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POTENTIAL EFFECTS OF GEOTHERMAL ENERGY CONVERSION ON IMPERIAL VALLEY ECOSYSTEMS

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POTENTIAL EFFECTS OF GEOTHERMAL ENERGY CONVERSION ON IMPERIAL VALLEY ECOSYSTEMS

ABSTRACT

This workshop on potential effects of geothermal energy conversion on the ecology of Imperial Valley, which was conducted from November 8 through 11, 1976, brought together personnel of Lawrence Livermore Laboratory and many collaborators under the sponsorship of the ERDA Imperial Valley Environmental Project (IVEP). This report reflects the expertise of the contributors in field experience and knowledge of the literature, and contains preliminary results from the IVEP. The LLL Integrated Assessment Team identified the electric power potential and its associated effluents, discharges, subsidence, water requirements, land use, and noise. The Working Groups addressed the ecological problems. Water resource management problems include forces on water use, irrigation methods and water use for crops, water production, and water allocation. Agricultural problems are the contamination of edible crops

and the reclamation of soil. A strategy is discussed for predevelopment baseline data and for identification of source term tracers. Wildlife resources might be threatened by habitat destruction, powerline impacts, noise and disturbance effects, gas emissions, and secondary impacts such as population pressure. Aquatic ecosystems in both the Salton Sea and fresh waters have potential hazards of salinity and trace metal effects, as well as existing stresses; baseline and bioassay studies are discussed. Problems from air pollution resulting from geothermal resource development might occur, particularly to vegetation and pollinator insects. Conversion of injury data to predicted economic damage is needed. Finally, Imperial Valley desert ecosystems might be threatened by destruction of habitat and the possible effects on community structure such as those resulting from brine spills.

PROJECT AND WORKSHOP OBJECTIVES

Goal of IVEP

The goal of the Imperial Valley Environmental Project (IVEP), spon-

sored by the Energy Research and Development Administration (ERDA), is to assure that the development of

geothermal resources in Imperial Valley, California, will proceed in an environmentally sound manner.

Workshop Components

To this end, the IVEP Integrated Assessment and Ecosystem Quality Subprograms of Lawrence Livermore Laboratory (LLL) sponsored their first joint workshop on 8-11 November 1976 at the University of California Conference Center, Lake Arrowhead. This report represents a compendium of information on the *Potential Effects of Geothermal Development on Imperial Valley Ecosystems* and constitutes a milestone report of the first year of the IVEP. *This material is provided entirely by IVEP personnel of Lawrence Livermore Laboratory and IVEP subcontractors and collaborators who were represented at the Workshop.* Nearly all of the attendees have experience in the field and are familiar with the ecosystems of the Imperial Valley.

IVEP Ecosystems Quality Subprogram, 1976

The IVEP Ecosystems Quality Subprogram consists of seven teams that are conducting baseline studies of ecosystems in the Imperial Valley.²

Site-Specific Studies

Soils, plants, and sediments are studied at major geothermal develop-

ment areas and trace elements are characterized (concentrations, origin, etc.) at each site.

Shoreline Habitat

Studies are conducted in the National Wildlife Refuges and riparian areas and are supported by subcontracts to study:

- Ecology of the Yuma Clapper Rail (Arizona State University), and
- Noise and disturbance effects on wildlife (St. Mary's College).

Aquatic Habitat

Bioassay methods are applied to a key marine polychete worm and to key freshwater fish. Subcontracts support studies on:

- Productivity of toxic effects on major Salton Sea fish (California State University, Hayward),
- Success and adaptability of Salton Sea polychete worms (Pomona College), and
- Toxic effects on the mosquito-fish in agricultural drains (North Carolina Central University).

This team also assists in fish collections (California Department of Fish and Game).

Agricultural Studies

Milk, crops, and soils throughout Imperial Valley are characterized by trace element analysis. Subcontracts support the studies on:

- Geothermal brine movement in soil (University of California, Riverside),
- Chemical speciation of geothermal brines in soil (Kearney Foundation), and
- Establishment of a sample-collection network (California Agricultural Extension Service).

Desert Habitat

Sensitive species near desert geothermal sites are examined and trace elements in plants, insects, and rodents are characterized. This work is performed by University of California, Los Angeles, Laboratory of Nuclear Medicine (ERDA contractor).

Air Pollution

The dose response of key plants and animals to geothermal air pollution is determined. Subcontracts support the studies on:

- Chronic exposures of crop plants (Statewide Air Pollution Research Center),
- Synergistic effects of ozone and geothermal gases (University of California, Davis), and
- Susceptibility of pollinator

insects to geothermal air pollution (University of California, Riverside).

Water Resources

Water consumption and management practices in Imperial Valley are assessed. Subcontracts support the studies on:

- Consumptive water use by crops (USDA Imperial Valley Conservation Research Center) and
- Regional water use (University of California, Davis).

Workshop Opportunity and Success

At the time of this workshop, IVEP subcontractors had operated for up to 4 months, and the LLL Ecosystem Quality subprograms progressed from planning and initial baseline collections to the attainment of preliminary results on trace element characterizations and on bioassays to determine susceptible species. To obtain the most meaningful results of an integrated assessment of ecosystem quality, this workshop was conducted at the first available opportunity following the initial phases.

ANTICIPATED GEOTHERMAL IMPACT SCENARIOS

Donald L. Ermak and David W. Layton

Development of Electric Power from Geothermal Energy Sources in the Imperial Valley

Imperial Valley contains six

regions that have been designated by the U.S. Geological Survey as Known Geothermal Resource Areas (KGRAs)

Fig. 1. Known Geothermal Resource Areas (KGRAs) of Imperial Valley, California.

(Fig. 1). These geothermal systems are liquid-dominated with the heat energy of the field stored in saline water. Four KGRAs, Salton Sea, Brawley, Heber, and East Mesa, contain resources that have temperatures greater than 150°C and therefore are potentially suitable for electric power generation. While there are no operational geothermal power plants in Imperial Valley, developers are seeking ways to exploit these resources. *The impact of future geothermal power plants on Imperial Valley will depend upon the geothermal technology, the level of electric power production, and the siting of the geothermal operations.*

Technology for Geothermal Energy Conversion

At present in the U.S., there are no operational electric power plants that utilize hot water resources. A number of hot water technologies are being considered for use in Imperial Valley including the flashed steam, binary, and total flow systems. The efficiencies of these systems in producing electric power are estimated to range from 8 to 18%, depending on the technology used and the physical characteristics of the brine. Consequently, the quantity of geothermal fluid and cooling water consumed and pollutants emitted to the environment

will depend upon both the geothermal technology and the resource area.

