the extent practical. If future geothermal power plants in the Imperial Valley meet the requirements of the act, and other cooling waters are not feasible, Colorado River water would then be available for cooling. Irrigation water delivered to energy facilities by the IID would come from MWD's share of the Colorado River. The applicability of this cooling water option will remain questionable, however, until other cooling water supplies in the valley are exhausted or are shown to be impractical for technical, economic, or regulatory reasons.

In summary, the current water policy of Imperial County essentially rules out the long term use of irrigation water for use by geothermal energy facilities. Greater use of irrigation water, however, might be realized if surplus water were distributed to power plants. Even though such irrigation water would not necessarily be a reliable supply, its use as supplemental cooling water, even on a temporary basis, would be beneficial because it is less costly than other supplies. The success of a policy supporting the consumption of surplus water will depend on the nature of future agricultural water use in the valley, the interpretation of existing laws, and the presence of political conditions favoring the use of irrigation water for nonagricultural purposes. Water from MWD's share of the Colorado River could also be made available for power plant cooling through provisions of the Lanterman Act; but until other sources of cooling water for geothermal facilities are shown to be unfeasible, this option appears unlikely.

STEAM CONDENSATE

Geothermal plants that have flashed-steam designs could use steam condensate as cooling water, thus eliminating or greatly reducing the need for an external water supply. The number of flashed-steam conversion systems and the nature of subsidence control policies will determine the role steam condensate eventually plays in meeting the cooling water requirements of geothermal facilities. To prevent, or at least reduce, potential impacts of subsidence on irrigation structures and subsurface drainage systems, current Imperial County policy[3] requires the full injection of all fluids withdrawn for geothermal operations in the irrigated portion of the valley (i.e., the volume of fluids withdrawn = volume of fluids injected). Deviations from that policy would only be considered by the county after the California Division of Oil and Gas approved the initial injection program. A full injection policy requires external water supplies to support the operation of a geothermal power plant. One available option, with a full injection policy is to use an external supply, such as irrigation water or agricultural waste water, for cooling and to inject all of the residual geothermal fluid. This option would be necessary for confined-flow binary conversion facilities, because condensate that could be used for cooling would not be produced. A second option is to use condensate from flashed-steam power plants as cooling water and an external water supply for injection. Salton Sea water, for example, could be used as an injection fluid for flashed-steam facilities near to the sea. Similarly, agricultural effluents could be used for injection at KGRAs in the valley. The injectability of those water supplies, though, has yet to be fully proven.

If partial injection were allowed, then condensate could be used as cooling water and no external supplies would be necessary. Although partial injection would be favored from the standpoint of water supply, three uncertainties are associated with the implementation of such a practice: (1) what would be the effect on subsidence if only 75 to 80% of the withdrawn fluids were injected over the 30-yr life of a power plant? (2) how sensitive are drainage systems and irrigated lands to changes in land elevation? and (3) what are the costs of mitigating the effects of subsidence?

Answers to these questions could eventually be obtained by conducting partial injection experiments. If results are positive, then condensate use might be permitted on a case by case basis for flashed-steam facilities in the irrigated part of the valley. The most plausible location for partial injection is the East Mesa KGRA, because it is in the valley's nonagricultural desert region where subsidence effects are not likely to be serious. But there too, subsidence will need to be carefully monitored to ensure that any unforseen problems and undesirable impacts do not arise.

AGRICULTURAL WASTE WATER

Drainage from agricultural lands, composed primarily of surface runoff from irrigation, subsurface drainage, and water losses from the canal system, is a third source of cooling water. Imperial County water policy favors the use of agricultural water effluents over irrigation water for rejecting power plant heat, because its quality is generally unsuitable for irrigation. The California State Water Resources Control Board also supports the use of agricultural waste waters for power plant cooling.[14] Waste water entering the Salton Sea from the Imperial Valley amounts to approximately 1000×10^3 af each year, making it a significant water resource in this arid region. However, several things must be dealt with before agricultural waste waters can be used extensively for power plant cooling.

- Saline blowdown resulting from the use of waste waters cannot be discharged to agricultural drains or the valley's rivers because of water quality regulations. Consequently, blowdown must be disposed of by subsurface injection or surface disposal to either evaporation ponds or, perhaps, a regional waste disposal site. Disposal to ponds would generally be unacceptable in agricultural areas because of possible conflicts arising from use of the land (e.g., a 100-MW power plant discharging 700 af/yr of blowdown would require about 121 acres of land for evaporation, assuming an annual evaporation rate of 5.78 ft). Subsurface injection would then be the only acceptable alternative. A regional Class II-1 waste disposal site could receive saline blowdown[36]; however, the costs of transporting blowdown to such a site could be prohibitive.

Subsurface injection is the only acceptable alternative to surface disposal. In Fig. 3 three subsurface disposal options for blowdown from a cooling tower are shown. The first option is attractive because residual geothermal fluids and blowdown are injected through the same well. A potential drawback to this option is the chemical reactivity of the two fluids. For example, sulfate precipitates could form if blowdown high in sulfate were combined with brines containing barium and calcium.[37] The precipitates are harmful because they plug the injection well and the formation receiving the fluids. Chemical pretreatment of the blowdown would then be necessary. The second option incorporates a separate well for blowdown disposal, but precipitates could still form when blowdown mixes with reservoir fluids. The third option utilizes a shallow injection well through which blowdown is injected to geologic strata above the geothermal reservoir. This approach avoids the problems of chemical incompatibility; however, the formation receiving the fluids will have to be carefully chosen in order to avoid contaminating any aquifers that may be protected by future regulations promulgated by the U.S. Environmental Protection Agency under the Safe Drinking Water Act of 1976. If none of the options prove viable, then use of waste water for cooling would not be possible until an acceptable disposal method is developed.

- Large scale consumption of agricultural effluents not only would cause the Salton Sea's elevation to decline but, at the same time, would cause its salinity to rise. The sea's salinity has been gradually rising through time—except in periods of high rainfall or agricultural drainage—and reductions of waste flows resulting from power plant withdrawals for cooling purposes would aggravate the situation. As the salinity rises, it will reach a point where the productivity of the sea's sport fishery will be adversely affected.[38] Also, the water quality control plan adopted by the Regional Water Quality Control Board states

> "Until a salinity control project is implemented, the objective is to limit the rate of increase of total dissolved solids of the Salton Sea to the lowest possible value, consistent with its primary purpose as a reservoir to receive and store agricultural drainage and seepage water."[18]

At the present time no salinity control projects are contemplated, and therefore, major withdrawals of waste water for cooling are likely to need the approval of the regional board. A beneficial impact of waste water withdrawals for cooling would be a decline in the sea's elevation. Rising water levels in recent years have damaged shoreline property, inundated irrigated lands, and flooded parts of the Salton Sea National Wildlife Refuge as well as the

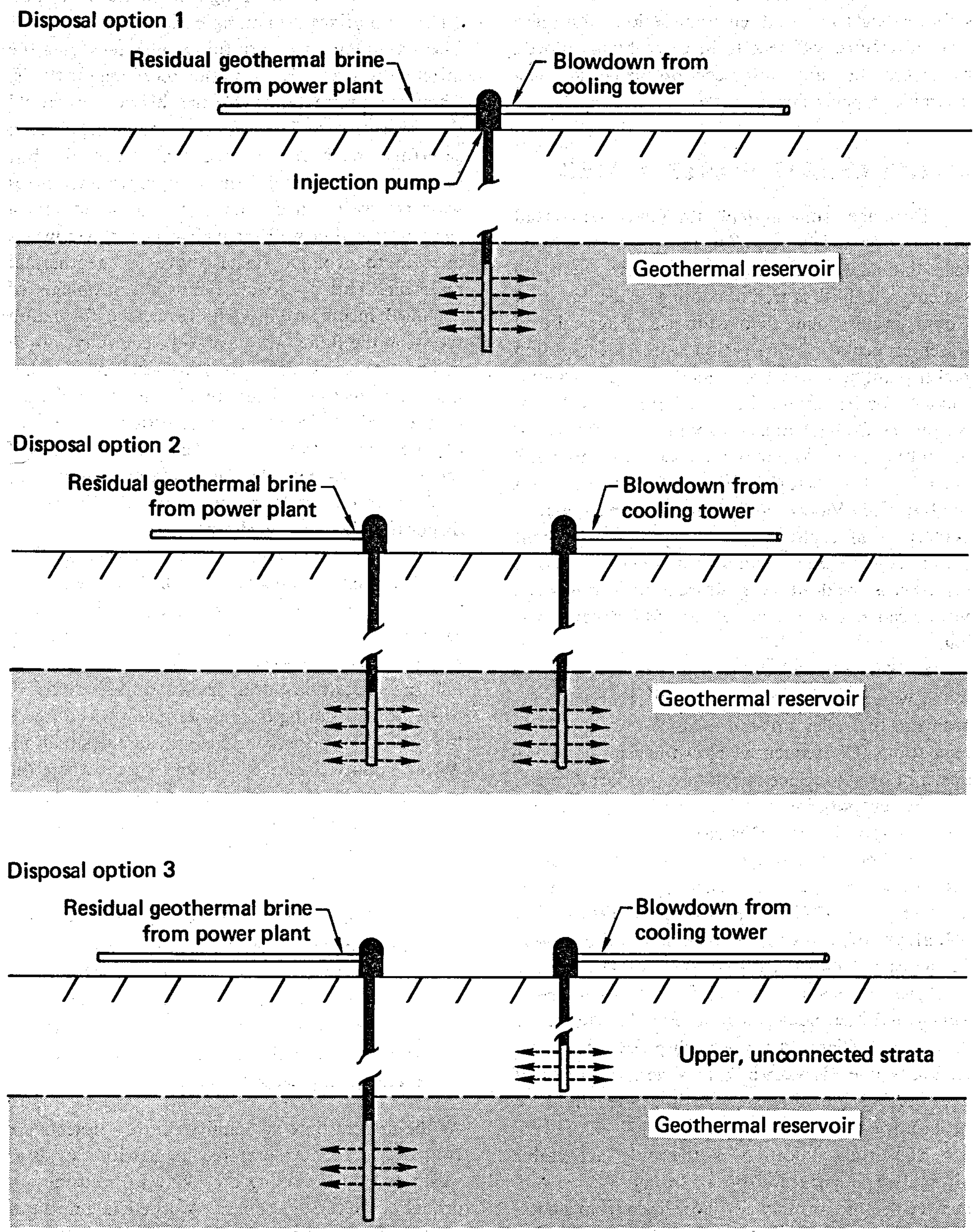


FIG. 3. Subsurface disposal options for cooling tower blowdown from geothermal power plants. In the first option, treated or untreated blowdown is combined with geothermal fluids and injected to the geothermal reservoir. Separate injection to the geothermal reservoir, shown in the second option, might alleviate problems of chemical incompatibility associated with the first option. The third option, injection of blowdown to shallow strata and injection of brine to the reservoir, isolates the two injection fluids to prevent mixing.

Salton Sea KGRA. A stable or decreasing sea level would reduce adverse impacts on those areas. But a decreasing elevation would result in higher salinity levels and adverse impacts on the sea's aquatic ecosystem.

- Waste flows that are unevenly distributed in time and space could pose difficulties with the acquisition of cooling water for some power plant sites. The Heber and East Mesa KGRAs, for example, are near the boundaries of the drainage system where waste flows are not as great as they are in the northern part of the valley. Seasonal variations in agricultural effluents resulting from changes in cropping patterns further complicate the use of waste waters in those resource areas. In addition, long term water conservation efforts by irrigators and the IID will mean that smaller volumes of waste water will be available for power plant cooling.

- Ownership of waste water flowing in the New and Alamo Rivers may have to be determined. Section 1201 of the State Water Code states

> "All water flowing in any natural channel, excepting so far as it has been or is being applied to useful and beneficial purposes upon, or in so far as it is or may be reasonably needed for useful and beneficial purposes upon lands riparian thereto, or otherwise appropriated, is hereby declared to be public water of the State and subject to appropriation in accordance with the provisions of this code."[39]

Thus, if the rivers are considered to be flowing in "natural channels," the water could be appropriated by a user putting the water to beneficial use, and the State Water Resources Control Board would then have jurisdiction over that water. On the other hand, the rivers do flow within the boundaries of the IID, and Section 22076 of the State Water Code states

> "A district may do any act in order to put to any beneficial use any water under its control."[40]

And by Section 22078,[41] the IID is empowered to recapture and salvage any water for the beneficial use of the district. Since nearly all of the water in the rivers is derived from Colorado River water imported to the valley by the IID, the district may indeed have control over that water.

- Even though historic flows in the New River crossing the United States–Mexican border have averaged over 100×10^3 af annually, the long term availability of water from the New River for major geothermal development in the Heber KGRA will remain uncertain until an agreement is reached between the two countries that guarantees the quantity of Mexican inflows. The current agreement dealing with flows from Mexico is Minute 197 of the International Boundary and Water Commission, United States and Mexico.[42] Under Minute 197, water discharged from the Mexican irrigation system (i.e., unused irrigation water) entering the United States cannot exceed an annual average of 35,000 af/yr for any five-year period. This flow restriction was implemented to promote the beneficial use of Colorado River water delivered to Mexico. It does not cover discharges of irrigation runoff or municipal wastes. A new agreement governing flows from Mexico that is favorable to geothermal development would not only have to be consistent with the purposes of Minute 197, but it would also have to address the quality of Mexican inflows, which include untreated domestic wastes.

- Salt drift emitted from cooling towers using drain waters having a high TDS content could cause crop damage in the vicinity of power plants located in agricultural areas. The actual occurrence of crop effects would depend on prevailing meteorological conditions, the salinity of water circulating in cooling towers, the chemical composition of drift, and the sensitivity of crops to drift. A thorough investigation of potential effects on crops should precede the widespread use of agricultural waste waters for cooling power plants to determine whether any mitigating measures (e.g., improved drift control) will be necessary.

- Consumption of agricultural drain waters to support large scale geothermal development will alter flows in the New and Alamo Rivers and affect riparian habitats as well as fish populations. If unacceptable damage is done, limitations may eventually be placed on appropriations of river water in order to protect in-stream uses.

EAST MESA GROUND WATER

Millions of acre-feet of water have been recharged to aquifers beneath East Mesa from the unlined All American, East Highline, and Coachella

Canals, making ground water there a potential source of cooling water. Preliminary indications are that although aquifers are a source of significant quantities of water,[22] additional geohydrologic studies are needed to confirm the extent of the resource. Even if exploitable ground waters were identified, wells would have to be placed in such a way that they obtained water stored in aquifers and not from induced ground water flow from unlined canals. However, there will be a greater opportunity for extracting ground waters without interfering with canals when the Coachella Canal is lined with concrete sometime in the 1980s.

Ground water will not become a major source of cooling water for geothermal development in the valley—even with substantial proven reserves—unless it can be transferred to the Heber, Brawley, and Salton Sea KGRAs; but there does not seem to be an effective method to transport it at this time. Ground water could conceivably be pumped into one of the canals crossing East Mesa, thereby allowing an equivalent volume of irrigation water to be delivered to geothermal facilities elsewhere in the valley. Before that could be done though, the quality of the water would probably have to be better than, or at least the same as, canal water. Existing water quality data[22] show that ground water quality varies a great deal on East Mesa, but some water might be suitable. In addition to the question of water quality, the legal implications of making such a transfer need to be examined. Use of pipelines is the only other method of transporting ground water to the valley's geothermal resource areas—but whether they will be economically feasible or not is uncertain.

SALTON SEA WATER

As a source of cooling water, the Salton Sea has several drawbacks. First of all, its salinity would pose problems of scaling and corrosion, and specially designed salt-water cooling towers would be necessary. Extensive chemical conditioning of the seawater would also be required to control the formation of calcium and silica precipitates. Furthermore, large quantities of saline blowdown would have to be disposed of in some acceptable manner; and that could be difficult because subsurface injection faces technical uncertainties and surface disposal requires substantial land for evaporation ponds. Another potential problem involving the use of seawater in a cooling tower involves salt drift that could cause crop damage when deposited on crops in the vicinity of a tower.

Salton Sea water could be more suitably used as an injection fluid for subsidence control purposes. In that use, it would serve as makeup water injected to a geothermal reservoir so that steam condensate could be used for cooling when full injection is required. The sea's salinity would also be lowered by withdrawing water for reservoir injection. That would happen because salts as well as water would be removed from the sea. But for such withdrawals to have a significant impact on salinity, thousands of acre-feet would have to be removed annually. In studying this aspect of sea water injection, Goldsmith[43] concluded that even with 2000 MW on-line in the Salton Sea KGRA in the year 1982, approximately 40 yrs of injection at 120,000 af/yr would be needed to stabilize the sea's salinity at 35,000 ppm TDS.

HISTORIC WATER BALANCES

The driving force in the Imperial Valley's water balance, as shown in Fig. 4, is the amount of water used by crops. The flow of irrigation water to the valley, displayed in Fig. 5 for example, changes monthly in response to the water demand of crops as a function of cropping pattern, climate, and cultural practices. Wastewater flows composed of canal losses, surface runoff, subsurface drainage, and some ground water discharge also fluctuate monthly and are related to inflows of irrigation water. The actual evapotranspiration (ETa) of the crops in the valley is equal to the amount of water supplied through surface irrigation and rainfall minus the discharges of water from irrigated lands, assuming that changes in surface and ground water storage within the valley are small.[44] Stated mathematically,

$$ETa = Ia + Pe - D,$$

where

$$D = O - C - G,$$

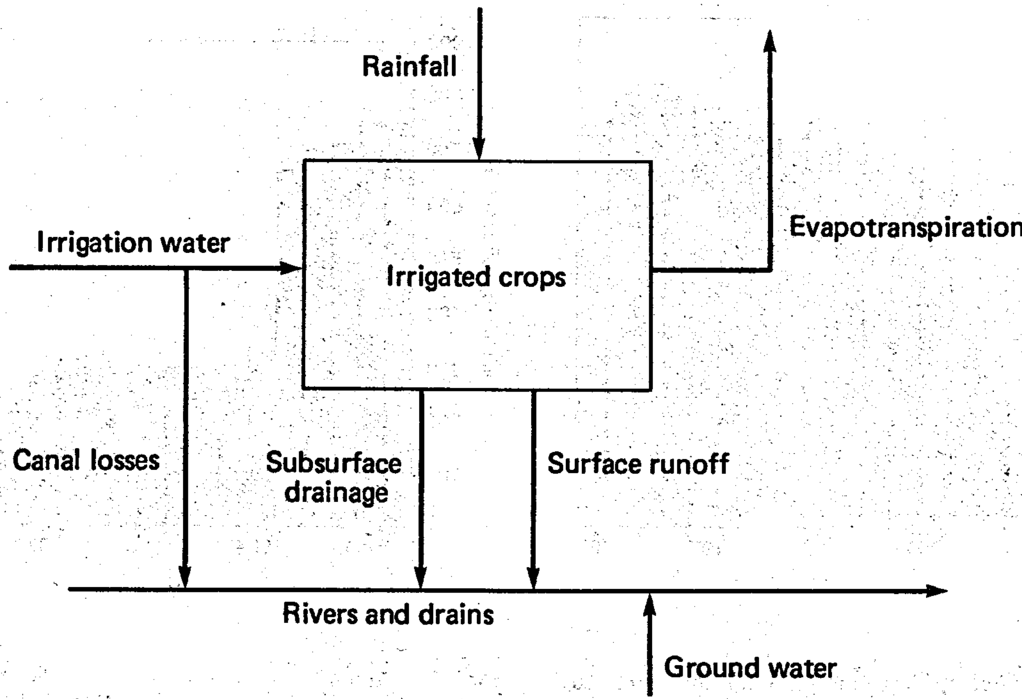


FIG. 4. Components of the Imperial Valley's water balance. The driving force in the water balance is the evapotranspiration of crops.

and

ETa = annual evapotranspiration of the applied water (af),
Ia = irrigation water applied to crops (af),
Pe = precipitation falling on irrigated lands (af),
D = surface and subsurface discharges from irrigated lands (af),
O = total outflow from the valley (af),
C = canal losses (af), and
G = ground water discharges to surface waters (af).

Using IID data,[45] the amount of water delivered to crops was determined by subtracting municipal and industrial water deliveries from the total amount of water the district distributes to all users. During the years 1959 to 1976, the annual applications of irrigation water rose from a low of 4.60 ft/acre in 1959 to a high of 6.12 ft/acre in 1974 (see Fig. 6). Precipitation falling on crops was estimated by multiplying annual rainfall by the net acres of irrigated crops. The annual net acreage is equal to the total acres of double cropped acres minus the acres having duplicate crops. The acreage under cultivation at any one time is generally 60 to 90% less than the annual net acreage, and therefore, the calculated rainfall received by crops will be somewhat higher than the rainfall actually falling on crops.

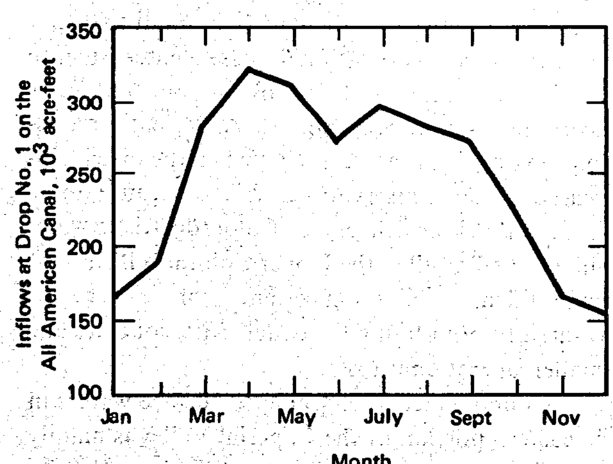


FIG. 5. Average monthly inflows of imported Colorado River water below Drop No. 1 on the All American Canal for the years 1971 to 1975. The inflows vary according to the evapotranspiration demand of the crops planted.

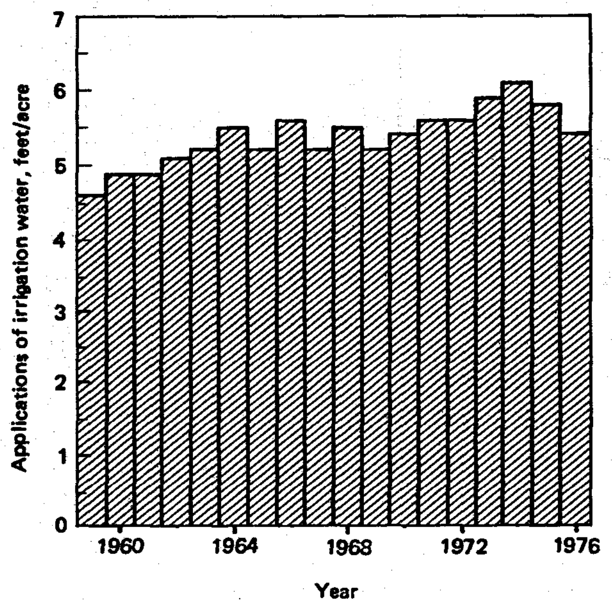


FIG. 6. **Annual applications of irrigation water to crops during the years 1959 to 1976. Application rates are affected by the efficiencies with which farmers irrigate, the water demands of the crops grown, and leaching requirements.**

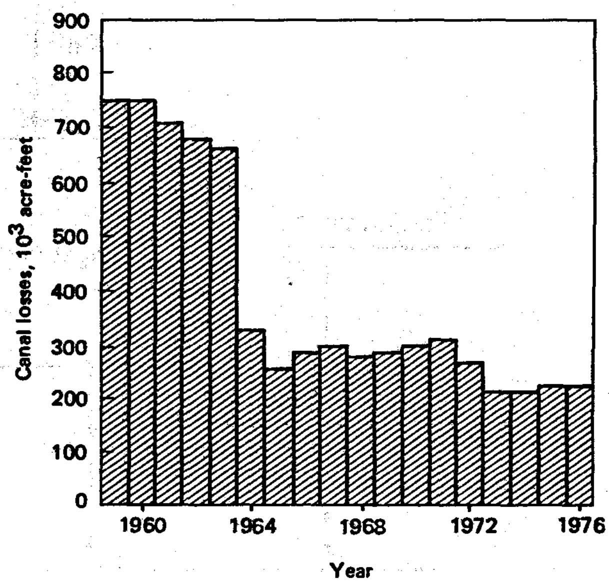


FIG. 7. **Annual canal losses from the Imperial Valley irrigation system. Canal losses were greatly reduced in 1964 when the Imperial Irrigation District increased water conservation efforts because of a cutback in deliveries of Colorado River water while Lake Powell in the Upper Colorado River Basin was being filled.**

Loss of water from canals within the irrigated portion of the valley was calculated by subtracting the amount of water distributed to all water users by the IID from the quantity of water conveyed to the irrigation system at the East Highline Canal (see Fig. 1). That calculation is based on the assumption that evaporation from the canals is small and that all seepage and operational losses enter surface waters. Since the year 1959, losses from the canals have steadily declined (Fig. 7). A dramatic reduction took place in the year 1964 when the district increased water conservation efforts because there was a cutback in delivery of Colorado River water while Lake Powell in the Upper Colorado Basin was being filled. Declines in recent years can be attributed to both lining the canals with concrete and smaller operational losses.

Ground water discharging to surface waters in the eastern portion of the Imperial Valley is mainly from the Coachella and the All American Canals. These canals are unlined and large quantities of water are thus lost through seepage each year. Leakage along a 50-mile stretch of the Coachella Canal starting at the All American Canal and ending at the 6A Check has averaged over 100×10^3 af/yr [22]; losses from Drop 1 on the All American Canal to the East Highline Canal averaged about 40×10^3 af/yr.

The quantity of water moving into the irrigated area west of the East Highline Canal was calculated using flow net analysis with the regional ground water level contours depicted in Fig. 8. Several flow channels were superimposed on the contours (Fig. 8) and then flow rate calculations were made for each channel by using this form of the Darcy equation[46]:

$$Q = TIL,$$

where

Q = rate of flow through cross section of aquifer in gallons per day (gpd),
T = coefficient of transmissivity (gpd/ft),
I = hydraulic gradient (ft/mi), and
L = average width of cross section of aquifer (mi).

The transmissivities of flow channels 1 to 3 were chosen to be 75,000 gpd/ft. It represents an intermediate value between the high computed

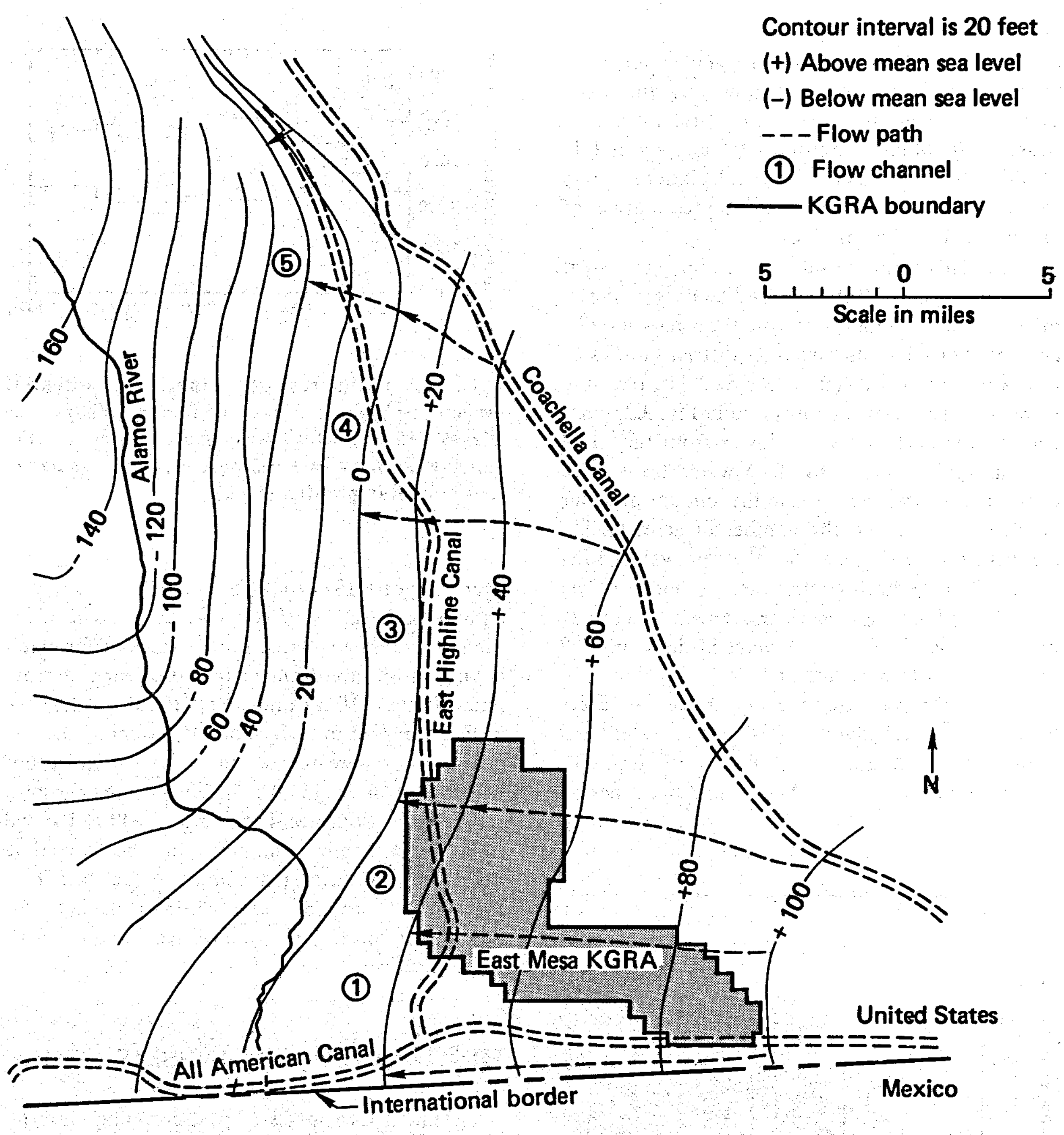


FIG. 8. Ground water contours[22] and flow paths for East Mesa. About 19,000 af/yr of ground water is estimated to be moving toward the central portion of the valley through the five flow channels.

transmissivities of East Mesa that are over 100,000 gpd/ft and the lower transmissivities of the central valley that are generally under 10,000 gpd/ft.[22] A transmissivity of 50,000 gpd/ft was selected for channels 4 and 5 because there was a lower computed transmissivity in the vicinity and a steeper hydraulic gradient. The movement of ground water toward the central valley was estimated to be nearly 19,000 af/yr based on the chosen transmissivities, the hydraulic gradients in the year 1965, and the widths of the flow channels. An additional source of ground water flowing to the Imperial Valley comes from the Mexicali Valley, Mexico. Loeltz[22] calculated that about 7000 af/yr flows in from Mexico beneath a 12-mile section between Calexico and the mountains to the west. Together, the inflows of ground water from East Mesa and Mexico amount to approximately 26,000 af/yr. For water balance calculations, it was assumed that those flows are representative of historic hydrologic conditions.

Effluents from the subsurface drainage system plus surface runoff from irrigated lands were determined by subtracting losses from the canals and discharges of ground water from the district's total surface water outflow to the Salton Sea. The resulting flows of waste water are displayed in Fig. 9. In contrast to the declining water losses from the canal system, surface and subsurface water flows have continued to rise. Increases in the amount of water applied per acre and the number of acres having subsurface tube drainage for the removal of salts from soils have both contributed to that rise. The acres of land having subsurface drains, for example, have increased from 253,000 acres in the year 1959 to just over 400,000 acres in 1976.

The IID[45] estimated the subsurface discharges indirectly by calculating how much water was pumped from more than 200 sumps collecting subsurface drainage. For the August to August period

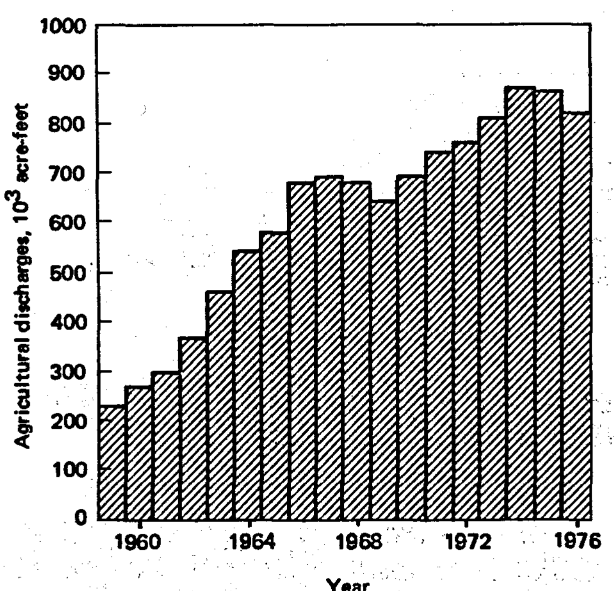


FIG. 9. Combined discharges of surface and subsurface drainage from the Imperial Valley. Increased discharges from irrigated lands are the result in part of improved subsurface drainage since 1959 and larger applications of irrigation water.

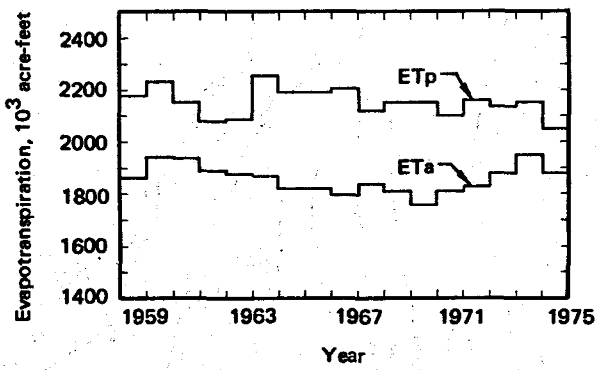


FIG. 10. Estimates of actual and potential evapotranspiration (ETp) in the Imperial Valley. The Blaney-Criddle method was used to estimate ETp; valley-wide water balances were used to estimate actual evapotranspiration (ETa).

over the years 1974 to 1975 and 1975 to 1976, the annual discharge rates were 0.75 af and 0.82 af for each acre drained. Based on the acres of farmland having subsurface drainage in those years, approximately 297 × 10^3 af and 326 × 10^3 af would have been discharged to surface drains, assuming the discharge rates were representative of the entire underground drainage system and were constant through time. Surface discharges of 640 × 10^3 and 577 × 10^3 af were computed for the two time periods by subtracting the sum of water lost from the canals, ground water discharged, and the amount of subsurface drainage from the district's total outflows.

HISTORIC EVAPOTRANSPIRATION

Annual ETa losses of past cropping patterns, computed by the water balance method, appear in Fig. 10. The 18-year average for the ETa values was 1859 × 10^3 af, with a standard deviation of 51 × 10^3 af. The maximum annual ETa was 1952 × 10^3 af and the minimum was 1766 × 10^3 af—a difference of 186 × 10^3 af. The potential evapotranspiration (ETp) of crops is also of interest because deficits between ETp and the amount of water actually used by a crop (ETa) can cause a reduction in yield.[47] ETp is the amount of water crops could consume through evaporation and transpiration under given meteorological conditions if sufficient soil water were available to completely satisfy crop water demands.

ETp was determined by the Blaney-Criddle (B-C) method.[48] With the B-C procedure, the ETp of a crop is found by summing the product of its monthly consumptive use coefficients, k, and a climatic factor, f, over the growing season. In equation form,

$$ETp = \sum kf,$$

where

k = monthly consumptive use coefficient,
f = mt/100,
m = monthly percent of annual daylight hours, and
t = monthly mean temperature (°F).

A seasonal consumptive use coefficient, K, may be substituted for the monthly coefficients if they are unavailable, and the formula becomes:

$$ETp = K \sum f$$

Calculations of the annual ETp of field, garden, and permanent crops grown in the Imperial Valley were based on semi-monthly consumptive use coefficients developed by Erie, French, and Harris[48] and seasonal K parameters derived from ETp estimates made by Kaddah and Rhoades[44] and Pruitt.[49] Temperatures used to compute the f values came from daily weather data collected by the IID at Imperial, California. Table 4 presents the results

TABLE 4. Potential evapotranspiration of 1975 crops calculated by the Blaney-Criddle method.