A schematic diagram showing the major components of a flash steam to isobutane binary geothermal power plant is given in Fig. 2. There are three fluids used in this system: geothermal steam-brine mixture, isobutane, and cooling water. The steam-brine mixtures from the geothermal well field are sent to the flash evaporators where the steam fraction is increased and separated from the liquid brine. The liquid brine is disposed of by reinjection into the earth, while the geothermal steam is sent to heat exchangers where its energy is transferred to the isobutane. The condensed steam from the heat exchangers produces a supply of relatively fresh water that can be used to supplement the cooling water requirements. Vaporized isobutane leaves the heat exchanger and passes through the turbine that drives the electric generator. It is then cooled in the water-cooled condenser and pumped back to the heat exchanger. Warmed cooling water is cooled back to ambient temperature by partial evaporation in the cooling tower.

This type of system will have a number of waste effluents besides geothermal brine. Noncondensable gases (CO_2 , H_2S , NH_3 , ...) in the geothermal fluid are generally emitted

from a stack release in the geothermal steam lines and from the cooling towers if the steam condensate is used as make-up water in the cooling cycle. The cooling towers also emit water drift that may contain trace amounts of toxic elements such as boron or mercury. Also, the blow-down water from the cooling cycle must be disposed.

Electric Power Potential

Recent estimates by Towse,³ Renner *et al.*,⁴ and Nathensen and Muffler⁵

for the total electric power capacity of the Imperial Valley geothermal fields are 3350 to 4580 MW for a 30-yr period. The Jet Propulsion Laboratory (JPL)⁶ used such information and the opinions of government and industry to develop a set of three projections for the growth of geothermal utilization in the State of California. The nominal projection is based on the current plans of geothermal developers with extrapolations to later years. The high projection assumes

Fig. 2. Flash steam to isobutane binary cycle.

Table 1. Predictions for nominal growth.⁶

	<u>On-line capacity (MW) by year</u>				
	1980	1990	2000	2010	2020
Salton Sea	10	730	1350	2000	2250
Brawley	—	290	540	800	900
Heber	50	290	540	800	900
East Mesa	—	150	270	400	450
Total	60	1460	2700	4000	4500

a geothermal resource greater than that currently envisioned and a stimulated growth rate; the low projection is based on a smaller resource potential and slower growth rate.

For Imperial Valley in the year 2000, the JPL projections are: low (600 MW), nominal (2700 MW), and high (4750 MW). Assuming power plants are installed in 100-MW increments, this corresponds to 6, 27, and 48 power plants, respectively. These projections are further broken down for each KGRA and predictions for nominal growth are given in Table 1. After 1980 the distribution of electric capacity among the KGRAs are estimated as: Salton Sea, 50%; Brawley and Heber, 20% each; and East Mesa, 10%.

As a reference for these electric power figures, the current California capacity is approximately 39,500 MW. The Geysers, the only operating geothermal power plant in California,

produces 502 MW or about 1.3% of the total capacity. Assuming a 4% yearly growth rate, the capacity required in California for the year 2000 would be 105,000 MW. The JPL nominal projection for Imperial Valley geothermal capacity in 2000 is about 2.6% of the total California capacity. If all the California geothermal resources are included, electric power from these resources will account for 7.5% of the total California capacity. These figures indicate an increasing role for geothermal power in meeting California's future electric power needs.

Power Plant Siting Areas

The designation of geographic areas for future power plant siting requires the consideration of numerous factors including: resource, exclusion-zone, and load-center locations; environmental and economic concerns; water availability; and

seismic risk. The main criteria for power plant siting in Imperial Valley are:

- Resource location. Power plants must be located near (1 mi) the geothermal well field to

Fig. 3. Land use in Imperial Valley, California.⁷

prevent large heat losses in transporting geothermal fluids.

- Land conflicts. Geothermal development must be compatible with the Imperial Valley agriculture and livestock industries.
- Power plant size. Power plant size will be about 50 to 100 MW.
- Exclusion areas. Power plants will be excluded from cities, habitats of endangered species, etc. The size of exclusion areas will depend on the buffer zones required by local ordinances.
- Water availability. Competition for water between geothermal, agricultural, and other users may limit the number of power plants that can be located in Imperial Valley.

These criteria could significantly restrict the locations of geothermal power plants. As an example, a set of hypothetical criteria were used to determine suitable siting areas. The criteria restricted the siting of geothermal power plants to locations that are: within existing KGRA boundaries; in accordance with existing zoning ordinances and the Imperial Valley Ultimate Land Use Plan (Fig. 3); at least 1/2 mi from hospitals, schools, residential areas, municipal boundaries, and feed lots; and not over the Salton Sea.

Suitable siting areas resulting from these criteria are shown in Fig. 4. *The area in which power plants are allowed is significantly smaller than the area of the KGRAs. The area within each KGRA is reduced by the following percentages: Salton Sea, 71%; Brawley, 48%; Heber, 39%; and East Mesa, 6%. While some of these criteria may be overly restrictive, they demonstrate the impact that local ordinances may have upon geothermal development in Imperial Valley.*

Ecological Concerns

The two primary areas of ecological concern related to geothermal power plants in the Imperial Valley are the consumption of natural resources and the release of pollutants to the environment. Geothermal facilities will extract large quantities of geothermal fluids, process them for energy production, and then reinject them. *Waste heat produced during the generation of electricity will require either steam condensate, surface water, or ground water for evaporative cooling devices such as cooling towers and possibly spray ponds. The power-plant sites will require land for conversion systems (including heat-exchange equipment, turbines, and electrical generators), cooling devices, and electric switching yards;*

Fig. 4. Suitable areas for the siting of geothermal power plants in Imperial Valley, California.⁸

the well fields will also require land for producing wells, reinjection wells, and pipelines. Effluents from power plants exist mainly as⁷ noncondensable gases (for systems using flashed steam), blowdown water from evaporative cooling systems, and drift from wet cooling towers. (Noise is an additional emittant.)

Resource Use

Geothermal Fluid Discharges. *The withdrawal and conveyance of geothermal fluids to a power plant presents the possibility of accidental spills of those fluids onto arable lands or into rivers or drains. Soils and aquatic organisms could be harmed by a spill. Preliminary estimates of brine flow to the San Diego Gas and Electric-ERDA 10-MWe test facility predict flow rates of up to 800,000 lb/h from two wells.⁷ This flow would consist of: water, 544,000 lb/h; water, solids, 136,000 lb/h; noncondensable gases, 24,000 lb/h; and steam, 96,000 lb/h. Crucial aspects of a brine spill are the location within the system and the time required to stop the flow. Since the chemical composition of geothermal fluids varies throughout the Valley, damage from spills will also vary. Table 2 shows the variation in brine composition. Large differences exist not only between KGRAs, but also among wells within a resource area. Gener-*

ally, the higher the temperature of the fluid, the higher the content of dissolved solids.

Subsidence. Long-term extraction of geothermal fluids may also result in subsidence. Natural subsidence is already occurring. *Additional subsidence from geothermal developments could conceivably result in localized disruptions in the subsurface agricultural drainage system that underlies most of the Valley.* Seismic activity caused by reinjection wells is another concern, especially since this is one of the more active seismic areas in the world.