Crop category	Crops	Acres planted (10^3)	ET_p Inches	Feet	Acre-feet (10^3)
Field	Alfalfa	158.7	77.7	6.48	1028.1
	Barley	3.5	21.0	1.75	6.1
	Bermuda	2.2	47.9	3.99	8.6
	Cotton	43.0	42.1	3.51	150.8
	Flax	0.1	26.3	2.19	0.3
	Oats	0.3	23.5	1.96	0.5
	Rye grass	8.7	31.3	2.61	22.8
	Sorguhm	24.2	29.0	2.42	58.7
	Sudan grass	13.0	30.1	2.51	32.8
	Sugar beets	71.4	41.5	3.46	246.9
	Wheat	155.6	23.5	1.96	304.8
	Misc.	5.7	35.6	2.97	16.9
	Total	486.6			1877.5
Garden	Brassica	1.0	20.0	1.67	1.7
	Carrots	6.0	17.7	1.48	8.9
	Cucurbits	13.6	19.1	1.60	21.7
	Lettuce	45.1	9.0	0.75	33.9
	Onions	10.1	22.7	1.89	19.2
	Tomatoes	5.9	28.8	2.40	14.1
	Misc.	1.6	19.6	1.63	2.7
	Total	83.5			102.2
Permanent	Asparagus	4.4	53.7	4.48	19.8
	Citrus	2.5	47.2	3.94	9.9
	Ponds	8.4	58.8	4.90	41.1
	Misc.	0.7	48.6	4.05	2.9
	Total	16.1			73.8
	Grand total	586.2			2053.6

of the ETp computations for the major crops grown in the year 1975. The acreages for each crop were from the IID.[50]

The total ETp of all major crops planted from the years 1959 to 1976 are shown in Fig. 10 along with the estimates of ETa. As expected, the ETp of the annual cropping patterns exceeded the ETa values made by the water balance method. The actual evapotranspiration is usually lower because of inadequate irrigation or reduced crop water demand because of diseases, cultural practices, pests, soil conditions, etc. In the years considered, the average ETp was 2155 $\times$ 10^3 af, equal to 4.9 ft/acre irrigated. By comparison, ETa was approximately 4.2 ft/acre, or 86% of ETp. The evapotranspiration deficits of Fig. 10 can be partially explained by the irrigation of major field crops. For example, if the year 1975 alfalfa crop was under-irrigated by 15%, while other major crops were properly irrigated, the total ETp of the crops displayed in Table 4 would have been 1899 $\times$ 10^3 af, or merely 1% more than the ETa of the crops estimated by the water balance method. Errors in the estimates of crop acreages and consumptive-use coefficients could also affect the size of the deficits.

WATER BALANCE RELATIONSHIPS

The most significant trends in the historic water balances have been the increases in effluent discharges from farmlands and the decreases in canal losses. Crop water use, as measured by ETa, has remained fairly constant despite the changes in the other components. The historic ETa of crops has averaged 78% of the irrigation water applied to crops. The major water balance components calculated from IID data of the August to August periods in the years 1974 to 1975 and 1975 to 1976 are expressed in Fig. 11 as percentages of inflows of the irrigation water to the valley at the junction of the East Highline and All American Canals. Figure 12 shows the surface runoff, subsurface drainage, canal loss, and groundwater flows as percentages of the total flow of waste water from the IID to the Salton Sea.

The leaching fractions (LF) of the two periods were calculated by this equation:

$$LF = \frac{U}{ETa + U},$$

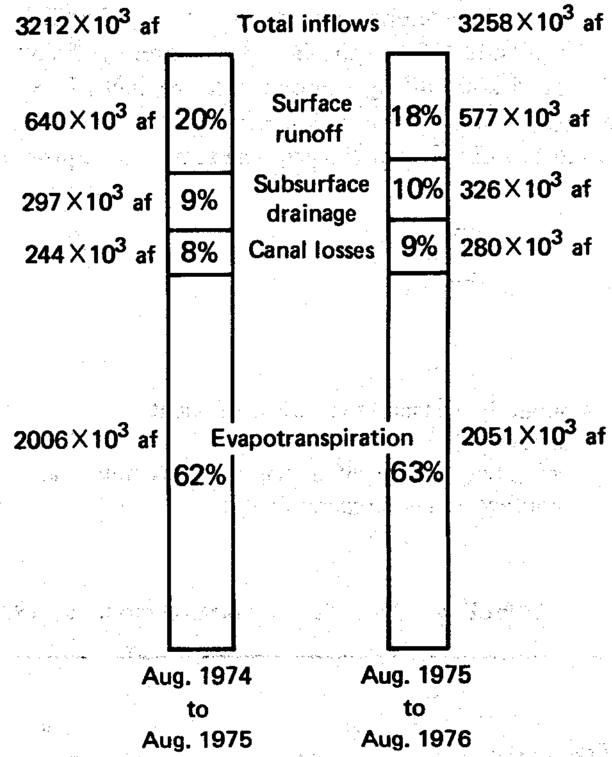


FIG. 11. Breakdown of inflows of imported Colorado River water reaching the irrigation system over 13-month periods (August to August) during the years 1974 to 1975 and 1975 to 1976. Percentages do not necessarily add up to 100% because of round-off errors and errors in the estimates of the components of the water budget.

where

U = subsurface drainage (af).

The resulting valley-wide LF values were 0.13 for both 13-month periods over the years 1974 to 1975 and 1975 to 1976.

Other measures of importance for the analysis of the historic water balances are the efficiencies with which irrigation water has been conveyed from Imperial Dam to the irrigation system, distributed to irrigators, and applied to crops. The conveyance efficiency, Ec, is calculated as the ratio of water delivered to the irrigation system at the East Highline Canal to the water diverted to the valley at Imperial Dam on the Colorado River. The distribution efficiency, Ed, is the ratio of water distributed to water users within the irrigation system to the water supplied the system at the East Highline Canal. Ec and Ed have averaged 0.95 and 0.90 since the year 1964.

The application efficiency, Ea, is defined as:

$$Ea = \frac{ETa + U - Pe}{Ia}$$

Over the two time periods of 1974 to 1975 and 1975 to 1976, when estimates of subsurface drainage were available, Ea was 0.78 and 0.80. It is assumed that the quantities of subsurface drainage used in the two time periods are not significantly greater than the minimum amounts of leaching water required to maintain the productivity of the crops being grown.

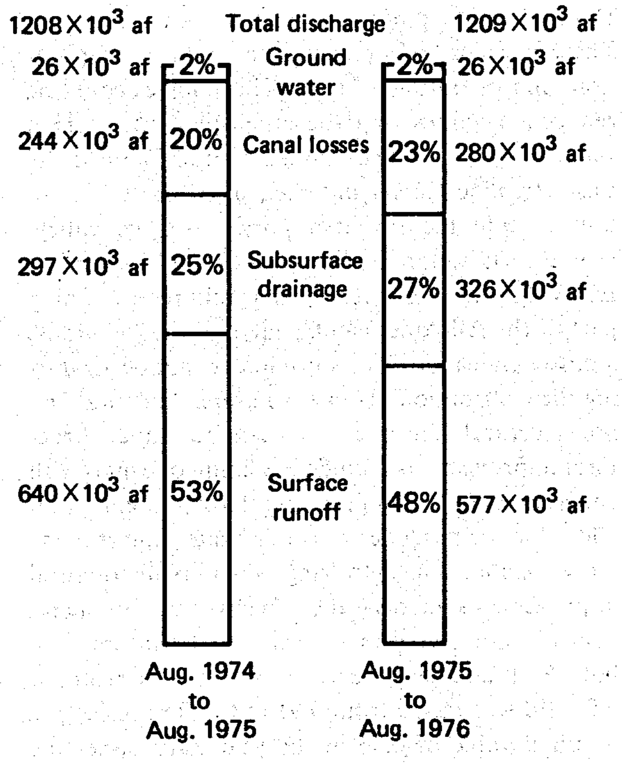


FIG. 12. Composition of waste waters discharged from the valley for 13-month periods (August to August) during the years 1974 to 1975 and 1975 to 1976.

FUTURE WATER SUPPLY CONDITIONS

Future inflows of irrigation water and outflows of agricultural drain water in the valley will vary according to the use of water by crops and the efficiencies with which irrigation water is conveyed to the valley, distributed to users, and applied to crops. Although future crop water use and irrigation efficiencies cannot be accurately predicted, values can be specified that produce a plausible range of inflows and outflows. The resulting water balance conditions can then be analyzed to determine how much water could be available for geothermal developments in the valley's KGRAs. Two sets of numbers indicating irrigation efficiencies are used to simulate future conditions: a reference (REF) case, representing existing efficiencies, and a conservation (CON) case, consisting of increasing values of Ea and Ed. The CON case will only occur if future economic and regulatory conditions change to promote the more efficient use of water by irrigators and if conservation activities are maintained by the IID. Low, medium, and high levels of crop ETa are used to represent the range of values for crop water use.

IRRIGATION PRACTICES

The application efficiency, Ea, has a major influence on inflows of irrigation water to the valley and runoff from irrigated fields. If Ea is high, surface runoff is low and less irrigation water needs to be applied to crops. Conversely, application inefficiencies result in increased runoff and higher irrigation requirements. In the Imperial Valley the main opportunities for increasing Ea involve the more effective use of existing irrigation methods and the introduction of new techniques.

Currently the predominant methods of irrigating crops are by border and furrow irrigation. Both of these methods require carefully leveled fields to promote the proper distribution and infiltration of water. When fields are correctly leveled and good water management practices followed, water can be efficiently applied to crops. However, excessive runoff can be produced whenever fields have too great a slope or when irrigation is poorly managed. Runoff from surface irrigation can be greatly reduced or eliminated through the use of pump-back systems that consist of a small reservoir for storing tail water and a pump for returning water to the head ditch serving the particular field being irrigated. At present pump-back systems are used on just a few farms in the valley.

A possible alternative to existing surface irrigation methods for some crops and fields is dead-level, or basin, irrigation. With this method a field is graded level and a basin formed by constructing a dike around the field. Irrigation water is then applied and remains on the field until it is infiltrated; there is no runoff. Application of the water must be done deliberately, taking into consideration crop evapotranspiration, soil characteristics, and leaching requirement. Another efficient method of irrigation that eliminates runoff is using sprinklers. They are now used primarily for germination, and control of root diseases and temperature.[51] Sprinkler systems may also be employed to reduce soil salinity.[52]

It should be pointed out that the introduction of efficient irrigation methods will depend primarily on economic incentives. Unless definite economic advantages are associated with pump-back, sprinkler, or other efficient irrigation technologies, it is unlikely that farmers will use them. Presently the low cost of irrigation water encourages the use of existing surface irrigation practices and discourages the implementation of more efficient methods that have higher capital and operating expenses. Even though increased water conservation resulting from use of alternative irrigation technologies may not be realized for some time, water savings can still be achieved in the near term through improved surface irrigation. The regulation adopted by the IID that imposes fines for excessive runoff is now one of the primary incentives to conserve water. That regulation is part of a larger water conservation program run by the district designed to promote the more efficient use of water.

The REF application efficiency was chosen to be a constant 0.79 through the years 1982 to 2010, the time frame in which water supplies for geothermal energy production are assessed. In the CON case Ea increases at a linear rate from an initial value of 0.79 to 0.90 in the year 2010 (see Fig. 13).

WATER CONVEYANCE AND DISTRIBUTION

Since the year 1973, about 87% of the Colorado River water received by the IID at the Imperial Dam diversion point has been delivered to users. The remaining 13% represented seepage, evaporation, and operational losses. Those losses could be reduced by improving the efficiencies with which water is conveyed (Ec) from Imperial Dam to the East Highline Canal and then distributed (Ed) to users within the irrigated portion of the valley. However, it is more feasible to increase Ed than it is Ec. A significant change in Ec would require lining part of the All-American Canal, and that would be a costly endeavor. To reduce losses that occur during the distribution of water to users, structural and nonstructural improvements can be made. Structural improvements include the lining of canals with concrete and developing regulatory ponds that allow for the holdover of excess water and provide more flexibility in delivering water. Nonstructural improvements involve the effective measurement, control, and diversion of water to irrigators.[53] In both REF and CON cases, Ec was held constant at 0.95; Ed was raised from 0.91 in the REF case to a terminal value of 0.95 in the year 2010 under the CON case (see Fig. 13).

LEACHING FRACTION

The salt tolerances of the crops planted in the Imperial Valley, the extent of subsurface drainage, soil types, and the salinity of irrigation water all affect the amount of water used to leach excess salts from the root zones of irrigated crops. In the valley, clay soils tend to swell when watered and often inhibit the application of leaching water, thereby reducing the amount of water that infiltrates. Most of the irrigated lands now have subsurface drains to facilitate the removal of soil salts. Even with the extensive subsurface drainage system, the valley's LF is lower than other irrigated areas like the Coachella Valley that have coarser soils.[54] Leaching requirements are apt to rise in the years ahead because the salinity of the Colorado River is expected to increase as a result of larger water diversions in the Upper Basin. But at this point, it is not possible to accurately forecast future salinity changes because of uncertainties about future flows in the Colorado River and its tributaries, diversions in the Upper Basin, and the implementation of salinity control projects. For the purposes of this study, it is assumed that LF values will rise from 0.13 to 0.15 (shown in Fig. 13) as the salinity of imported Colorado River water increases from 860 ppm TDS in the year 1982 to 1270 ppm in the year 2010. This

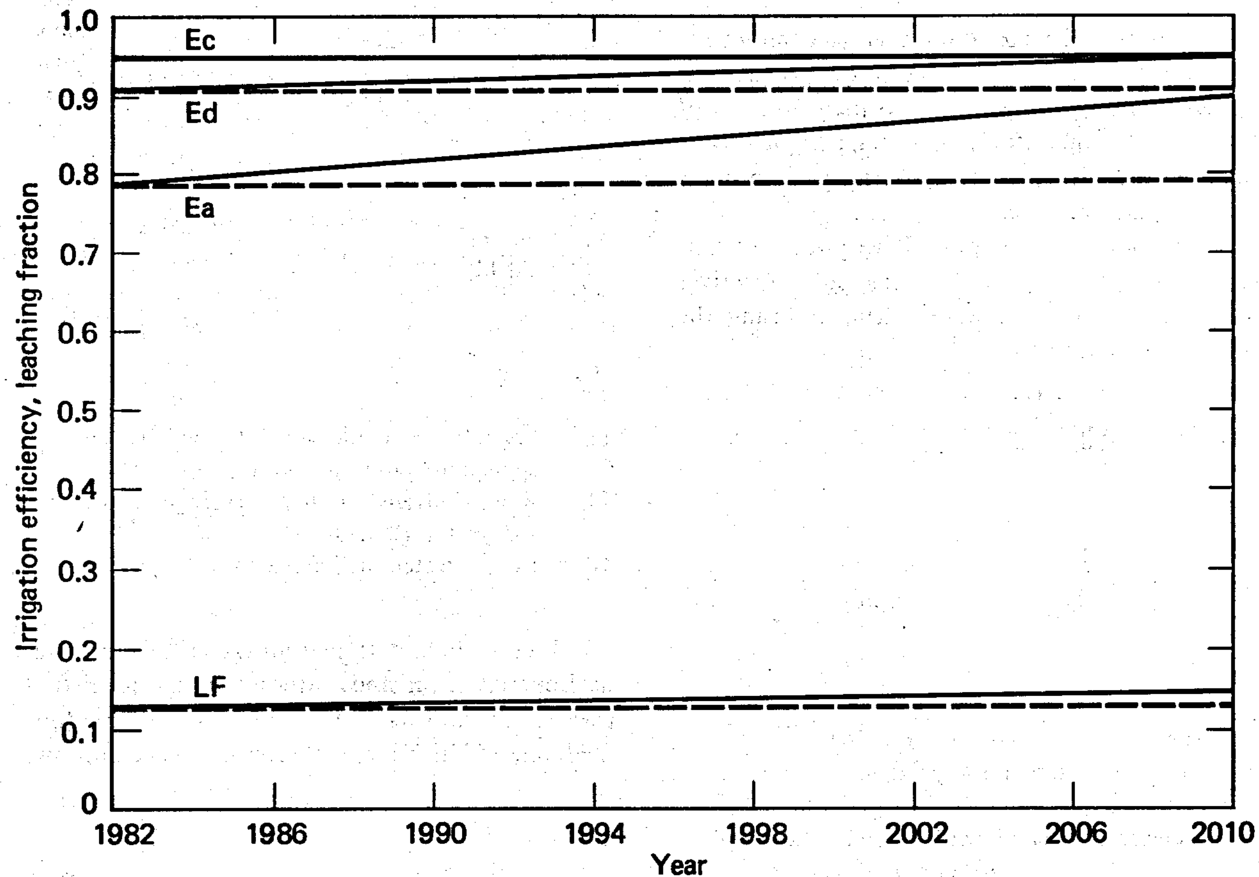


FIG. 13. Leaching fractions (LF) and efficiencies of conveyance (Ec), distribution (Ed), and application (Ea) representing existing water use practices (REF case) and improved water use efficiencies (CON case). The efficiency values selected to define the CON case will only occur if future economic and regulatory conditions change to promote the more efficient use of water by irrigators and if conservation efforts are maintained by the Imperial Irrigation District. Dashed lines refer to REF conditions; solid lines refer to the CON case.

salinity increase is an extrapolation of a projection made by the Colorado River Basin Salinity Control Forum[55] through the year 1990. This projection was based on an average undepleted annual flow of 14×10^6 af at Lee Ferry, a low rate of depletion from the river, and the implementation of four authorized salinity control projects. The comparatively smaller change in the LFs is meant to represent the situation in which improved irrigation practices are implemented and subsurface discharges reduced.[56]

CROP WATER USE

In order to examine the conditions of water balance associated with potential irrigation, conveyance, and distribution efficiencies, future amounts of water used by crops must be specified. For the purposes of this analysis, three levels that provide a range of values for future crop ETa were chosen. A low ETa limit of 1720×10^3 af/yr was chosen corresponding to the situation in which a low ET rate (4.0 ft/acre/yr) occurs with a low irrigated acreage (430×10^3 acres). An upper limit of 1974×10^3 af/yr was also selected. This limit is equivalent to the product of the largest net acreage since the year 1959 (459×10^3 acres) and ETa rate of 4.3 ft/acre/yr. As a base case, the years 1959 to 1976 average annual ETa of 1859×10^3 af was chosen corresponding to 440×10^3 irrigated acres and an ETa of just over 4.2 ft/acre/yr. The selection of these ETa levels assumes that water requirements for future crops will be similar to past ones. Such an assumption is realistic if there are no major substitutes of crops with high ETa, such as alfalfa, by less consumptive ones and if no new irrigated lands are introduced.

INFLOWS AND OUTFLOWS

Analysis of the inflow and outflow components of future water balances in the valley was accomplished by expressing those flows as a function of water use by crops; efficiencies of application, conveyance, and distribution; and effective precipitation and leaching fraction.

Diversions of Colorado River water at Imperial Dam (Im_t), the accounting point for river diversions to the IID, were calculated using the following equations:

$$Im_t = \frac{ETa + U_t - Pe_t}{Ed_t\, Ec_t\, Ea_t} ,$$

and

$$U_t = \frac{LF_t\, ETa}{1 - LF_t} ,$$

where

U_t = subsurface drainage for yr t (af),
LF_t = leaching fraction for yr t,
Pe_t = effective precipitation 0.22 ft/yr times net acreage associated with the ETa, (af), and
Ed_t, Ec_t, and Ea_t = distribution, conveyance, and application efficiencies for yr t.

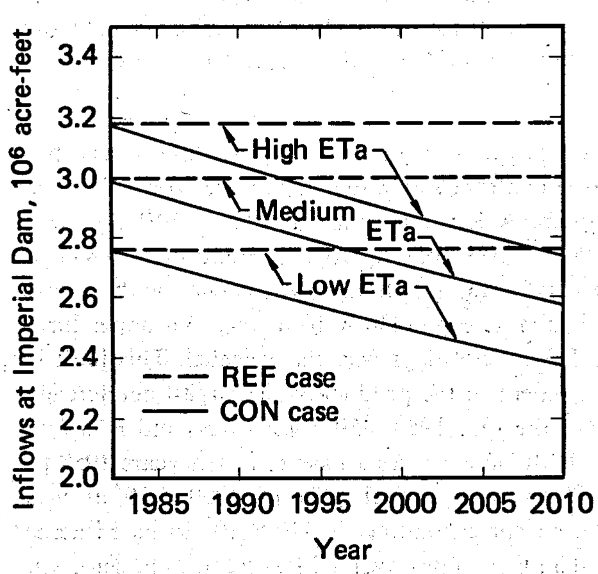


FIG. 14. Inflows of irrigation water at Imperial Dam. Inflows are predicted for low, medium, and high levels of actual crop evapotranspiration (ETa) under existing water use practices (REF case) and increased water conservation (CON case).

Outflows from the valley in yr t (O_t) were estimated by:

$$O_t = U_t + (1 - Ea_t)\, Ia_t + (1 - Ed_t)\, Id_t + G_t ,$$

where

$$Id_t = Ec_t Im_t ,$$
$$Ia_t = Ed_t Id_t ,$$

and

Ia_t = irrigation water delivered to farmers and applied to crops for yr t (af),
Id_t = water delivered to the East Highline Canal for yr t (af), and
G_t = ground water discharged in yr t (af).

Figures 14 and 15 present the inflows of water at Imperial Dam and outflows from the district (neglecting inflows from Mexico) for the low, medium, and high levels of crop ETa. The outflows

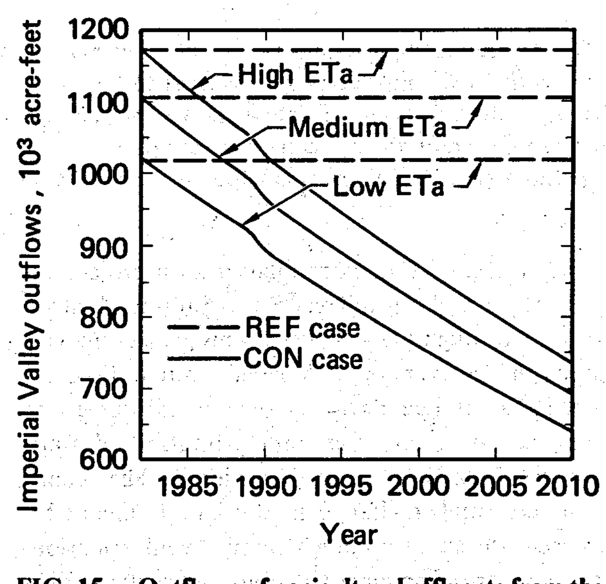


FIG. 15. Outflows of agricultural effluents from the Imperial Valley. Flows are predicted for low, medium, and high levels of actual crop evapotranspiration (ETa) under existing water use practices (REF case) and increased conservation (CON case). Discharges are reduced in the late 1980's to account for the lining of the Coachella Canal and the resulting decline in ground water discharges to surface waters in the valley.

shown in Fig. 15 were lowered by 16×10^3 af/yr after the year 1990 to reflect the use of the Coachella Canal and consequent decline in ground water flow to the valley. Under the REF case, outflows make up 37% of the inflows for the three levels of crop water use. In the CON case outflows decline to 26% of inflows in the year 2010.

SURFACE WATER SUPPLIES FOR GEOTHERMAL OPERATIONS

The physical availability of irrigation water as well as agricultural waste waters will be controlled by the amount of water used by crops (ETa) in the valley and the efficiencies with which water is conveyed, distributed, and applied to crops. With increased water conservation and lower crop water requirements, surplus irrigation water could become available for nonagricultural uses, because less water would be imported from the Colorado River. At the same time, though, waste waters resulting from irrigation would be reduced. The amounts of irrigation water potentially available for use by future geothermal developments were calculated by subtracting the predicted annual inflows for the REF and CON cases at Imperial Dam from 3000×10^3 af and multiplying the difference by 0.66. The amount of excess water was adjusted downward because it is difficult to forecast the amounts of water needed for agricultural operations and the amount of water available from the Colorado River. In the REF case, 162×10^3 af/yr of irrigation water was available after the irrigation requirements associated with the low level of crop ETa were met; 8.7×10^3 af/yr was available with the medium ETa; and none was available with the high level ETa. In the CON case, with its increasing water use efficiencies, 417×10^3 af/yr would become available in the year 2010 with the low ETa level, 284×10^3 af/yr with the medium ETa level, and 177×10^3 af/yr with the high ETa level. Surplus water would be unavailable with the high level of crop water use until the early 1990s when inflows of water to the valley would fall below 3000×10^3 af.

Agricultural waste waters, unlike irrigation water, must be collected from a river or drain and then transported to a power plant. The Salton Sea and Brawley KGRAs could use river water because of their proximity to the New and Alamo Rivers that together carry most of the valley's agricultural drainage to the Salton Sea. The Heber and East Mesa KGRAs have less access to waste waters because they are near the borders of the drainage system. The variability of discharges in rivers and drains, caused by daily and monthly changes in crop irrigation, further complicates the use of agricultural effluents for cooling. Without any surface storage at power plants, the annual safe or dependable yield of a particular waste water stream can be conservatively defined as the annual equivalent volume of the lowest expected rate of discharge. With one or two days of surface storage, a larger portion of waste water discharged to a drain or river can be used because cooling water requirements during transitory low flows would be met by water held in storage. Low flows that persist for more than a couple of days could result in reduced energy production—depending on the magnitude of cooling water withdrawals. In such low-flow conditions, temporary allocations of irrigation water could conceivably be made to geothermal facilities to prevent, or at least ameliorate, cutbacks in power generation. Flashed-steam facilities, using condensate for cooling and waste water for injection because of subsidence control requirements, could also conceivably adjust withdrawals so that the necessary fluid volume was injected over a certain period of time (e.g., 30 d).

The minimum monthly flow associated with an annual discharge of waste water was used as an estimate of the dependable yield from a drain or river for power plant cooling. The amount of waste water in the New and Alamo Rivers available for use in the Salton Sea KGRA under the REF and CON cases was calculated as follows: the predicted annual discharge from both rivers was multiplied by 0.047 (i.e., the smallest ratio of the monthly discharges from the two rivers to their total annual discharge for the years 1965 to 1976) to get the minimum monthly discharge; and then, the minimum monthly discharge was multiplied by 12 to get the annual equivalent volume. The annual yield for the Brawley KGRA was assumed to be 80% of the yield for the Salton Sea KGRA because 80% of the valley's drainage area is to the south of the northern border of the Brawley KGRA. Figure 16 depicts the yields available to the Salton Sea and Brawley KGRAs for the two water use cases.

Yields for the Heber resource area were calculated differently because the primary drainage area of interest was ungauged. This resource area

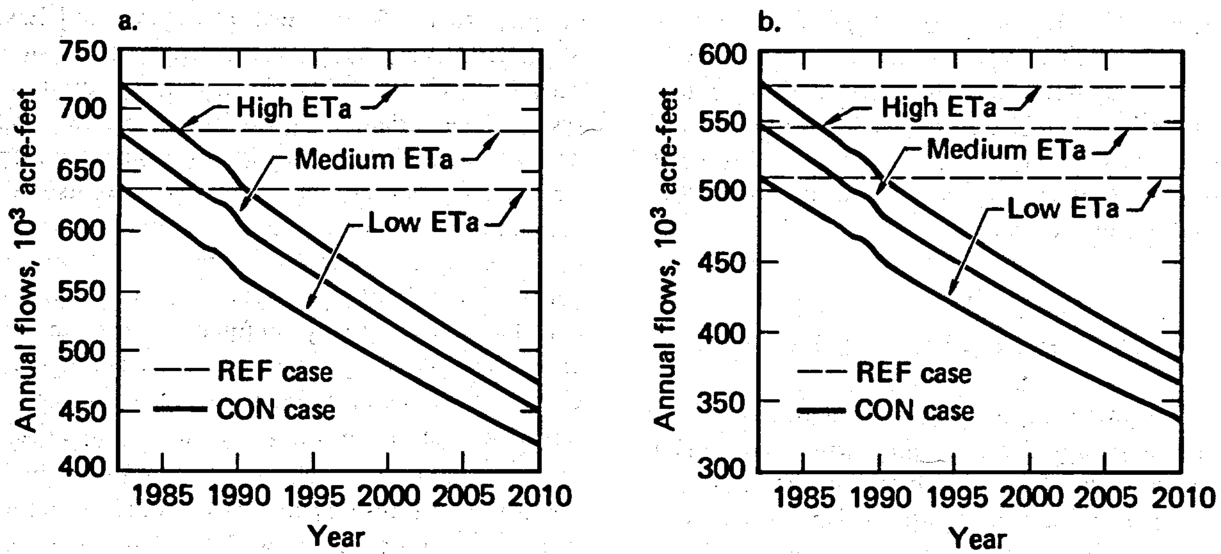


FIG. 16. Agricultural drainage flows available to the Salton Sea and Brawley KGRAs. Drainage discharges are predicted for low, medium, and high levels of crop evapotranspiration (ETa) under both existing water use practices (REF case) and increased conservation (CON case). a. Salton Sea KGRA. Discharges represent the annual equivalent volume of the smallest monthly discharge likely to occur each year. Flows were adjusted in the late 1980's to reflect reduced ground water discharges after the Coachella Canal is lined. b. Brawley KGRA. Annual drainage is assumed to be 80% of the flows for the Salton Sea KGRA since 80% of the Imperial Valley's agricultural drainage area is to the south of the northern border of the Brawley KGRA.

has essentially two sources of waste water: inflows from Mexico in the New River and waste waters flowing in the Central Drain, which receives agricultural effluents from irrigated lands in the KGRA. Figure 17 shows the boundary of the Heber geothermal resource area, surface drains in the area, and a potential diversion point for withdrawal of waste water. The average runoff per acre of the entire area drained by the Central Drain for the years 1974 and 1976 was 1.26 ft/acre. During the same years, runoff from all agricultural lands in the valley averaged about 1.74 ft/acre.

Waste water flows available from drainage within the KGRA, shown by the shaded area in Fig. 17, were computed in several steps. First, the average annual discharges from agricultural lands in the valley, associated with the REF or CON cases in a given year, were multiplied by 0.72 (i.e., the average ratio of annual Central Drain runoff/acre to annual valley runoff/acre for the years 1974 to 1976) to obtain the rate of runoff for the Central Drainage area. Next, annual discharge from the drainage area in the KGRA was calculated by multiplying the adjusted rates of runoff by the acreage of the drainage area (i.e., 24×10^3 acres). The minimum amount of monthly discharge in af was computed assuming that the minimum monthly discharge/annual discharge relationships for the valley as a whole are applicable to the Heber drainage area. The annual discharge was multiplied by 0.47 to get the monthly discharge that was then multiplied by 12 to obtain the annual equivalent volume.

Inflows from Mexico in the New River are available as an additional source of water for geothermal power production in the Heber resource area. The smallest monthly flow since the year 1959 was 5.1×10^3 af, or an annual equivalent flow of 61.2×10^3 af. Total flows available for geothermal development from both the New River and the Central Drain under the REF and CON cases are shown in Fig. 18a.

Potential drainage areas and diversion points for the East Mesa KGRA are outlined in Fig. 19. Estimates of the yield for those drainage areas were made using the same procedures applied to the Central Drain in the Heber KGRA. The rates of runoff were assumed to be the same as those in the lands discharging agricultural effluents to the Central Drain (i.e., they are 70% of the valley-wide discharge rates associated with the REF and CON water use cases). Annual yields for the East Mesa drainage areas are presented in Fig. 18b. To improve the estimates for safe-yield in the drainage areas near the Heber and East Mesa KGRAs, drainage discharges will need to be monitored.

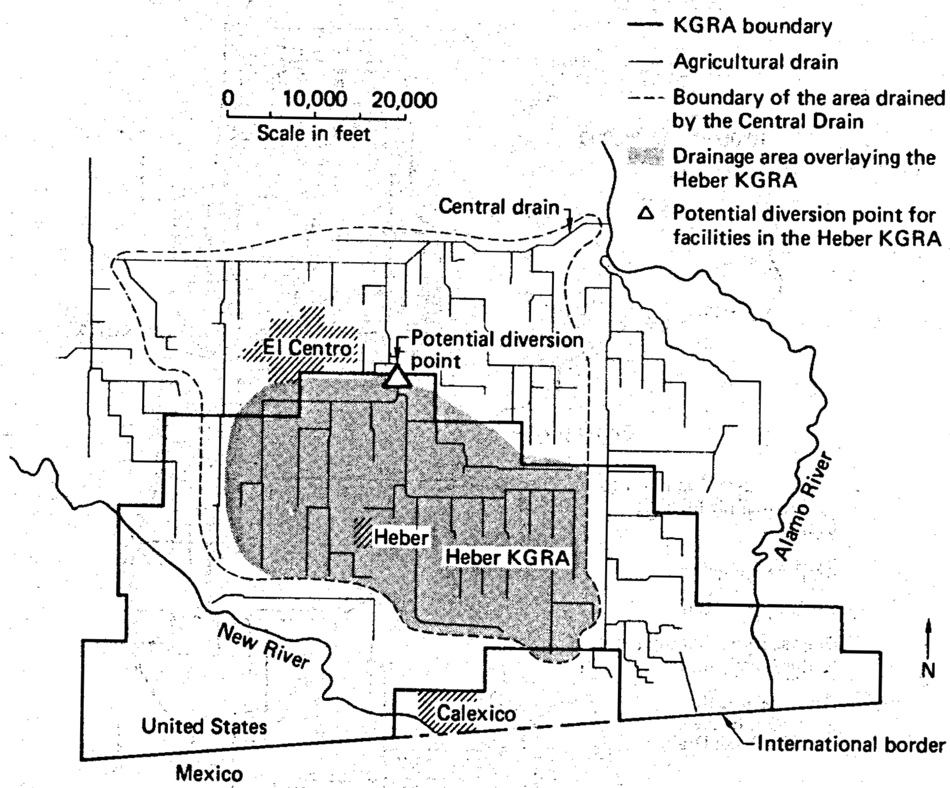


FIG. 17. Location of the Heber KGRA with respect to rivers and agricultural drains. Waste water diversions for geothermal facilities in the KGRA could be made at points along the New River and at the outlet of the shaded drainage area that receives drainage water from irrigated lands in the central portion of the resource area.

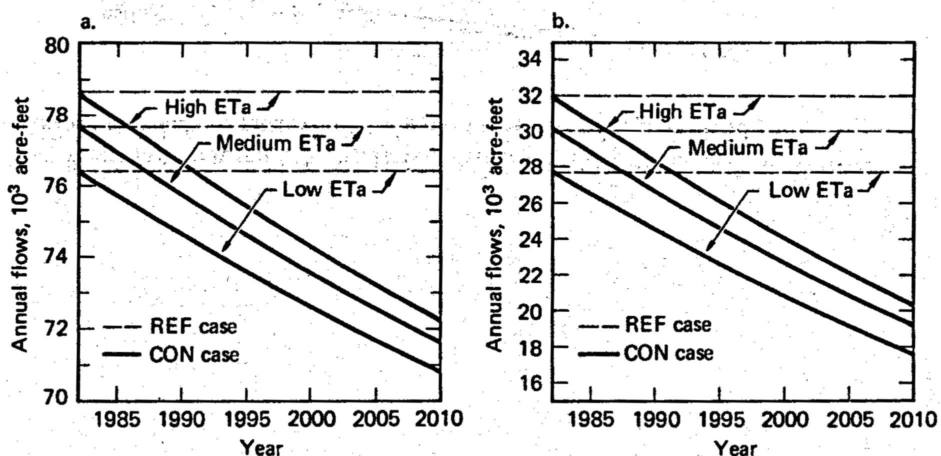


FIG. 18. Agricultural waste waters available to the Heber and East Mesa KGRAs. Annual discharges from irrigated lands are predicted for low, medium, and high levels of crop evapotranspiration (ETa) under existing water use practices (REF case) and increased conservation (CON case).a. Heber KGRA. The waste water flows include inflows from Mexico in the New River (61.2 × 10^3 af/yr) plus the annual equivalent volume of the minimum monthly discharge expected from irrigated lands within the KGRA (see Fig. 17).b. East Mesa KGRA. Waste water flows are from two ungauged drainage areas near the KGRA (see Fig. 19).