Water Requirements. Geothermal power plants have low thermal efficiencies, and thus large amounts of water are needed for evaporative cooling devices to reject waste heat. Fortunately, steam condensates from liquid-dominated geothermal resources underlying the Valley can be used to meet cooling water requirements, either in part or completely. When condensate is not available for a power plant because of environmental, technical, or other reasons, then surface or ground waters will be required. The magnitude of potential water uses by three different types of geothermal energy technologies is depicted in Table 3. *A single-stage, flashed-steam system uses 52 acre-feet (af)/WEe-yr at a reservoir temperature*

of 572°F (300°C). More water is required by less efficient conversion technologies and lower reservoir temperatures. In comparison, a large scale coal-fired power plant would consume about 14 af/MWe-yr, a little

Table 2. Geothermal brine composition of Salton Sea and East Mesa wells.

	East Mesa $\bar{C}$, ^a ppm ΔC ^b	Salton Sea $\bar{C}$, ^c ppm ΔC ^b
TDS ^d	2,120 ± 336	214,000 ± 98,000
Na	701 ± 68	46,000 ± 18,000
K	41 ± 17	13,000 ± 6,500
Ca	39 ± 36	21,000 ± 9,800
Mg	1.2 ± 0.8	374 ± 634
HCO ₃	532 ± 141	2,500 ± 2,600
Cl	541 ± 80	124,000 ± 54,000
SO ₄	172 ± 45	180 ± 230
B	2.8 ± 0.6	317 ± 199

^a Average concentration of 4 wells.

^b Standard deviation among wells (indicates variance among wells).

^c Average concentration of 9 wells.

^d Total dissolved salt.

Table 3. Cooling water requirements of energy conversion technologies.^a

Technology	Consumptive use ^b (af/MW-yr)	Power-to-heat rejection ratio	Once through cooling (10 ³ af/yr) ^c
One-stage flashed steam	52	0.21	260
Total flow	61	0.18	306
One-stage flash binary	73	0.15	367

^a Reservoir temperature, 572°F; condenser rise, 20°F.

^b 2% Evaporation rate of circulating flow in mechanical draft cooling tower.

^c 100-MW capacity power plant.

over a quarter of the demand of the flashed-steam process. Surface waters diverted for wet cooling towers could produce certain environmental impacts on the water resources of the Valley. *Large withdrawals of water from a river (50,000 af/yr), for example, could change the environment of aquatic organisms. They would also reduce the Salton Sea's surface elevation and increase its salinity.*

For once-through cooling, water is usually withdrawn from a river having adequate flow, passed through a condenser where the water temperature is increased, and then discharged into the stream. This method of heat disposal probably cannot be used with power plants in the Valley because of environmental problems of thermal pollution, stringent water-quality regulations, and the large withdrawal rates required (see Table 3).

Land-Use Requirements. Land needed for geothermal facilities will vary with the type of installation. The SDG&E/ERDA test facility utilizes 18.2 acres that includes 2 acres for a spray pond and just over 1 acre for the process area. The wells are encompassed in a 20-ft² area.⁹ Pipelines to the conversion facility from wells follow existing roads, removing minor amounts of land from other uses.

Effluents

Noncondensable Gases. A major

concern has been the release of non-condensable gases to the atmosphere. Table 4 gives the mass emission rates of gases and solids from a representative plant in The Geysers resource area of Northern California. Hydrogen sulfide (H₂S) has received much attention at The Geysers where it often occurs in concentrations that produce noticeable odors. A state air quality standard has been set at 30 ppb for a 1-hr averaging period. *The Cerro Prieto plant has higher emissions than The Geysers, indicating that significant H₂S releases might occur at other Imperial Valley KGRAs.*

Cooling-Water Drift. Drift from mechanical draft cooling towers (Fig. 5) is another potential source of environmental problems. At The Geysers boron in drift particles falling on vegetation is the primary cause of leaf damage. In the Imperial Valley drift deposited on lands near a power plant could cause damage to crops. *Of particular concern is the use of steam condensate from highly saline geothermal brines as make-up water because boron and other toxic substances may be present.*

Blowdown Discharges. To reduce the salinity level in a cooling tower to control corrosion, accumulated salts in the circulating water are removed by discharging a certain amount of

water known as blowdown. That water often contains biocides and corrosion inhibitors such as heavy metals that can have adverse effects on aquatic organisms. Such effects can be avoided by reinjecting the water, discharging it to evaporation ponds, or treating it for surface-water discharge (see Fig. 5).

Noise Emissions. Noise should also be included as a pollutant. It is of concern at The Geysers where steam is under substantial pressure. When

wells are vented, noise levels are severe in the immediate vicinity of the vented wells, and special mufflers are required. In the Imperial Valley the geothermal fluids are not under great pressure, so similar noise will not be produced. Nevertheless, noise from cooling towers, drilling, and power plant operation will occur.

Noise effects on humans or wildlife from geothermal resources and technologies are not yet analyzed fully for the Valley.

Table 4. Noncondensable gas and volatile solid emissions at the Geysers geothermal plant.¹³

	Noncondensable gases ^a		<u>Solids</u> kg/MW-yr
	kg/MW-hr	% ^b	
CO ₂	25.93	81.9	
H ₂ S	1.80	5.7	
NH ₃	1.54	4.8	
CH ₄	1.54	4.8	
H ₂	0.45	1.4	
N ₂	0.42	1.3	
As			0.017
B			35.0
Hg			0.001

^aNoncondensable gases constitute 0.4% (dry weight) of the atmospheric emissions with steam constituting the remaining 99.6%.

^bPercent of the noncondensable gas fraction.

Fig. 5. Cooling tower effluents.

PROBLEMS OF WATER-RESOURCE MANAGEMENT

David Layton, Gary Frey, Burl Meek,
and William Pruitt

Water Use and Conservation in the Imperial Valley

For many years the use of irrigation water in the Imperial Valley was governed by extremely low water rates that encouraged inefficiencies.

Although water is still inexpensive, other factors recently emerged that might result in the conservation of water. The examination of trends in water use is important because they might affect the water available for

geothermal facilities as well as the water assessments of those facilities.

The primary forces influencing water use in the Valley are economic in nature. Historically, the low cost of water and labor promoted the use of furrow irrigation and discouraged the use of more efficient irrigation methods. However, new irrigation methods such as sprinkler systems are in use because they offer economic advantages in the cultivation of certain crops. The introduction of dead-level irrigation to the Valley could also result in lower water-use rates by farmers. A water conservation program started by the Imperial Irrigation District (IID) might further encourage more efficient use of water. Currently the conservation program includes charging of fines for excessive amount of surface runoff, the concrete lining of irrigation canals, and the construction of ponds for the regulation of water delivery to irrigators.