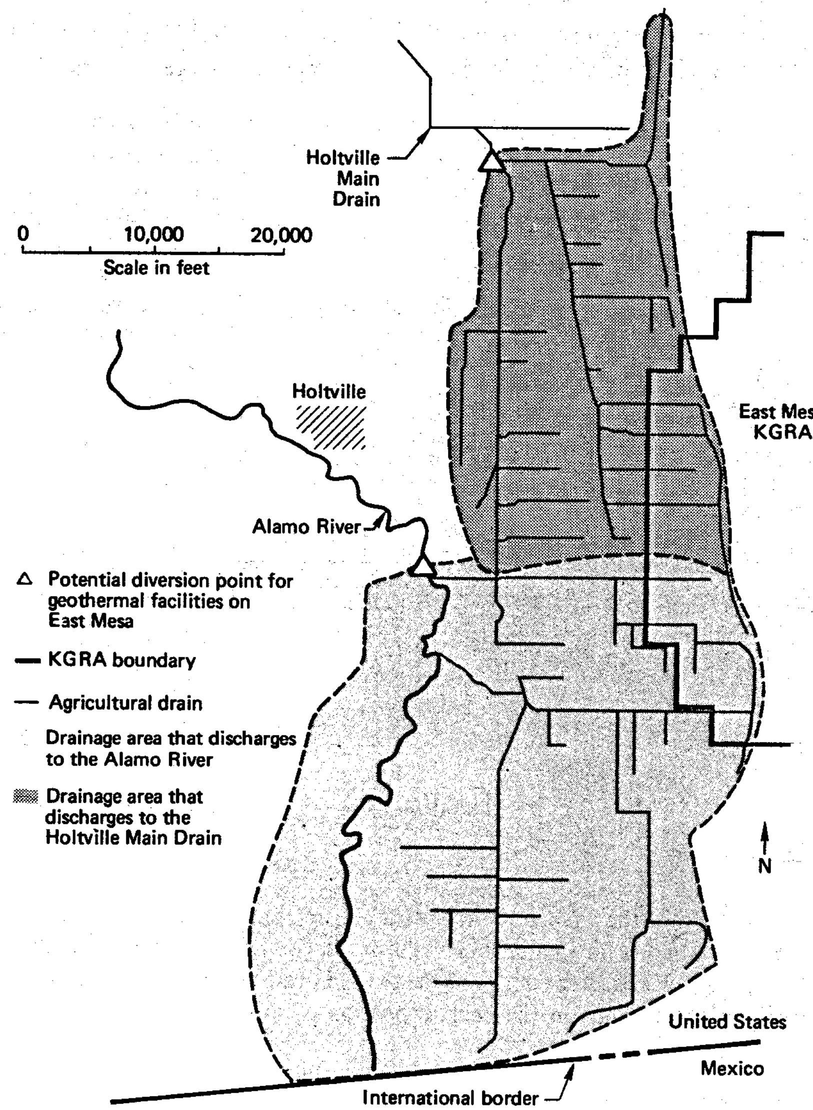


FIG. 19. Location of the East Mesa KGRA with respect to drainage areas that could provide agricultural waste waters for geothermal operations.

WATER SUPPLY CONSTRAINTS

The amount of cooling water available for geothermal power plants in the Imperial Valley will be controlled through the use of future water policies that emerge at the local, state, and federal levels of government. If these policies prove overly restrictive, then geothermal energy production will be constrained. The extent and type of future constraints on water supplies are examined in this section using six combinations of policies affecting the availability of irrigation water, steam condensate, and agricultural waste waters; three scenarios of geothermal energy growth in the valley; and potential surface water supply conditions.

GEOTHERMAL ENERGY SCENARIOS

Three scenarios of geothermal energy production are used to analyze the adequacy of cooling water supplies. They consist of low, medium, and high forecasts of future geothermal growth, as developed by Ermak,[57] and define a series of plausible geothermal energy futures for the valley. The low forecast seen in Fig. 20 begins in the year 1986

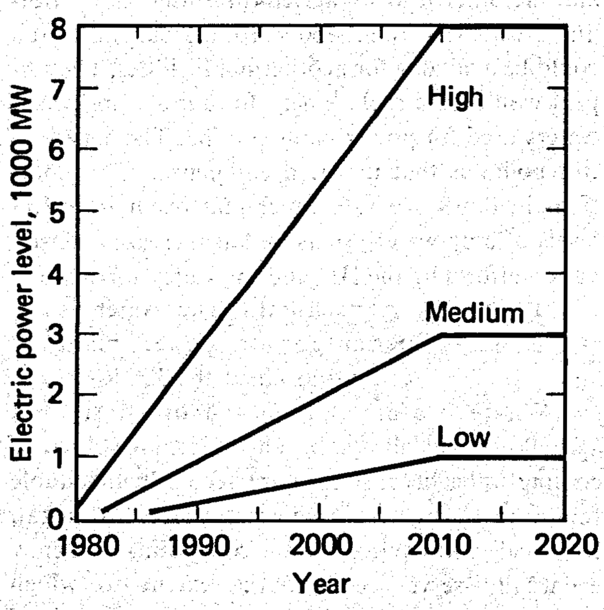


FIG. 20. Projected growth rates of geothermal power generation in the Imperial Valley.[17] Low energy growth takes place at 40 MW/yr, medium growth at 100 MW/yr, and high growth at 250 MW/yr. Maximum levels of energy production are 1000 MW for low growth, 3000 MW for medium growth, and 8000 MW for high growth.

with the production of 100 MW and grows at a linear rate of nearly 40 MW per yr, and reaches 1000 MW in the year 2010. It represents restricted growth brought about by potential technical, economic, resource, and political problems. The contribution of each of the four KGRAs to the total amount of energy produced in the valley is shown in Table 5. The medium forecast has a growth rate of 100 MW per yr, going from 100 MW in the year 1982 to 3000 MW in the year 2010. This is similar to the historic growth at The Geysers. In addition, the amount of energy produced from the KGRAs is within existing resource estimates.[57] The high forecast attains 8000 MW of production in the year 2010 after increasing at a rate of 250 MW per yr from an initial 100 MW in the year 1980. Accelerated growth, as in the high forecast, could only occur if economic, technical, and political circumstances were highly favorable and if the geothermal resources are much greater than current estimates. Implicit in the scenarios are the following assumptions[17]: the economic feasibility of geothermal conversion facilities is proven within the next decade, technologies are developed that can overcome the scaling and corrosion problems associated with the Salton Sea KGRA, and the demand for geothermal energy exceeds the capacity to produce it.

WATER POLICIES

Five policies affecting either the use of steam condensate, irrigation water, or agricultural waste water were chosen to represent possible geothermal water policies. Policies affecting Salton Sea water and ground water were not included because their use is more likely to be controlled by nonpolicy factors such as technical feasibility, economics, or availability of resources. Two of the policies selected involve steam condensate, two involve the use of irrigation water, and one involves agricultural waste water. Six combinations of the policies were then identified and the consequences of adopting different sets of policies were studied.

Policy I. Power plants on East Mesa are the only facilities allowed to use condensate for cooling without the need to inject an equivalent volume of an external water

TABLE 5. Geothermal growth scenario for the Imperial Valley.[17]

Power level (MW)	Year power level attained			Power distribution (MW)			
	High growth	Medium growth	Low growth	Salton Sea	Brawley	Heber	East Mesa
400	1982	1985	1994	100	100	100	100
1000	1984	1991	2010	300	300	300	100
3000	1991	2010	Never	1400	600	700	300
8000	2010	Never	Never	4000	1400	1800	800

supply for subsidence control purposes.

This policy is based on the assumption that East Mesa lands are less susceptible to impacts caused by subsidence than are the agricultural lands within the central portion of the valley. Thus, condensate could be used without injecting an equivalent volume of some other water to control subsidence. The importance of steam condensate as a source of cooling water will also be a function of the technology mix of flashed-steam conversion facilities and binary-fluid facilities incorporating down-hole pumps that do not allow geothermal fluids to flash to steam. For assessment purposes, it is assumed that 50% of the electrical output from the East Mesa KGRA is produced by flashed-steam plants and the other 50% by binary plants.

Policy II. Partial injection of geothermal fluids is permitted for all geothermal facilities in the valley's four KGRAs.

It is conceivable that a policy of partial injection (e.g., 80% of the withdrawn fluids are injected) might be adopted to allow flashed-steam plants in the Heber, Brawley, and Salton Sea KGRAs to consume condensate for cooling if future subsidence, related to the production of geothermal fluids in the irrigated part of the valley, proves to be minor and does not significantly disrupt agricultural operations. It is assumed here that 50% of the projected electrical output from the East Mesa, Heber, and Brawley KGRAs will be produced by flashed-steam facilities. However for the Salton Sea KGRA, it is assumed that 75% of the electricity generated will be from flashed-steam plants and 25% by binary technologies relying on down-hole pumps. The reason for the lower percentage of binary technologies is the possibility that corrosion and scaling problems will hinder the use of down-hole pumps with the brines of the Salton Sea resource area.

Policy III. Irrigation water is limited to the first 75 MW of energy produced in each KGRA.

Imperial County's geothermal water policy is essentially the same as Policy III; however, with Policy III irrigation water can be used indefinitely.

Policy IV. Irrigation water is allocated to geothermal facilities only when surpluses exist.

In years when the diversions of water from the Colorado River to the IID fall below 3000×10^3 af and the other priority agricultural users in California divert less than 850×10^3 af, surplus water could be available for geothermal facilities. The surplus would be a replacement for agricultural waste waters used for power plant cooling. The benefit of this policy is that it would compensate for reductions in flows of waste water that result from low levels of crop water use as well as increased conservation efforts by the IID and the valley's irrigators.

Policy V. Agricultural waste water is permitted for power plant cooling in all of the KGRAs.

Waste water effluents from irrigated agriculture will always be an important source of cooling water because they are generally unsuitable for other uses. Nevertheless, there are legal, technical, and environmental constraints that may eventually serve to limit the extent to which agricultural waste waters are used for cooling. Policy V, though, does not include any limitations on waste water use by geothermal facilities.

The water policies were combined in six ways to create a range of policy combinations (A through F in Table 6) representing some of the ways in which they might be jointly implemented. Each of the policy sets differs according to the amounts of

TABLE 6. Water policy combinations representing future regulatory controls.

Water policies	Policy combinations A	B	C	D	E	F
I.[a] Limited condensate	X	X			X	
II.[b] Increased condensate			X	X		X
III.[c] Fixed allocation of irrigation water	X		X			
IV.[d] Variable allocations of irrigation water		X		X		
V.[e] Unrestricted agricultural waste water use	X	X	X	X	X	X

[a]Policy I allows the partial injection of geothermal fluids in the East Mesa KGRA so that steam condensate can be used for cooling. It is assumed that 50% of the energy is produced by flashed-steam power plants with the remaining 50% generated by binary plants using down hole pumps that do *not* allow *geothermal fluids to flash to steam.*

[b]Policy II permits the use of condensate in all of the valley's resource use areas for power plant cooling. Half of the energy generated in the East Mesa, Heber, and Brawley KGRAs is assumed to be from flashed-steam facilities, and 75% in the Salton Sea KGRA.

[c]Policy III limits the use of irrigation water to the first 75 MW of energy generated in each KGRA.

[d]Policy IV allocates surplus irrigation water to geothermal facilities for cooling.

[e]Policy V supports the unrestricted use of agricultural waste waters for cooling, regardless of possible impacts.

cooling water it makes available for geothermal operations and the impacts it causes. For example, using combination E would produce a greater reliance on the use of agricultural waste waters by geothermal facilities than would using combination D containing policies that promote the expanded use of condensate and irrigation water for cooling. As a result, the elevation of the Salton Sea would decline more rapidly under combination E because less water would be entering the Sea to replace evaporative losses.

WATER SUPPLY ALLOCATIONS

An allocation scheme was defined to simulate the use of water supplies made available by the various water policy combinations. It determined the sequence in which KGRAs receive cooling water and the order in which water supplies are used. Under the allocational procedure, the East Mesa KGRA receives annual water supplies first, followed by the Heber, Brawley, and Salton Sea resource areas. This sequence was chosen because it represents one way in which development could occur, i. e., from resource areas having the least saline geothermal fluids to areas having the highest. To satisfy the cooling water requirements associated with a projected level of energy production in the KGRA, water supplies are used in this order: steam condensate, then irrigation water, and finally, waste water. Surplus irrigation water is consumed before agricultural waste waters, even though it is considered a supplemental supply for cooling systems designed to use waste waters, because the treatment and disposal costs are lower for irrigation water. If condensate and irrigation water do not meet the cooling water requirements of power plants in a KGRA, then agricultural waste waters are used to satisfy the remaining demand. Water supply deficits arise when the safe yields of waste water flows are smaller than the requirements for cooling water.

As an illustration of how the allocation scheme works, water available from policy combination D (see Table 6) would be distributed in this fashion: (1) flashed-steam power plants accounting for 50% of the projected energy production in the East Mesa, Heber, and Brawley KGRAs and 75% of the production in the Salton Sea area would use their own steam condensate exclusively for cooling; (2) surplus irrigation water available from Policy IV would be used to satisfy the cooling water requirements of other plants in the East Mesa, Heber, Brawley, and Salton Sea KGRAs; and (3) waste waters would then be used to meet remaining requirements beginning with the East Mesa KGRA.

As irrigation and waste water supplies are consumed in the four KGRAs, water balances will be altered in the valley. The important water balance components involved with the use of waste waters and irrigation water for cooling are shown in Fig. 21. Drainage flows available to the Brawley and Salton Sea KGRAs will be affected by changes in waste flows caused by discharges of blowdown, losses from canals, and use of waste water in the

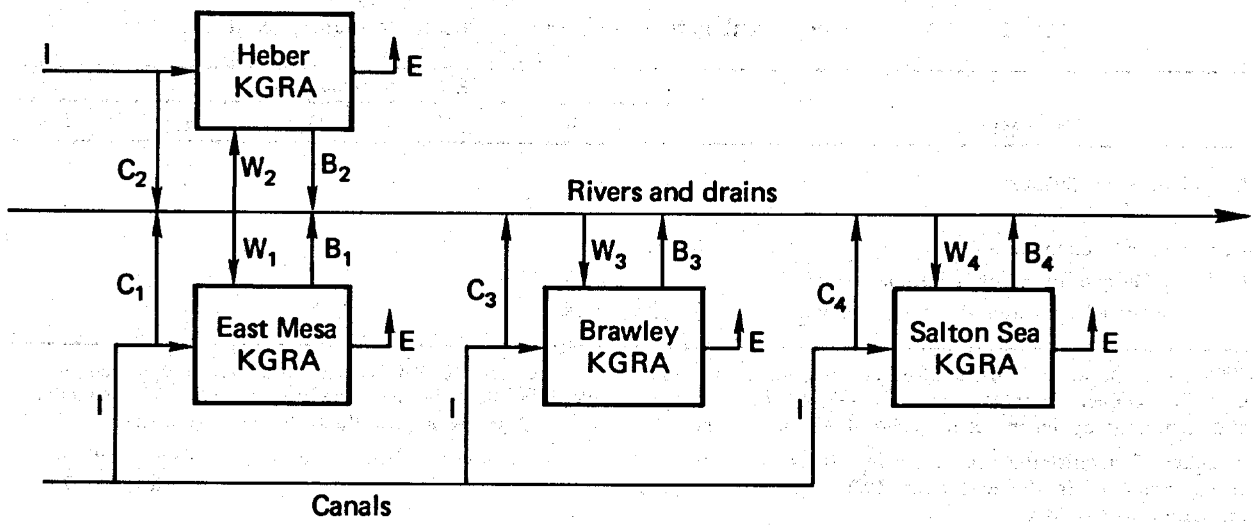


FIG. 21. Water balance components associated with cooling water used in the Heber, East Mesa, Brawley, and Salton Sea KGRAs, where W_i = waste water withdrawals, B_i = blowdown discharges, I = irrigation water, C_i = canal losses, E = cooling tower evaporation, and i = KGRA #1,2,3 or 4.

Heber and East Mesa resource areas. Waste water flows then must be adjusted with every allocation of irrigation water and waste water. The yearly waste water flows available for either the Brawley or Salton Sea KGRA can be expressed as:

$$F_{3,4} = Y_{3,4} + \sum_{i=1}^{i-1} (B_i + C_i - W_i) ,$$

where

$F_{3,4}$ = annual waste water flows available for geothermal operations in either Brawley or Salton Sea KGRA (af),
$Y_{3,4}$ = yield of waste water flows for either the Brawley or Salton Sea KGRA without geothermal development (af),
B_i = blowdown discharges from the i^{th} KGRA (af),
C_i = canal losses associated with deliveries to the i^{th} KGRA (af),
W_i = waste water consumption of the i^{th} KGRA (af), and
i = 1 (East Mesa KGRA), 2 (Heber KGRA), 3 (Brawley KGRA), or 4 (Salton Sea KGRA).

Annual surpluses and deficits of waste water for a KGRA were computed by subtracting the amount of waste water needed to support the projected geothermal energy production from the quantity of waste water available to the KGRA. For calculating water balances, waste water use was set equal to the annual safe-yield when withdrawals of water exceeded safe-yield. Energy production was therefore constrained to whatever the safe-yield could support. The water supply analyses were started at the 400-MW level of production. As shown in Table 5, that level will be attained in the year 1994 under low growth, in the year 1985 under medium growth, and in the year 1982 under high growth.

WATER SUPPLY DEFICITS

None of the water policy combinations produced water supply deficits in any of the KGRAs when the low and medium energy growth scenarios were used. For the high growth scenario, only the Heber and East Mesa KGRAs had deficits. In Table 7 the extent of contraints to high energy growth in the Heber KGRA caused by using the different water policy combinations is shown. Consistent deficits result from policy combinations A and E because the use of condensate and irrigation water for cooling is restricted. The most constraining policy set is E. Condensate use is limited to 50% of the projected energy production at the East Mesa resource area. The remaining energy production at that KGRA as well as the other KGRAs relies on agricultural waste waters for cooling or for injection. Reliance on water flows in drains and in the

TABLE 7. Projected water supply deficits for the Heber KGRA with low, medium, and high levels of crop water use and high energy growth in the years 1995 and 2010.