Improved Irrigation Methods

The ultimate impact of improved irrigation practices will be to reduce the amount of tailwater flowing to the Salton Sea in the Valley's rivers and drains. Surface runoff from fields is estimated to be between 10 and 20% of the water delivered to irrigators. Most of that water can be saved if new irrigation methods were widely

adopted. Better on-farm management of irrigation applications will yield additional savings.

In the future, sprinklers will probably receive the most widespread use, followed by drip- and basin-irrigation methods. Pumpback systems are another method of conservation, although less favorable. The following paragraphs outline existing and potential irrigation methods for the Valley.

Flood or Furrow Irrigation. This method of water application is used extensively in the Imperial Valley. Efficiency was improved greatly by lining farm laterals and canals with cement, which allows better control of water and reduces seepage loss. Grated piping is used on a small scale, which aids in the delivery of water to furrows. Flood or furrow irrigation can be improved by adjusting water flows and ensuring proper water distribution.

Sprinkler Irrigation. Sprinkler irrigation will reduce the tailwater from irrigated lands to almost zero. This type of irrigation, if used for germination of lettuce, will reduce surface runoff during a time when runoff is high with furrow irrigation because of low water use by crops. The moving sprinkler method is presently in use on alfalfa on a trial basis. It is hoped that sprinkler

irrigation will increase yield of alfalfa on clay soils from 6 to 7 tons/acre to 10 tons/acre. Yields will be recorded this year to decide on an expansion of operations.

Drip Irrigation. This method will not be extensively applied during the next few years in the Imperial Valley, partly because more research is needed to evaluate its usefulness. Potential advantages of drip irrigation are better control of nutrients, less disease problems, less labor, and continuation of irrigation during harvest of certain crops. Problems of drip systems are the cost of installation and the need for proper water applications.

Basin or Dead-Level Irrigation. Basin irrigation is used in Arizona on sandy soils, but not in the Imperial Valley at present. Under this irrigation method, water is added to a diked field in such a way that it can infiltrate the soil within 24 hr. If too much water is applied, then water will stand on the soil surface and damage crops. Basin irrigation can be adapted easily for crops such as lettuce that withstand waterlogging.

Pumpback Systems. Water savings can be realized by pumping tailwater back to an irrigation ditch for reuse. However, the main disadvantages are the costs associated with the purchase and operation of a pump and the

construction of a small storage reservoir. Usually no increase in the salinity of the reused tailwater occurs, but pesticides present in the runoff water may be a problem.

Structural Improvements

Water can also be saved by structural changes in the irrigation system. The IID has a program to line the irrigation canals with concrete to cut down seepage losses. In addition, regulatory ponds are being constructed by the District. Such ponds will give the District more flexibility in delivering water and storing unused water. The ponds will become more important as the concrete lining program expands, providing more flexibility in operations.

Water Balance and Trade-off Possibilities

An estimate of the total consumptive use of water by crops grown in 1973 was made with lysimeter data and empirical estimates of evapotranspiration (ET). The water use of 434,800 acres of field crops, based on available lysimeter data, is shown in Table 5. Using procedures developed by the Food and Agriculture Organization¹⁴, 113,800 acres of field, garden, and permanent crops were estimated to consume 276,800 acre-feet (af). The remaining 37,000 acres of miscellaneous crops cultivated in 1973 was estimated to use 92,500 af,

assuming an average ET demand of 2.5 af/acre. The total water use of the crops is 2,243,000 af.

During 1973, approximately 2.67×10^6 af of water were delivered to farmers to meet the ET requirements of crops. However, since about 12% of the delivered water becomes runoff and another 15% is used for leaching¹⁷, the actual water use of crops was less than the potential ET of 2.243×10^6 . The difference may result from high estimates of ET and from irrigation practices that result in lower crop water use.

Examples of Water Savings Through Crop Pattern Changes. In 1973 alfalfa acreage was 174,000 acres, and 1,178,600 af of water were lost through ET. If the acreage were reduced to 90,000 acres, only 607,500 af will be required for ET, a savings of 571,100 af from the 1973 value. Now if the 84,600 unused acres were planted in another crop, the actual savings will be somewhat lower. For example, if sugar beets with an ET value of 3.8 af/acre were planted on those acres, 401,850 af will be used for ET. The possible savings

Table 5. Evapotranspiration (ET) of selected crops as measured by lysimeters at the Brawley Field Station.

Crop	Measured ¹⁵ ET af/acre ^a	1973 ¹⁶ acreage 10 ³ acres	Total ET 10 ³ af
Alfalfa ^b	6.75	174.6	1,178.6
Cotton	3.50	36.9	129.2
Sugar beets	3.80	69.8	265.2
Wheat and oats	2.10	95.7	201.0
Barley	1.80	17.4	31.3
Sorghum	1.70	39.4	67.0
Sorghum (silage)	1.40	1.0	1.4
		434.8	1,873.7 = 1,873,700 af or 2.31×10^9 m ³

^aaf = acre-ft/yr or 1233.5 m³/yr.

^bDoes not include 1,660 acres for seed.

will then be about 169,250 af /($0.209 \times 10^9 \text{ m}^3$). It must be pointed out that such crop alterations will occur only if the economics favor less water-consumptive crops. *In summary, by substituting crops consuming less water than alfalfa, a conservation of about 3 af/acre-yr (9140 m^3 /hectare-yr) will be feasible.*

Water Production from Geothermal Facilities

Desalinization of geothermal brines is technically feasible as demonstrated at the US Bureau of Reclamation, East Mesa Test Site. Systems tested include Multistage Flash and Vertical Tube Effect. Each system relies on the flashing of brine at the surface and using energy in the steam to extract water from the remaining brine. Indications are that up to 70% of the water can be recovered from the brine. The amount of water that can be produced is limited only by the volume of extractable brine from the subsurface reservoir. In the short term, the present effort is aimed at developing a 500,000-gal/d ($1894 \text{ m}^3/\text{d}$) prototype plant with a longer range goal of producing 2.5 million af/yr ($3.08 \times 10^9 \text{ m}^3/\text{yr}$).

Major constraints are associated with this program. Primarily, high

capital investment will lead to high cost water that is economically unattractive by today's standards. Desalinization in conjunction with other geothermal development, such as power generation, would be more attractive.

Desalinization might have adverse effects on deeper aquifers and subsequently cause subsidence. In effect, 70% of the volume would be withdrawn and the remainder of the brine reinjected. A detailed monitoring program of land subsidence is needed to evaluate effects of geothermal development over the present naturally occurring subsidence. In the worst case, importation of large volumes of low quality water might be required for reinjection purposes.

Another unanswered question concerns legal ownership of desalinated waters originating at East Mesa. Determination of ownership might place constraints on the use of product water. *Desalinized water can be placed in either the East Highline or All-American Canal systems for distribution through the IID irrigation system. However, legal and institutional considerations might require transport to the Colorado River System. Industry or agriculture can be developed locally. High value crops, e.g., strawberries, can be then grown economically with agricultural water costing up to \$100/af.*

Allocation of Conserved Water

More efficient irrigation practices, less water-intensive cropping patterns, and structural improvements in the irrigation system might eventually result in water savings. It is not yet clear how quickly Valley water will be saved through conservation activities. The timing of water savings will influence the IID allocations of conserved water. A slow, incremental increase in water savings

will favor the use of conserved water for new farm land. Agricultural land will then be developed as measurable water savings occur, and, if conservation efforts slowed, some land might be taken out of production. Geothermal facilities, on the other hand, will need guaranteed amounts of water for long periods of time. Thus, if water conservation efforts are to be of value to energy facilities, they must result in significant water savings on a continuing basis.

GEOTHERMAL DEVELOPMENT AND POTENTIAL IMPACT ON THE MANAGED AGRICULTURAL ECOSYSTEMS

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The development of Imperial Valley's geothermal resources is sometimes viewed with skepticism by those within the local agricultural community and, considering the political and economic influence of this group, it becomes essential that careful assessment of all environmental aspects of geothermal energy development be accomplished.

California's Imperial Valley constitutes a major agricultural resource of the nation. As a result of good soils, adequate water, and a year-

round growing season, it is a major producer of vegetable and field crops, as well as the site of an intensive livestock industry. Some examples from the 1975 growing season are: 45,000 acres planted in lettuce, producing 604,000 tons at a value of more than \$75 million; 109,000 acres of alfalfa hay, producing 920,000 tons, valued at more than \$122 million.¹⁸

The discussion of the agricultural ecosystem/geothermal energy interaction is divided into two parts, the establishment of baselines and the

research on the effects and the reclamation of accidental geothermal brine spills.

Agricultural Ecosystems Baseline Data

Because of practical constraints, collection and analysis of baseline information must be limited, and an intensive, descriptive study of chemical elements in the Valley ecosystem is obviously prohibited. The collected samples and their analyses are therefore chosen according to priorities based on the potential environmental damage and on the usefulness of the data to confirm environmental contamination.

Source-Term Tracer

The identification of specific elements, ions, and/or ion ratios in geothermal brines that differ significantly from the natural abundance levels in the Valley would provide a valuable tool for the baseline characterization of agricultural elements. A source-term tracer (STT) can be used to describe these species or ratios. An important factor in choosing an STT, in addition to its high concentration in geothermal brine, is that its natural abundance must be relatively constant so that changes in the concentration of other elements can be compared to its concentration. For example, nitrate levels are

closely managed in the Imperial Valley, and levels in soils are quite variable. To achieve a 90%-confidence level that a value for nitrate is within 20% of the true mean, 20 samples are required from a 20-acre field (Table 6). Since zinc is less variable, only eight samples are required. Obviously for nitrate to qualify as a satisfactory STT it must be present at much higher levels in the brine than elements with lower variability in the soil. Some tentative STTs are Li, F, B, and the ratio Sr/Ca.

Sample Preservation

The agricultural baseline-sampling program also currently includes a sample-preservation plan. Soil and plant samples taken by IVEP and any other research agency will be preserved for future analysis. This pool of historic samples should be valuable for establishing prerelease baseline levels of constituents that may be of interest in the future.

Sample Variation

Care must be taken to obtain statistically valid samples. Sampling is dependent upon the number of samples required to obtain an appropriate confidence level. Samples for chemical analysis are selected from a composite of field "grab" samples to reduce the influence of individual plant or soil location. Duplicate

and known samples are included to determine analytical variation.

Plant-Tissue Baseline Procedure

Tissue samples of plants from specific sites are selected at each cluster of geothermal wells. Transects are established along each cardinal point of the compass and at selected distances along each transect grab samples are taken or pooled. To correlate an increase in a component to a geothermal source, rather than to fertilizer, irrigation water, etc., requires a knowledge of management history of the sampled fields. *The four crops - lettuce, alfalfa, melons, and sugar beets - have been identified as target crops, and samples of*

each are taken throughout the valley from existing university, federal, and extension-service field experiments.

Soil Baseline Procedure

Soil samples are taken concurrently with all plant-tissue samples both for the site-specific and the Valley-wide baseline studies of elements. *Additionally, benchmark soil profiles are sampled for comparison with other sampling networks and to act as primary references.* Sites for benchmark sampling are natural, undisturbed, and as close as practical to geothermal development areas. The initial sampling is essentially that of collecting control or reference data.

Table 6. Minimum number of samples required per 20-acre field to obtain selected degrees of reliability of data on soil constituents.^a

	Accuracy, 90%		Accuracy, 95%	
	Sugar beets	Lettuce	Sugar beets	Lettuce
pH	1	1	1	1
Cation-exchange capacity	6	13	9	18
NO ₃ ⁻ N	20	50	28	70
P	29	21	41	30
K	13	15	19	21
Zn	8	10	11	14
Organic matter	21	—	2	—

^aThe data are the minimum number of samples required so that with the given accuracies the true mean for the factor listed will be within $\pm 20\%$ of the mean calculated from the experimental data. Data from Toscano and Ribel¹⁹ based on an Imperial Valley fertility project.

Site locations are carefully marked. Should either a confirmed or questionable geothermal release occur, immediate repeated sampling of the site would be appropriate, as well as sampling at 6-month intervals.

Source-Term Baselines

Acquisition of chemical analysis of geothermal brine, blowdown water, and other sources of potential environmental contamination is not specifically assigned to the Ecosystems Quality Subprogram of the IVEP. *Our panel underscores the need for a rigorous and carefully planned source-term program that should be maintained within the IVEP.* Precise quantitative analysis of brines from each KGRA are required to validate each STT and to identify air and water contaminants. The brine-sampling program must be designed so that variations in element between wells with depth, temperature, flow rate, etc., are obtained. Confirmation of theories regarding consistency of STTs even with large changes in flow rate, KGRA location, and with time is required. *Because a brine leak might occur below the ground and at various stages of brine use, changes in elemental concentrations should be examined as brine moves up the well casing and through various stages of energy conversion.*

Similar information should be obtained on all sources of cooling

water and blowdown water for proper assessment of either intended discharges or accidental releases. The program for acquisition and analysis of brine and cooling/blowdown water should be a continuing one, designed to identify rapidly any changes in source terms with time.

Effects and Recommendations for Reclamation

Problems of Brine Spill

No substantial literature is available for the assessment of possible influences of geothermal energy-related contamination on the agricultural ecosystem. *The IVEP program will include future studies of brine movement through Valley soils, chemical and physical effects on soils, influence of high salt environment on the availability of transition and heavy metals and chemical speciation, and the tracing of brine components through the water-soil-plant system.* Physical characteristics of the soil, such as hydraulic conductivity of brine will be determined and efforts to assess brine movements in the hydrologic region following a hypothetical leak should be made. The need for precautionary measures such as dikes or other barriers, pond linings, holding-pond construction, etc., cannot be properly assessed without

more information on the severity of possible environmental contamination.