Crop water use	Water policy combination	Water use efficiencies	Waste water deficit (10^3 acre-feet)		Energy produced (MW)		Energy deficit (MW)	
			1995	2010	1995	2010	1995	2010
Low	A	REF	4	85	890	890	42	910
		CON	7	91	860	831	72	969
	B	REF	none	none	932	1800	none	none
		CON	none	none	932	1800	none	none
	C	REF	none	<1	932	1789	none	11
		CON	none	6	932	1731	none	69
	D	REF	none	none	932	1800	none	none
		CON	none	none	932	1800	none	none
	E	REF	11	92	815	815	117	985
		CON	14	98	785	756	147	1044
	F	REF	none	8	932	1714	none	86
		CON	none	14	932	1655	none	145
Medium	A	REF	3	84	903	903	29	897
		CON	6	90	871	839	61	972
	B	REF	10	91	828	828	104	972
		CON	none	none	932	1800	none	none
	C	REF	none	none	932	1800	none	none
		CON	none	6	932	1739	none	61
	D	REF	none	7	932	1728	none	72
		CON	none	none	932	1800	none	none
	E	REF	10	91	828	828	104	972
		CON	13	97	796	764	136	1036
	F	REF	none	7	932	1728	none	72
		CON	none	13	932	1664	none	136
High	A	REF	2	83	914	914	18	886
		CON	5	89	880	846	52	954
	B	REF	9	90	839	839	93	961
		CON	2	none	912	1800	20	none
	C	REF	none	none	932	1800	none	none
		CON	none	5	932	1746	none	54
	D	REF	none	6	932	1739	none	61
		CON	none	none	932	1800	none	none
	E	REF	9	90	839	839	93	961
		CON	12	96	805	771	127	1029
	F	REF	none	6	932	1739	none	61
		CON	none	12	932	1671	none	129

New River because of policy set E would limit energy production to approximately 800 MW of production in the Heber KGRA. But if Mexican inflows in the New River became unreliable for some reason, energy production would be severely curtailed because water in the New River represents about 80% of the total waste water supply available to the KGRA. However, if the actual energy potential of the Heber KGRA is lower than 800 MW, then geothermal development will not be constrained.

Policy sets C and F allow the use of condensate for cooling with flash-steam facilities without the need for an external supply of reservoir-injection fluid to control subsidence. This results in limited deficiencies of cooling water. The deficits could be eliminated if flashed-steam technologies made up a larger portion of the assumed technology mix. Variable allocations of surplus irrigation water, included in policy combinations B and D, greatly reduced water supply deficits except when all of the imported irrigation water was needed to irrigate crops for the high water use case.

Potential deficits of water and energy for the East Mesa KGRA are shown in Table 8. No major water supply problems are evident except in the CON case where increased water conservation results in reduced flows of waste water from the two

TABLE 8. Projected water supply deficits for the East Mesa KGRA with low, medium, and high levels of crop water use and high energy growth in the years 1995 and 2010.

Crop water use	Water policy combination	Water use efficiencies	Waste water deficit (10^3 acre-feet) 1995	Waste water deficit (10^3 acre-feet) 2010	Energy produced (MW) 1995	Energy produced (MW) 2010	Energy deficit (MW) 1995	Energy deficit (MW) 2010
Low	A or C	REF	none	3	405	772	none	28
		CON	none	13	405	660	none	140
	B or D	REF	none	none	405	800	none	none
		CON	none	none	405	800	none	none
	E or F	REF	none	10	405	697	none	103
		CON	none	20	405	588	none	212
Medium	A or C	REF	none	none	405	800	none	none
		CON	none	11	405	679	none	121
	B or D	REF	none	none	405	800	none	none
		CON	none	none	405	800	none	none
	E or F	REF	none	7	405	722	none	78
		CON	none	18	405	604	none	196
High	A or C	REF	none	none	405	800	none	none
		CON	none	10	405	692	none	108
	B or D	REF	none	5	405	742	none	58
		CON	none	none	405	800	none	none
	E or F	REF	none	5	405	742	none	58
		CON	none	17	405	617	none	183

drainage areas near the KGRA (see Fig. 18b) late in the high energy scenario. This creates water supply deficits with policy combinations A, C, E, or F. The largest deficit results in the production of about 600 MW, or over 200 MW less than the amount forecast. Of the 600 MW generated, steam condensate supported 400 MW, or half of the projected output in the year 2010, and agricultural waste waters only supported 200 MW. Waste waters could support another 100 MW with REF water use efficiencies and low corp ETa. However, if the diversion of waste water flows is uneconomical, then steam condensate, irrigation water, and possibly ground water would have to support geothermal development.

Without any cooling water constraints to energy production under the high growth scenario and using all the KGRAs, 8000 MW would ultimately be produced. With water policy combination E and average crop water use, though, maximum growth would be limited to about 7000 MW for the REF water case and 6800 MW for the CON case. Power production would be slightly lower in both water cases for low crop ETa because there would be less surface runoff from the irrigation of crops. Maximum production could be reduced further if the use of steam condensate at East Mesa was restricted or if water inflows from Mexico in the New River proved to be an unreliable source of cooling water for the Heber resource area.

SALTON SEA IMPACTS

The most important water-related impacts of geothermal development involve changes in the Salton Sea's elevation and salinity because of decreased inflows of agricultural waste water. The sea was formed in the year 1905 when flood waters from the Colorado River destroyed the headgate of the Alamo Canal. The canal was then carrying water to the Imperial Valley via a route through Mexico, and the loss of the headgate allowed the entire flow of the river to enter the valley.[58] The inflowing waters began inundating the Salton Sink, and the newly created sea quickly rose in elevation from 270 to 195 ft below sea level in the two years before the river was finally diverted back into its regular channel to the Gulf of California. In the following years, evaporation caused the elevation to decline to over 250 ft below sea level; but since the year 1925, inflows from agricultural lands have generally exceeded evaporation, and the sea's level has continued to rise. Today the Salton Sea is California's largest inland body of water. As the amount of salt in the sea accumulated over time, its salinity also rose, except when evaporative losses were lower than inflows. In Fig. 22 the trends in the sea's elevation and salinity are depicted.

Future changes in the sea will largely depend on the magnitude of water and salt inflows. These inflows will be affected by practices of agricultural water use, patterns of precipitation, and changes in salinity in the Colorado River. Diversions of waste water for geothermal operations will also alter water and salt inflows. Increased efficiency in the use of water in agriculture coupled with the use of geothermal waste water by geothermal facilities would decrease the sea's elevation and increase its salinity. The higher salinities would negatively impact the sea's aquatic ecosystem, which includes an important sport fishery. Lower surface elevations, on the other hand, would reduce destruction of shoreline property.

SEA ELEVATION

The response of the sea's surface elevation to reduced inflows of agricultural effluents can be predicted. This is done by estimating changes in the sea's volume resulting from inflows, precipitation,

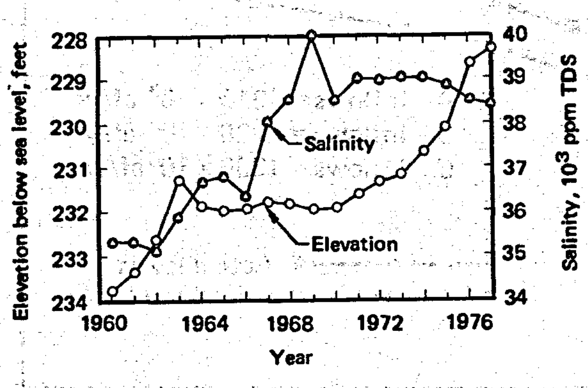


FIG. 22. Historic changes in the Salton Sea's salinity and elevation. The Sea's elevation has been increasing because inflows have exceeded evaporative losses. The large increase in salinity over the years 1966 to 1969 was a result of higher than normal accumulations of salt.

and evaporation and then relating these volumetric changes to sea elevations. The following recursive equation was used to compute yearly volumetric changes:

$$V_{t+1} = V_t \pm \Delta V ,$$

where

$$\Delta V = I_{t+1} + P_{t+1} - EVP_{t+1} ,$$

and

V_t, V_{t+1} = volumes of the sea at the end of yrs t and t + 1 (af),
ΔV = change in the sea's volume between t and t + 1 (af),
I_{t+1} = inflows to the sea from all sources during the yr t + 1 (af),
P_{t+1} = rainfall on the sea during the yr t + 1 (af),
EVP_{t+1} = evaporation from the sea during the yr t + 1 (af).

Using equations developed by Rodriquez,[59] the sea's surface elevation in feet below sea level at the end of year t + 1 (H_{t+1}) was expressed as a function of the surface acreage of the sea (A_{t+1}), its volume (V_{t+1}), and an empirical constant, M, as seen in the following equation:

$$H_{t+1} = \frac{1}{M} \ln \left(\frac{A_{t+1}}{221{,}800} \right) - 235 ,$$

where

$$A_{t+1} = M(V_{t+1} - 5{,}360{,}100) + 221{,}800 ,$$

and

$M = 0.012242$ when $V_{t+1} > 5{,}360{,}100$ (af), or

$M = 0.023816$ when $V_{t+1} < 5{,}360{,}100$ (af).

The recursive formulation was tested for simulating long-term trends in the Salton Sea with data for the years 1957 to 1971. Inflows of agricultural waste waters from the Coachella and Imperial Valleys during that 15 yr period averaged 1236×10^3 af/yr. Ground water inflows were estimated at 50×10^3 af/yr.[60] The quantity of ungauged nonagricultural surface discharges to the sea were unavailable, and so were represented by discharge rates of 30×10^3 af/yr, 40×10^3 af/yr, and

50×10^3 af/yr. The corresponding rates of total inflow were 1316×10^3 af/yr, 1326×10^3 af/yr, and 1336×10^3 af/yr. For the amount of rainfall during that particular time period, an average depth of 0.15 ft/yr was used; and for evaporation, a value of 5.80 ft/yr.[38] Year-end elevations for the years 1957 to 1971 were calculated for the three rates of inflow, and the resulting curves are depicted in Fig. 23. The average elevation for the 15 yr period was 232.6 ft below sea level, while the averages of the predicted elevations, starting with the smallest inflow rate, were 233.1, 232.8, and 232.5 ft below sea level.

Changes in the sea's surface elevation resulting from future agricultural water use, but without geothermal development, are shown in Figs. 24a and 24b. In Fig. 24a surface elevation changes under the REF case for three levels of ETa are shown; and in Fig. 24b changes under the CON case are seen. Inflows to the sea are composed of discharges from the Imperial Valley, ungauged and non-agricultural surface-inflows, ground water discharges, and agricultural-return flows from the Coachella Valley. Outflows from the Imperial Valley are made up of agricultural discharges (i.e., irrigation-surface runoff, subsurface drainage, and canal losses), ground water discharges, and flows from Mexico in the New River. Ground water discharges from the Imperial Valley were set to 26×10^3 af/yr until the year 1990, when they were lowered to 10×10^3 af/yr to account for the decrease in ground water movement to the central portion of the valley because the Coachella Canal will be lined. Mexican inflows were 113×10^3 af/yr based on the average annual flow from the years 1959 through 1976. Values assigned to the other sources of inflow to the sea were: 141×10^3 af/yr for discharges from the Coachella Valley, 50×10^3 af/yr for ground waters discharging

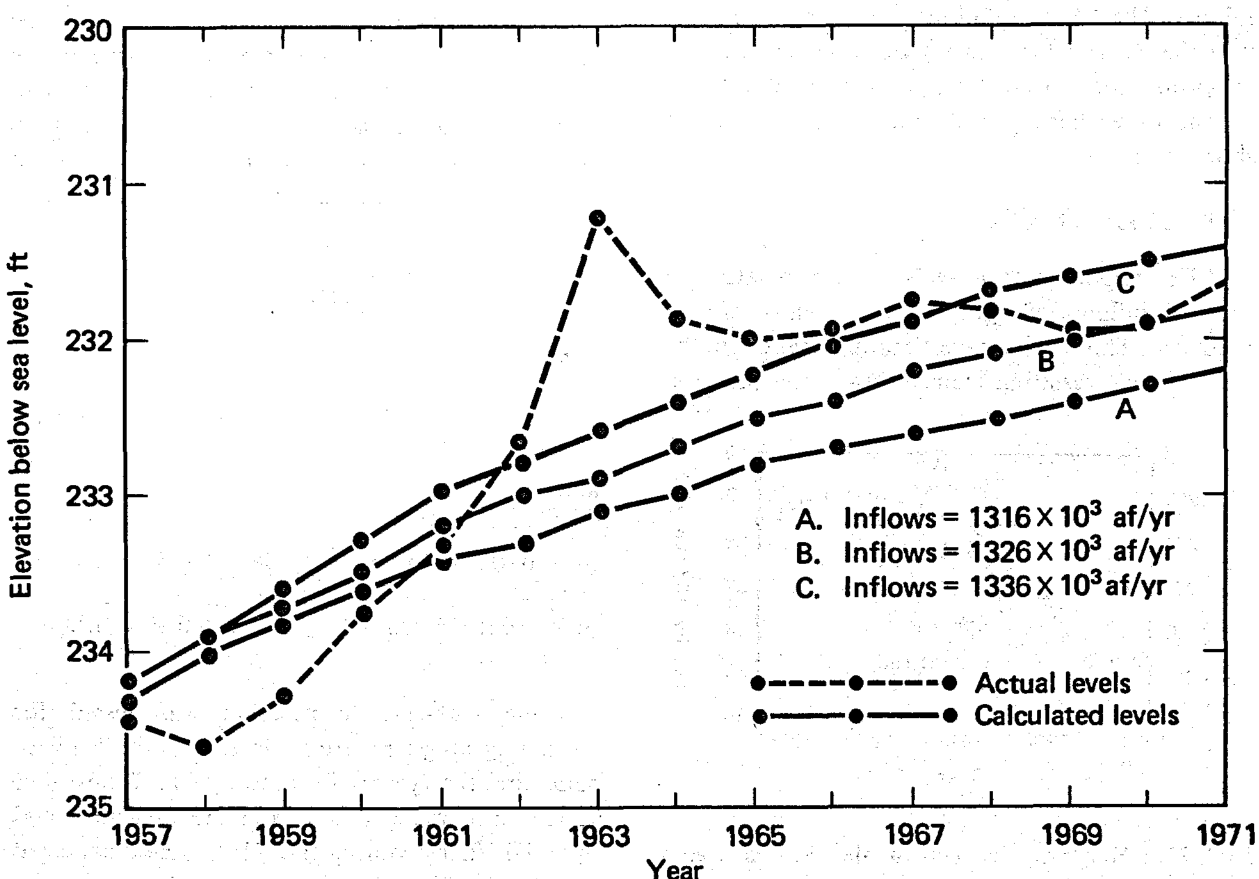


FIG. 23. Actual year-end elevations in the Salton Sea and elevations computed by using a recursive water balance model. Elevations were calculated using 15-year averages for evaporation and precipitation. In addition, three inflow regimes were used to represent alternative estimates of average inflows to the sea.

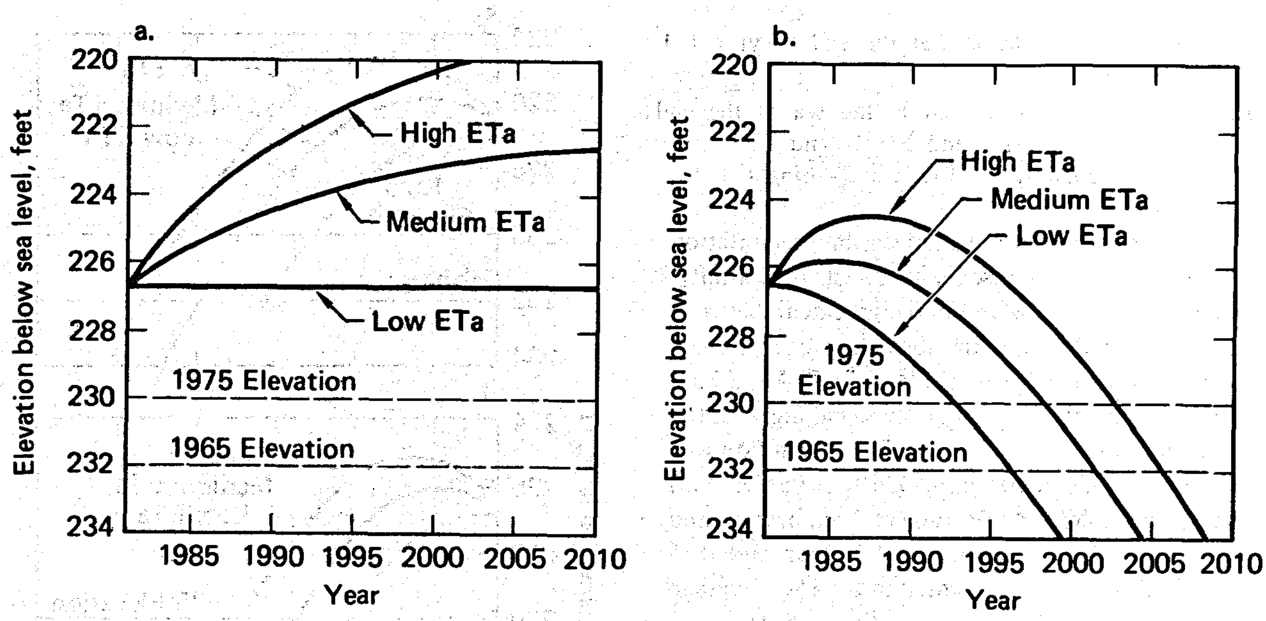


FIG. 24. Predicted elevations of the Salton Sea based on different irrigation efficiencies in the Imperial Valley, 3 levels of crop evapotranspiration (ETa), and no geothermal development. a. Existing irrigation efficiencies. b. Higher irrigation efficiencies.

directly to the sea, and 40 × 10^3 af/yr for direct surface runoff. Evaporation and precipitation were held constant at 5.78 ft/yr and 0.22 ft/yr.[60]

As indicated in Fig. 24a, higher elevations will accompany medium and high levels of water use by crops in the valley if REF water conditions persist and flows from Mexico and the Coachella Valley continue at previous rates. Increases in the Salton Sea's elevation will mean that agricultural lands next to the sea will be inundated unless protective dikes are maintained. More of the Salton Sea KGRA will also be flooded. Low crop water use, however, would arrest future increases. In contrast, increased conservation could have a drastic effect on the sea's elevation (see Fig. 24b). But even with the CON case, the surface elevation would not return to the 1975 year-end elevation until almost the year 2000 under medium crop water use.