Soil Reclamation and Mitigation

Reclamation research efforts will also be included in IVEP agricultural ecosystems effort. Methods of preventing the eventual transport from small areas of contaminated land will be examined, because the first resort will be to accept damage to a small reserved area.

The simple measure of purchase and dedication of a few acres of contaminated land is probably the most prac-

tical method of minimizing further environmental degradation. Leaching of larger contaminated areas will probably be required, but because immediate application of quality irrigation water will probably cause soil structural degradation and thus severely restrict further water movement, staged leaching will undoubtedly be required. The chemical makeup and volume of each leaching stage and the number of stages must be determined for representative Imperial Valley soils by a series of experimental trials.

POTENTIAL PROBLEMS TO WILDLIFE RESOURCES

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Habitat Destruction

Current Problems

The worst problem confronting all wildlife habitats in general is the encroachment of the Salton Sea.

Rising levels of the Salton Sea have reduced the Salton Sea National Wildlife Refuge from 36,000 to 3,000 acres, and this trend is definitely continuing. This rising water level affects the wildlife in many ways.

- Marsh habitat has been adversely

affected through the drowning of cattail (*Typha* sp.) and bulrush (*Scirpus* sp.) stands.

These stands provide nesting and feeding cover for many shore birds such as Clapper Rail (*Rallus longirostris yumanensis*).

- Reduction in the area of mud flats because of rising water levels approaching the diked ponds has resulted in fewer feeding areas for many shore

birds. These birds have been forced to use inland flooded fields to an increasing degree in recent years.

- As the tree vegetation is slowly covered by the rising water level, the nesting sites and roosts for herons, egrets, and some of the shore birds are slowly decreasing in number.
- As the Salton Sea rises and breaches the dikes, the fresh water contained within these areas is suddenly altered. This may result in changes in primary food production with concomitant effects on the food web of these areas.
- Changes in solute concentration within the sea can alter the interrelationships among organisms. Since the trophic structure of the Salton Sea is simple, disturbances at any one trophic level because of salinity changes may result in large changes at other levels.
- As upland areas are flooded, nesting and feeding areas of inland species such as mourning doves, verdins, and other desert nesting species will decrease. Considerable loss of salt cedar may have reduced already some of the mourning dove habitat.

- Increasing levels of saline water are slowly washing away the New and Alamo River deltas, decreasing riverine nesting and feeding habitat.

Expected Problems from Geothermal Development

General Habitat destruction is likely during construction and operations in the immediate area of the geothermal facility and wells.

Breeding and wintering areas for shorebirds, herons, and rails may be lost. Also terrestrial mammals lose habitat where they feed and reproduce. Wintering areas for waterfowl would be lost by construction of roads, well pads, and power plants. This problem is somewhat ameliorated by the positive incentive from hunting revenues that pay for maintenance of suitable waterfowl areas. *Emphasis must, therefore, be placed on problems of resident wildlife that are not hunted when considering the amount and type of habitat destroyed.*

Potential Solutions

When a geothermal plant is constructed and assumes normal activity, the buffer area around the site may be developed in various ways, including the development of wildlife habitat, agricultural areas, recreational areas, or scientific research areas. These buffer zones will be delimited primarily by secondary factors such

as noise effects and airborne pollutants. These topics are discussed elsewhere.

A newly developed wildlife habitat can be used in many ways. Management and manipulation of the habitat can be oriented toward a particular endangered species such as the Clapper Rail or for a number of species that may use the area concurrently, i.e., cattail and mud flats for shorebirds, or open water and tall tree roosts for herons and waterfowl. More general habitat associations may be planned such as salt-cedar or cottonwood-willow stands.

In many operations the opportunity should exist to manipulate the better quality water used or produced by geothermal operations for the creation of wildlife habitat.

Conclusions

Wildlife-habitat destruction resulting from the rising level of the Salton Sea is increasing each year. Losses in marsh, mudflat, estuarine, riparian, and desert uplands decrease feeding, wintering, roosting, and nesting habitat of migrating and resident birds and mammals. Increasing salinity of the Salton Sea or intrusions of seawater into freshwater impoundments effects the vegetation and food resources required by wildlife. Future disturbance of habitat could occur through the develop-

ment of geothermal power plant sites and wells. *Buffer zones or the creation of these critical habitats is possible in or around the geothermal sites to enhance both endangered species or wildlife in general.*

County ordinances could be passed, prohibiting development within the buffer zone around the wildlife-refuge areas or critical habitats.

Powerline Corridors and Local Lines to Power Plants

Important Wildlife Habitat

The Salton Sea and adjacent habitats are of major importance to migratory birds. According to figures compiled by the California Department of Fish and Game, approximately one-third of the shorebird usage of land within the state occurs in the Salton Sea area.²⁰ Large numbers of waterfowl (ducks and geese) use the area, primarily for wintering. *Approximately 3% of the waterfowl harvest for the entire Pacific Flyway occurs in the Salton Sea area, which indicates the magnitude of the area's importance to waterfowl.* The area is also of primary importance to the Yuma Clapper Rail, an endangered species. *Approximately 15% of the total population of Yuma Clapper Rails nest and rear their young in habitats on the south and east of the Salton Sea.*²¹

The importance of the area to several other endangered species is less certain.

The foregoing remarks identify the importance of the Salton Sea and its associated wildlife habitats, principally those on the south and east of the Sea, to three categories of migratory birds: shorebirds, waterfowl, and the Yuma Clapper Rail.

Powerline Impacts

Migratory birds encounter three kinds of problems with powerlines: collision with powerlines, the need to alter normal flight patterns, which in turn exposes birds to added hazards or makes desirable habitat unavailable,²² and disruption of orientation because of electromagnetic effects.²³ Of these problems, the first two are probably more critical, although the third may be important in some cases.

Factors of Susceptibility to Powerline Impacts

Factors that influence the impact of powerlines on migratory birds include (careful analysis may identify additional factors):

- The species of bird. Bird behavior varies by species in flight characteristics and tendencies to avoid strange objects. Also, there are inherent differences in the values of bird species; for example, the impact of a loss of a few Yuma

Clapper Rails would be much greater than the loss of an equal, or even several-fold greater, number of coots.

- Movement of local or migratory birds. Local birds that are familiar with an area are less likely to come in contact with a powerline than are migrating birds meeting an unknown barrier. On the other hand, migrating birds potentially encounter the barrier fewer times. If other circumstances alter movements of local birds (feeding flights, etc.), the impact of powerlines may be substantially increased. Also, local and migratory birds move at different altitudes.
- Time of day. Nocturnal flights are more likely to encounter powerlines than diurnal movements.
- Weather. Storms, wind, fog, etc., alter the altitude at which birds move and reduce the birds' abilities to avoid powerlines.
- The height and configuration of powerlines. Powerlines at altitudes frequently used by birds will obviously cause greater difficulties. On the other hand, anything to make the lines more conspicuous to birds will undoubtedly reduce the hazard.

- The relationship of powerlines to flight patterns and to physical features of the landscape. Bird movements are influenced by many physical features (water courses, terrain, treelines, buildings, etc.) so that they establish regularly used flight patterns. These patterns vary with species and are influenced by factors such as local land use. Powerlines across traditional or well defined flight patterns will create the most severe difficulties to bird populations.

The above factors should be different in each situation of potentially significant interaction between migratory birds and powerlines.

Therefore each situation should be evaluated separately. Ultimately, the importance of a particular migratory bird resource will probably dictate effort that is warranted in minimizing or avoiding the impacts related to powerlines.

In the Salton Sea area, the value of the migratory bird resource is great, and therefore considerable effort is warranted to minimize powerline impacts on the three categories of migratory birds identified earlier.

Potential Solutions

Fortunately, the ways to avoid or to minimize the impacts of powerlines

on migratory birds are fairly simple. Major areas of movement must be identified and these areas must be avoided by powerline construction. These solutions are at least rhetorically simple. Unfortunately, time is too often unavailable to document flight patterns, or there is an unwillingness to consider such information in siting decisions. In the Salton Sea area, fortunately, these pitfalls do not seem likely. Time is available to obtain the needed data, and also there appears to be a greater than usual willingness by planners (including power companies) to protect the important migratory bird resources of the Salton Sea area.

Noise and Disturbance Effects on Wildlife

The noise emissions from geothermal resource development may adversely affect wildlife in various ways. Certainly the development and operation of geothermal power plants at The Geysers and Cerro Prieto have been accompanied by noticeable increases in noise levels. Very little is known about the impacts of noise on wildlife in these areas, although research on this problem is underway at The Geysers.

Noise Potential of Imperial Valley Geothermal Development

Geothermal development in the Imperial Valley will require advanced

technologies to harness the available heat energy. These fall into two basic categories of noise potential. Confined flow systems will not release to the atmosphere any portion of the geothermal fluid. Noise emissions will be comparable, therefore, to standard steam turbine power plants and can be contained in the immediate vicinity of the installation. Flashed steam processes, whether involving direct turbine use or heat exchangers, will release pressure to separate the steam that will propagate a fairly intense noise. The separation strategy will determine the dispersion or centralization of noise at the power plants.

Development operations, including drilling new wells, will continue throughout the life of the geothermal field, concurrently with the electrical generating operations referred to above.

*Recently an extensive series of noise measurements was conducted at The Geysers and Cerro Prieto that provide a good data base on geothermal industry operations at these sites.*²⁴ However, these data do not provide a realistic model that can be applied directly to the Imperial Valley because: The Geysers is a vapor-dominated resource, and the method of brine disposal at Cerro Prieto (a major noise source) presumably will not be utilized at U. S. sites.

The process of geothermal well drilling in the Imperial Valley will probably not involve sound pressure levels (SPL) over 80 dBA at 15 m (50 ft.) because compressed air drilling will not be used.²⁴ No data on well cleanout or production testing are available for the Imperial Valley, but SPLs are not expected to be high for a liquid-dominated resource. During normal operation of a power plant and associated wells, noise sources would include steam separators, steam release valves, the operations in the turbine building, and the cooling tower. Noise measurements are available for the latter two sources and indicate SPLs of 60 to 70 dBA at a distance of 150 to 200 m.

*The general conclusion seems to be that geothermal development in the Imperial Valley will not create noise greater than 80 dBA at 15 m. Noise should drop off to 54 dBA at 300 m.*²⁵ Existing background noise levels in many areas, especially in agricultural lands, are often fairly high, with aircraft and motor vehicles operating freely. Relatively little change should occur with geothermal development.

Impact Potentials of Noise and Development

Impacts on wildlife from geothermal noise per se will probably be minimal

because most of these noise emissions have a relatively low intensity and are steady and continuous. However, intermittent human activity and vehicular traffic associated with construction and maintenance of wells, roads, and pipelines in prime wildlife habitat may pose a greater noise problem, particularly to some species. The Yuma Clapper Rail, because it resides in sound-screening areas of thick cover, is not likely to be adversely affected. *However, waterfowl and shorebirds may be particularly susceptible to such disruption.* While this may not be a serious biological problem in that reproduction and survival of these species will not usually be jeopardized, it may require a compensatory reduction in recreational use of the resource.

Conclusions

The problem of the effects from the noise and disturbance accompanying geothermal development in or adjacent to wildlife habitats is basically a land use conflict. It may well be possible to manage both resources in such a way that the noise and disturbance from geothermal industry operations have minimal impacts that can be compensated by appropriate planning and habitat enhancement activities.

Potential Effects of Noncondensable Gas Emissions

If the Salton Sea and Brawley KGRAs are developed, noncondensable gases are the only effluents that are certain to reach the areas of wildlife refuge and the Yuma Clapper Rail habitat. Therefore, the potential effects of this effluent stream on the overall ecosystems that comprise these areas are questioned. We are concerned not because of known effects that can be anticipated, but because of a general lack of knowledge to predict these effects or to guarantee their absence.

Effects of Hydrogen Sulfide

The noncondensable gas of primary concern at present is hydrogen sulfide. The effects of hydrogen sulfide on diverse members of various trophic levels are unknown. On the other hand, no evidence exists at The Geysers of an impact from the total development on the ecosystems that support wildlife, including avian species, although it may be too early for this conclusion. The ecosystem supporting wildfowl areas surrounding the Salton Sea now exists with the naturally occurring evolution of H_2S from the anaerobic decay in marsh areas.

Other chemicals carried by the noncondensable effluent may be ultimately of more concern. Volatile

compounds of As, Se, and particularly Hg, if emitted, may have deleterious effects on bird populations through food chain transport and accumulation of toxic levels. Sufficient information probably exists to evaluate these possible effects after a source-term for these compounds is established.

Thus, while we have no specific information to suggest an effect from noncondensable gas emissions, the possibility should be investigated by effects or assessment studies.

Secondary Impacts of Geothermal Energy Development on Wildlife Resources

Geothermal energy development in Imperial Valley may have secondary impacts on wildlife habitat that could occur through: increased human population, increased industrial development, increased consumptive water usage for power plant cooling, or increased recreational use of wildlife habitat areas.

Increased Human Population Pressures

Estimates of increased employment opportunities at geothermal electrical generating facilities are relatively modest. Development of the well systems for power plants would require approximately 24 persons per drill rig. One or two rigs would probably be needed permanently in each geothermal field or KGRA, to give a total of perhaps 200 persons employed

throughout the Imperial Valley.