Reductions in surface elevations resulting from geothermal development will vary according to the amount of agricultural waste water used for cooling power plants, or alternatively, for reservoir injection. Consequently, policy combinations like B and D, which minimize the use of waste water would cause smaller surface level changes than combination E, which promotes the greatest use of agricultural effluents. Figure 25 depicts the changes in elevation associated with each of the geothermal energy scenarios resulting from increased consumption of waste water under policy set E, CON water use conditions, and three levels of crop ETa. With low energy growth (Fig. 25a), declines in surface elevation from the predicted levels without geothermal activity are small. But for the medium and high growth forecasts (Figs. 25b and 25c), there are sizeable declines below those predicted for no development. Figure 26 shows elevation changes for the three energy scenarios under the REF case. The declines are smaller than those associated with the CON case because use of water under REF conditions produces greater discharges of agricultural effluents to the sea. With medium crop ETa, the effects of the other policy combinations in decreasing order are: E, A, F, B, C, and D. Using policy sets B, C, and D results in smaller declines in the sea's elevation, because the use of steam condensate and irrigation water for cooling is encouraged.

SEA SALINITY

Salinity changes in the sea were calculated by:

$$S_{t+1} = \frac{J_{t+1}}{0.00136\, V_{t+1}} ,$$

where

$$J_{t+1} = J_t + N_{t+1} ,$$

and

S_{t+1} = salinity of the sea at the end of yr t + 1 (ppm),

J_t, J_{t+1} = total tons of salt in the sea at the end of the yrs t and t + 1, and

N_{t+1} = salt added from all sources during t + 1, (tons).

This model does not address the precipitation of salts and the consequent effect on salinity. Nevertheless, there was good agreement between the salinity predicted by the above approach and actual salinities for the years 1957 to 1971. In Fig. 27 are shown the actual salinities of the sea along with the predicted values associated with water inflows of 1316×10^3, 1326×10^3, and 1336×10^3 af/yr and a salt input of 4605×10^3 tons/yr. Evaporation and precipitation rates were set at 5.8 ft/yr and 0.15 ft/yr. The salt inflow was equal to the 15-yr average of annual salt loads of waste water flows from the Coachella and Imperial Valleys plus an estimated 68×10^3 tons of salt from ground water discharges. The salt content of ungauged surface water inflows was assumed to be negligible. The average salinity of the sea for the years 1957 to 1971 was 36.81×10^3 ppm TDS, and the averages of the predicted values were 36.83×10^3, 36.45×10^3, and 36.09×10^3 ppm for the low, medium, and high water inflows to the sea.

In order to predict future salinity changes connected with the REF and CON conditions of water use and alternative levels of crop ETa, estimates were made of the salt loads in waters discharging to the Salton Sea. Salt loads derived from irrigated lands and ground water discharges within the Imperial Valley were predicted by this regression equation:

$$TS_t = 134.0 \times 10^3 + 1.86 \times 10^6\, P_t + 1.04\, R_t$$

$(R^2 = 0.84,\ F(2, 16) = 43.6,\ \underline{p} < 0.001)$,

where

$R_t = Sc_t\, Ia_t$,

and

TS_t = tons of salt from agricultural lands and ground water,

P_t = annual precipitation during yr t (ft),

R_t = tons of salt in water applied to crops in yr t,

Sc_t = salinity of inflowing Colorado River water in yr t (tons/af), and

Ia_t = irrigation water applied to crops in yr t (af).

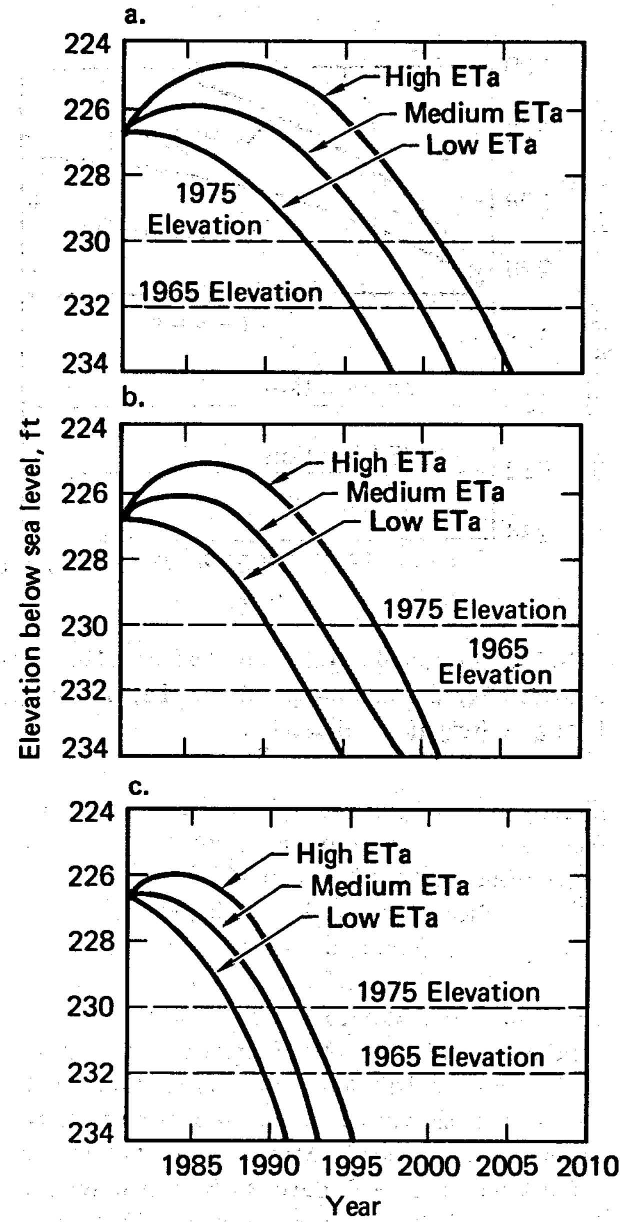


FIG. 25. Predicted elevations of the Salton Sea resulting from water policy combination E, higher irrigation efficiencies in the Imperial Valley (CON case), and three levels of crop evapotranspiration (ETa). a. Geothermal energy growth of 40 MW/yr after an initial 400 MW production in the year 1994. b. Geothermal energy growth of 100 MW/yr after an initial 400 MW production in the year 1985. c. Geothermal energy growth of 250 MW/yr after an initial 400 MW production in the year 1982.

Future values for the salinity of the Colorado River were based on one of several projections made by the Colorado River Basin Salinity Control Forum.[55] The projection used here shows salinity

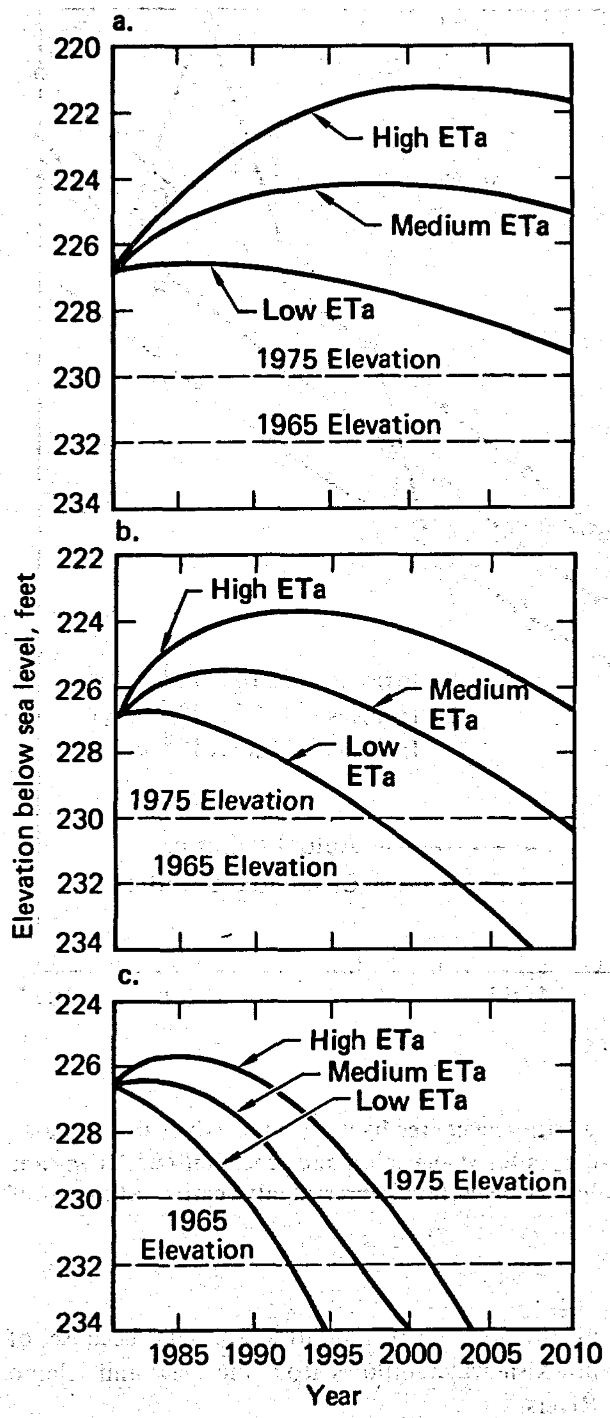


FIG. 26. Predicted elevations of the Salton Sea resulting from water policy combination E, existing irrigation efficiencies in the Imperial Valley (REF case), and three levels of crop evapotranspiration (ETa). a. Geothermal energy growth of 40 MW/yr after an initial 400 MW production in 1994. b. Geothermal energy growth of 100 MW/yr after an initial 400 MW production in 1985. c. Geothermal energy growth of 250 MW/yr after an initial 400 MW production in the year 1982.

rising at Imperial Dam from 860 ppm in the year 1982 to approximately 945 ppm in the year 1990. These figures represent a growth rate of 10.6 ppm/yr. Values for salinity after the year 1990 were assumed to increase at the same rate in order to obtain the additional values needed to the year 2010. Annual precipitation was kept constant at the rate of 0.22 ft/yr, the long term average for the area. Salt from canal losses and inflows from Mexico (i.e., 678×10^3 tons/yr) were added to the salt load predicted from the regression equation to get the total salt load entering the sea from the valley. Salt from the Coachella Valley was assumed to be a constant 376×10^3 tons/yr and salt derived from ground water discharges to the sea was estimated to be 68×10^3 tons/yr. Figure 28 presents the salinity changes predicted with REF and CON conditions of water use and no geothermal development. The CON case exhibits faster increases in salinity than the REF case because higher irrigation efficiencies result in reduced inflows of irrigation drainage to the sea. With smaller inflows to dilute the sea, its salinity rises more quickly.

The predicted changes in salinity will directly affect the sea's aquatic ecosystem, which includes an important sport fishery composed of orange mouth corvina (*Cynoscion xanthulus*), sargo (*Anisotremus davidsoni*), and gulf croaker (*Bairdiella icistia*). Fish-toxicity studies indicate that the mortality rate of eggs and larvae of gulf croaker and sargo can be expected to increase significantly with salinities higher than 40,000 ppm TDS.[61,62] Other work[38] suggests that young gulf croaker, sargo, and corvina, in contrast, are able to withstand salinities around 50,000 ppm. A study directed at the effects of salinity on pile worms (*Neanthes succinea*), an important organism in the sea's food web, demonstrated the ability of the worms to tolerate salinities over 67,000 ppm.[63] Oglesby[64] showed that reproduction of the pile worms will probably continue with salinities as high as 45,000 to 50,000 ppm TDS.

The eventual response of the sea's aquatic ecosystem to future salt concentrations will be governed by the toxic effects on aquatic organisms, the role of those organisms in the sea's food chain (depicted in Fig. 29), and by any adjustments made in the ecosystem. At this point it is not possible to accurately quantify the effects of elevated salinities on the sea's fishery because not enough is known about the lethal and nonlethal impacts of salinity on the life cycles of fish. However, the consequences of

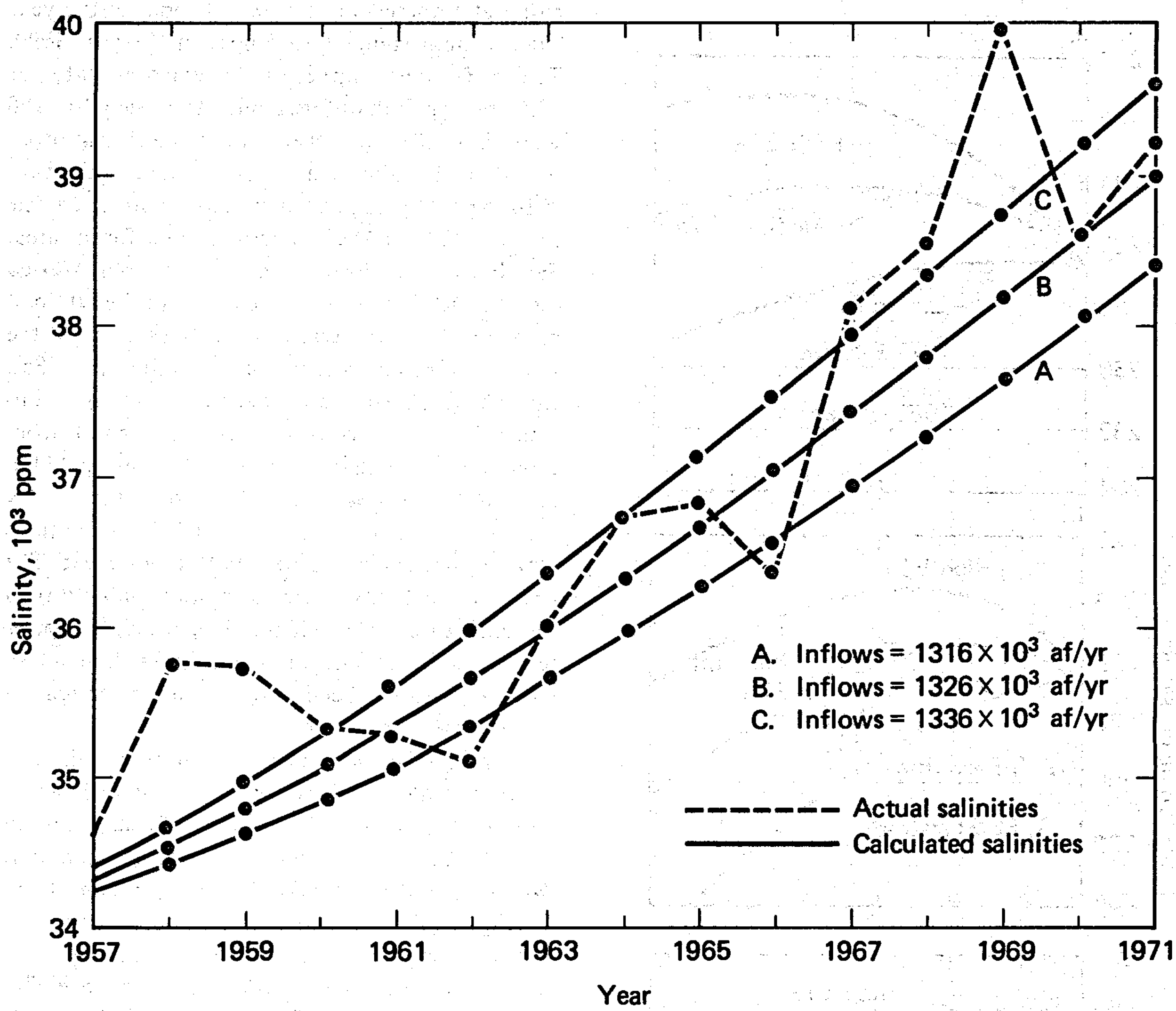


FIG. 27. Actual year-end salinities in the Salton Sea and salinities computed by using a recursive salt and water balance model. Elevations were calculated with 15-year averages for evaporation and precipitation. A constant salt input of 4605 $\times$ 10^3 tons/yr was used with three inflow regimes that represent alternative estimates of average water inflows to the sea.

future salinity changes can still be analyzed qualitatively by comparing predicted salinities with three toxic ranges or thresholds based on previous toxicity studies. The first threshold occurs when salinity exceeds 40,000 ppm. Above that level fish and pile worm reproduction would be reduced. The next threshold is in the range between 50,000 and 60,000 ppm where the mortality of adult fish increases. The third threshold is defined by the range of 60,000 to 70,000 ppm where fish populations would be drastically reduced in most of the sea. Adult pile worms would also be threatened at those salinities. However, some fish may still live in parts of the sea where salinities are less because of brackish water inflows from the New and Alamo Rivers.

When the three ranges are compared to the previous salinity projections (Fig. 28), it is apparent that the fishery is not in immediate danger of collapse if no major reductions in agricultural waste water flows occur. In the REF case (Fig. 28a) under average crop water use, the sea's salinity exceeds the 40,000 ppm threshold by the year 1990; but in the CON case (Fig. 28b) the 40,000 ppm level is reached about five years sooner. Once the initial threshold is surpassed, fish and pileworm reproduction should

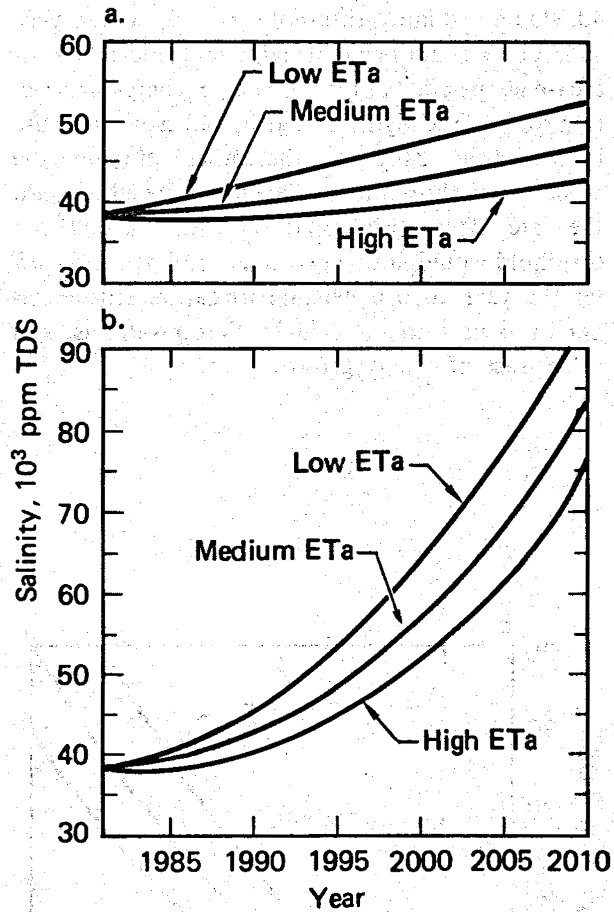


FIG. 28. Predicted salinities of the Salton Sea based on different irrigation efficiencies in the Imperial Valley, three levels of crop evapotranspiration (ETa), constant salt input from agricultural waste waters, and no geothermal development. a. Existing irrigation efficiencies. b. Higher irrigation efficiencies.

gradually decrease. Changes in salinity as a result of the low, medium, and high energy growth scenarios under policy combination E and REF conditions are presented in Fig. 30. The scenario for low-energy growth (Fig. 30a) results in negligible changes from the predicted values without geothermal energy production. Adverse impacts on the Salton Sea occur quickly with low ETa but more slowly with the medium and high levels, because there are larger discharges of irrigation drainage. The threshold of 50,000 ppm is reached after the year 2000 under medium crop ETa with the medium geothermal growth rate (Fig. 30b). However, it is reached prior to the year 1995 for the scenario of high energy growth (Fig. 30c). In Fig. 31, changes for CON conditions are shown. Again, for each of the energy projections, low ETa has the greatest increases in salinity followed by the medium and high levels. With medium geothermal energy growth, medium crop water use, and CON conditions (Fig. 31b), toxic effects on fish would begin in the early 1990s when the threshold of 50,000 ppm is surpassed. The threshold was reached later in the low energy prediction and earlier in the high because of the different amounts of agricultural waste water needed to support the scenario.

To summarize, increases in salinity will be slow if medium or high levels of ETa continue with existing efficiencies of irrigation, as seen in the REF case, and there is no geothermal development. Toxic effects on the sea's aquatic ecosystem would

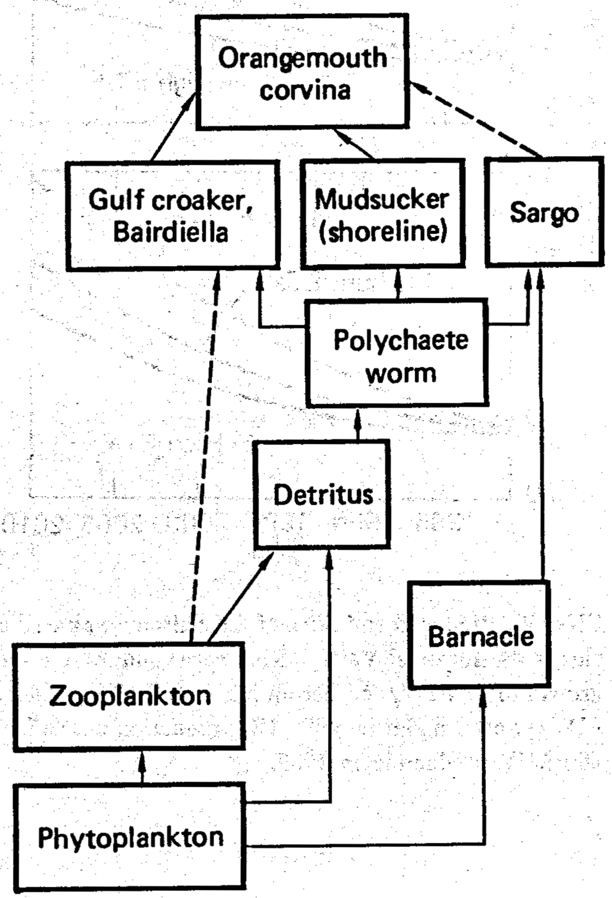


FIG. 29. Basic food web of the Salton Sea. Dashed lines refer to minor diet items.[60]

not occur until after the year 1990 for these conditions. However, low use of water by crops and increased conservation of water would accelerate the rise in salinity and related effects on the reproductive cycles of fish and pile worms. Changes in salinity associated with geothermal development would be greatest with those policies that encourage consumption of agricultural waste waters for power plant cooling. For example, because policy combination E results in almost a complete reliance on waste water for cooling, salinities could exceed the 40,000 ppm salinity threshold as early as the year 1985. This could occur if irrigation efficiencies increase as specified in the CON case, energy production follows the higher scenario, and crop water use is low (Fig. 31c). At the other extreme, the 40,000 ppm threshold would not be reached until the late 1990s (Fig. 30a), and the 50,000 ppm threshold would not be exceeded until sometime after the year 2010 if existing irrigation efficiencies persist along with a high level of crop water use and a low rate of energy growth.

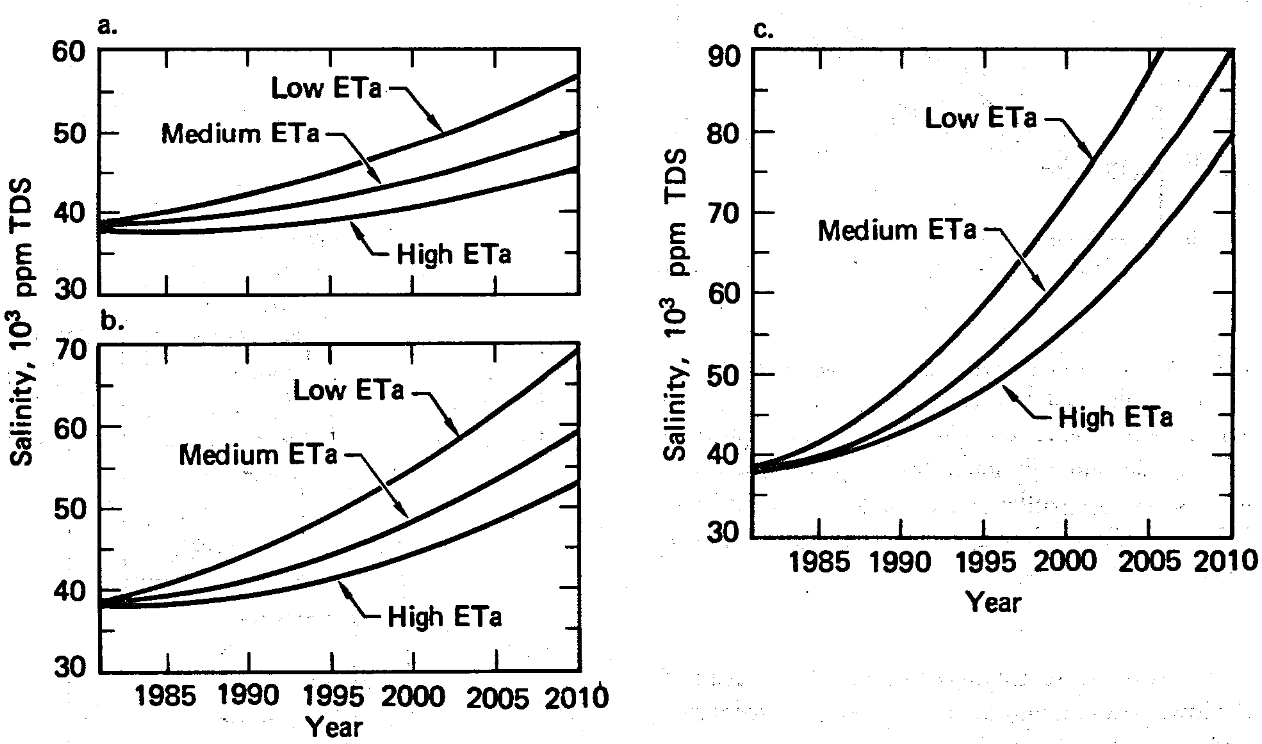
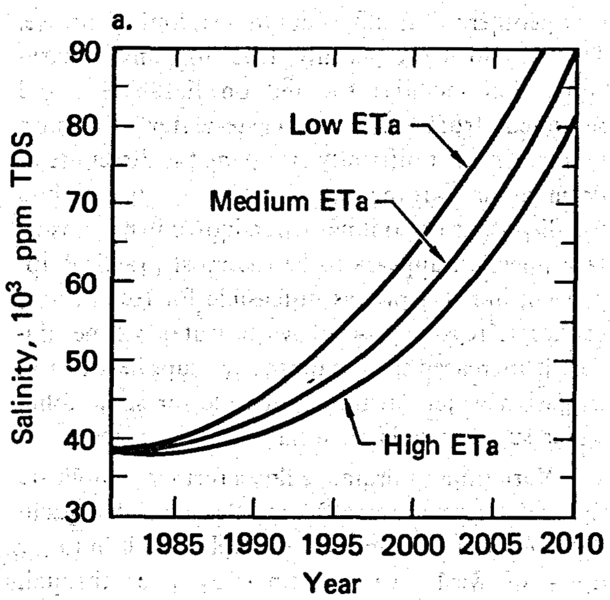


FIG. 30. Predicted salinities of the Salton Sea based on water policy combination E, existing irrigation efficiencies in the Imperial Valley (REF case) and three levels of crop evapotranspiration (ETa). a. Geothermal energy growth of 40 MW/yr after an initial 400 MW production in the year 1994. b. Geothermal energy growth of 100 MW/yr after an initial 400 MW production in 1985. c. Geothermal energy growth of 250 MW/yr after an initial 400 MW production in 1982.



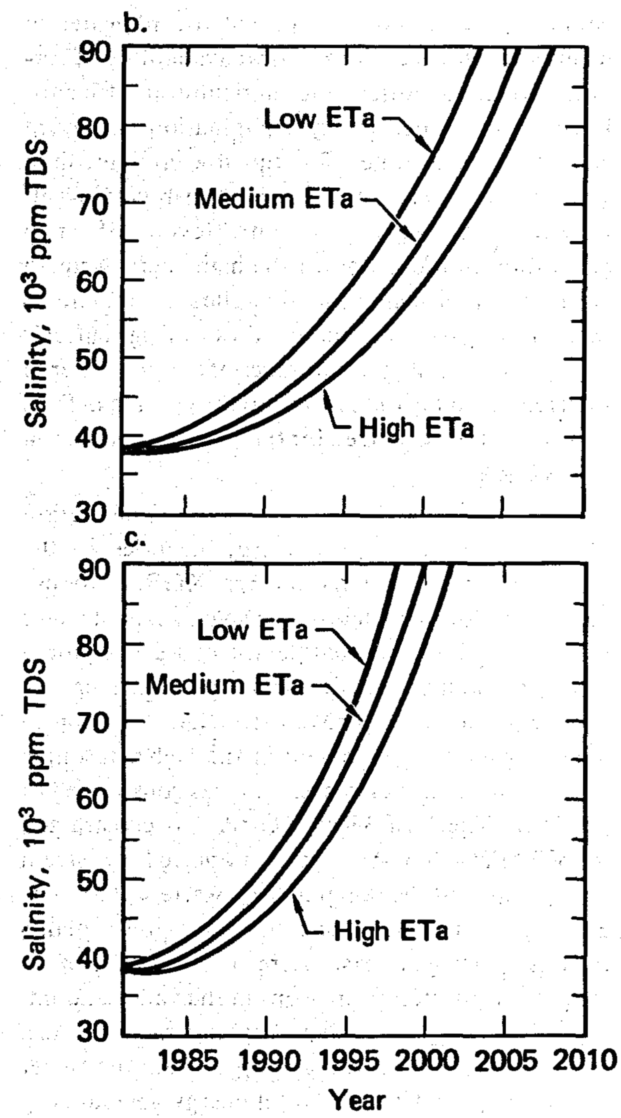


FIG. 31. Predicted salinities of the Salton Sea based on water policy combination E, higher irrigation efficiencies in the Imperial Valley (CON case), and three levels of crop evapotranspiration (ETa). a. Geothermal energy growth of 40 MW/yr after an initial 400 MW production in the year 1994. b. Geothermal energy growth of 100 MW/yr after an initial 400 MW production in the year 1985. c. Geothermal energy growth of 250 MW/yr after an initial 400 MW production in the year 1982.

REVIEW AND CONCLUSIONS

The analysis of potential water supply constraints to geothermal development in the Imperial Valley was based on:

- A series of alternative policies affecting the use of irrigation water, agricultural waste water, as well as steam condensate for cooling, and
- Different conditions of agricultural water use affecting the physical availability of irrigation water and agricultural waste water.

Five policies were discussed that affect the distribution of the individual water supplies to geothermal facilities. Six combinations of the separate policies were defined, representing the scope of future regulatory controls on the use of cooling water. Two trends in agricultural water use were used to simulate future water balances in the valley. A conservation case was chosen to represent increased efficiencies in the distribution and application of irrigation water. A reference case based on the assumption that present practices of water use will continue unchanged was also selected. Annual flows of irrigation and waste water associated with the two cases were predicted for low, medium, and high values of crop evapotranspiration.

The quantity of water available from the various supplies to meet the cooling requirements associated with three scenarios of energy production was primarily a function of water policy combinations and the use of water in irrigation. The policy combinations controlled the allocation of cooling water supplies while the use of water in irrigation controlled the physical availability of surplus irrigation water and agricultural effluents. Each of the water policy combinations provided enough cooling water for the low and medium scenarios of energy production under varying efficiencies of water use and levels of crop evapotranspiration. But for the high energy growth level, the implementation of policy combinations that promoted a reliance on flows of agricultural waste water resulted in shortages of cooling water in the Heber and East Mesa resource areas. No deficits in water supply occurred for the Brawley and Salton Sea KGRAs.

Implementing the most restrictive combination of water policies forced energy facilities in the Heber, Brawley, and Salton Sea KGRAs to use agricultural drain waters as the sole source of water for cooling, and restricted the use of steam condensate for cooling to half of the projected energy production at the East Mesa KGRA. As a consequence, energy development in the Heber resource area for the high energy scenario was constrained to 800 MW. The East Mesa KGRA was constrained to 600 MW—400 MW were supported by steam condensate and the remainder by waste waters. The agricultural drainage flows sustaining power plants in this particular case were based on average evapotranspiration from crops in the valley and improved efficiencies in using water in irrigation. As a result of the reduced energy output from the Heber and East Mesa KGRAs, total energy generated in the valley amounted to approximately 6800 MW in the year 2010, 1200 MW less than specified by the high energy growth scenario. That constraint to energy production is somewhat artificial, though, since the high growth scenario is based on the assumption that the resource potentials of those KGRAs is a lot greater than present resource estimates.

Even though annual discharges of waste waters from agricultural lands can satisfy the requirements for cooling water of substantial geothermal development, maximum use of those discharges could be limited by several water-related problems. For example, at the present time there is no agreement between the United States and Mexico to guarantee minimum flows in the New River; and until one is obtained, the full development of the Heber resource area may be in jeopardy. The costs of collecting and transporting drain waters to distant geothermal facilities could also limit their use. This would be especially true for any binary-conversion facilities situated on East Mesa and removed from suitable waste-water diversion points. Another difficulty involving the direct use of drainage flows is the selection of a suitable method for disposing of cooling-tower blowdown. Subsurface injection appears to be the most practical approach; but if it proves unfeasible for technical or economic reasons, use of waste water will be hindered. Increased use of alternative supplies such as irrigation water, steam condensate, or some other water supply would then have to take place.

Variations in drainage flows further complicate the use of agricultural effluents. Seasonal changes in the irrigation of crops, for example, result in lower flows of waste water from November through February, limiting the quantities of water that can be withdrawn for cooling purposes. One solution to the uncertainties of the availability of water during months of low flow would be to use waste waters for injection into geothermal reservoirs and steam condensate for cooling. In that way, injection could be adjusted to match flow conditions and still provide the necessary volumes of fluids to satisfy any requirements for the full injection of fluids to a reservoir. For this alternative to be successful though, the feasibility of injecting agricultural effluents to a geothermal reservoir on a long term basis will have to be proven.

Another possible constraint to using waste water concerns changes of salinity in the Salton Sea. The sea's salinity has been slowly increasing and eventually it will reach levels that threaten the sea's sport fishery. With increased conservation of irrigation water in the Imperial Valley, yearly increases in salinity will be faster than at present because less water will be discharged to the sea to make up for losses through evaporation. Water policies that encourage the use of waste waters for cooling geothermal power plants will also accelerate the rate of salination.

Geothermal energy growth of 250 MW/yr starting after an initial production level of 400 MW in the year 1982 (i.e., the scenario of high energy growth), could cause the sea's salinity to reach toxic levels—greater than 40,000 ppm—by the year 1985 if:

- Drain waters are used to meet all the requirements for cooling water for facilities in the

Heber, Brawley, and Salton Sea KGRAs along with those of binary power plants on East Mesa,

- Normal hydrologic conditions persist, and

- The use of water by crops remains the same.

Without geothermal development, the sea would probably reach toxic salinities in the early 1990s. A beneficial result of extensive use of waste water would be a decrease in the elevation of the Salton Sea, which has been rising in recent years. However, with normal levels of crop water use, it would take a high rate of geothermal energy growth or greatly improved irrigation efficiencies to significantly reduce the sea's elevation.

To minimize the effects of geothermal operations on salinity, a mix of cooling-water supplies will be necessary. Irrigation water could support some development, but existing policies would have to change before expanded use is possible. Steam condensate could provide all the cooling water needed for flashed-steam power plants, thus eliminating any need for drain waters from agriculture. However, the full injection of geothermal fluids may be necessary; and in that case, drain waters would be needed for either cooling or reservoir injection. Finally, Salton Sea water, if used for reservoir injection in the Salton Sea KGRA, would have the beneficial effect of removing both salt and water from the sea. Unfortunately, annual diversions in excess of 100,000 af would be needed to depress the sea's salinity and stabilize its elevation.

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