Operation and maintenance of production and reinjection wells and pipelines might employ another 5 to 10 persons in each KGRA, to give a maximum total of 40 workers. Operation of the power plants themselves would involve about 20 persons in each KGRA to give a total of 80 employees. Increased employment directly attributable to the geothermal industry would thus amount to several hundred jobs at most. The total increase in resident population would be about 1000, counting families of employees. This is a small increment relative to the present Imperial County population of 80,000 especially because not all workers may be new immigrants to the Imperial Valley.

Although increased population would certainly lead to greater demand for recreational facilities, it is unlikely that the resulting use of State and Federal wildlife areas would be significantly greater.

Major industrial development related to geothermal industry expansion is not anticipated. The electrical energy generated in the Imperial Valley will not be significantly cheaper at its source. The main beneficiary of geothermal development will be the service segment of the local economy. Non-electrical uses of geothermal heat energy may be implemented

in processing agricultural products, but the types of crops that are produced do not generally require energy-intensive processing.

Conflicts over Water Usage

Water consumption for evaporative cooling in electrical generating facilities may use up to 10% of the flow to the Salton Sea for a total capacity of 1000 MW. This will certainly reduce the flow to the Sea and may help stabilize the water level, which would be beneficial in preserving wildlife habitats. However, fresh water or agricultural waste water must still be made available in sufficient quantities to wildlife refuge areas to maintain essential habitat management programs. Power

plant water requirements probably would not be great enough to create shortages that would imperil the supply to wildlife areas. Beneficial effects may be achieved by creating new habitats at impoundments of cooling water for the power plants.

Conclusions

In summary, then, increases in human populations or in industrial development resulting from the utilization of geothermal resources probably will not produce serious pressures on wildlife habitat. Water demands for power plant cooling may have beneficial impacts if water supplies for wildlife areas can be assured as geothermal development progresses.

AQUATIC ECOSYSTEMS AND GEOTHERMAL DEVELOPMENT IN THE IMPERIAL VALLEY

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The Imperial Valley aquatic ecosystem can be divided into two specific, although overlapping, systems: the marine ecosystem of the Salton Sea and the freshwater ecosystem dominated by the New and Alamo Rivers with contributions from numerous

freshwater drains. The former, the result of an initial flooding by the Colorado River and subsequently maintained by natural runoff and irrigation-return flows, has developed into an extensive recreation resource with the introduction of the Salton Sea

Sport Fishery. The latter, strictly a corollary benefit of the extensive agricultural development in the Imperial Valley, supports a highly abundant and complex freshwater ecosystem.

The existing stress on the above ecosystems is twofold. *The extensive use of fertilizers and pesticides places a constant pressure on the freshwater species.* There exist 31 documented cases of fish kills in the freshwater drains resulting principally from inadvertent pesticide releases (thiodan, DDT, parathion).²⁶ Conversely, a recent study that assessed the pesticide influence on components of the Salton Sea (barnacles, pileworms, fish, substratum, and water) found little or no pesticide pressure on the marine ecosystem.²⁷

Potential Aquatic Hazards from Geothermal Resource Development

The potential impact of geothermal resource development upon the aquatic ecosystem will naturally depend upon the extent of development. Principal hazards might result from inadvertent spills of geothermal brines, inadvertent leaks of geothermal brines, releases of blowdown water, and contamination of recycled cooling water. Impacts might be immediate killing of local aquatic life resulting from osmotic and thermal stress, and long-term chronic effects from elevated

levels of heavy and transition elements.

Salton Sea Ecosystems

Lower Trophic Level: Benthic Worms

The pileworm, *Nereis (Neanthes) succinea*, was introduced into the Salton Sea in 1929 by personnel of the California Department of Fish and Game, along with numerous other live bait, in preparation for the introduction of a striped bass fishery. The striped bass were not successful,^{28,29} but the pileworm survived to become crucial to the present sport fishing (see Food Chain, Fig. 6).^{30,31}

By the mid 1960's, the pileworm was one of two dominant benthic invertebrates, along with the barnacle *Balanus amphitrite*. The pileworms breed year round with only minor seasonal variation.^{32,33} The planktonic pileworm larvae are important zooplankton feeders of phytoplankton.^{30,34} After metamorphosis, the pileworms are principally detritus feeders.

Carpelan and Linsley^{32,33} estimated pileworm densities of up to 2,000 worms/m² and 60 to 70 g/m² in the most favorable shoreline substrates. Assuming an average of 40 g/m², extrapolating over all the suitable shoreline habitat, and incorporating seasonal variation, one arrives at a pileworm biomass of 8,700 tons in the summer, 14,500 tons

Fig. 6. Feeding relationships in the Salton Sea in 1967. Modified from D. Young.³⁰

in the fall, and 34,800 tons in the spring (75, 125, and 300 lb/acre, respectively). Present densities are comparable to those in the mid-1950's.³⁵

This immense biomass of pileworms is cropped extensively by the fishes. The sargo and croaker feed primarily on pileworms; young corvina feed on pileworms, and then on croakers as adults.^{28,29} There are other benthic invertebrates, chiefly the barnacle, that are cropped to some extent by the

sargo, and an amphipod, *Gammarus mucronatus*, whose ecological role is unknown. Neither of these are prominent in the food chain supporting the sports fishery; hence, with the present ecological system of the Salton Sea, failure of the pileworm would result in collapse of the sport fishery.

Studies on environmental factors affecting Nereid polychaetes have related primarily to effects of low salinities.^{36,37} *Nereis succinea* is

typical in being an osmotic conformer whose osmoregulation is limited to salinities less than 25 to 35% seawater. At lower salinities it is a hyperosmotic regulator, although it cannot survive in freshwater.³⁸ The two environmental factors endangering the survival of the pileworm in the Salton Sea are the increasing salinity of the sea and the possibility of trace metal contamination resulting from geothermal energy development.

Salinity Effects on Pileworms. A brief study³⁹ indicated that acute exposure of Salton Sea pileworms to concentrated Salton Sea water did not cause a significant 4-day mortality in salinities as high as 67.5%. Oglesby (unpublished communication) observed long-term survival of adult Salton Sea pileworms in salinities of 60 to 65%. *The adult pileworm seems to have a great tolerance for high salinities.*

Smith⁴⁰ studied the effects of salinity on reproduction of *Nereis diversicolor*, primarily addressing the effects of low salinity. In this species, fertilization, cleavage stages, and early larval stages were all much more sensitive to high and low salinities than were adults. This pattern is consistent with less complete observations on other species.^{36,37} Hargreaves, a Pomona College student, worked on high salinity effects on the reproduction of

Salton Sea pileworms. His results, however, were inconclusive because of bacterial contamination.

More comprehensive studies on the effects of elevated salinities on reproductive success should be conducted. Preliminary studies indicate that fertilization of heteronereids (sexually mature swarming adults) collected from the Salton Sea can be successful in the laboratory and that development can proceed normally up through the neotochaeta stage when the larvae begin to feed. We will concentrate on studies of reproductive success of Salton Sea pileworms in elevated salinities to establish salinities at which reproduction is depressed significantly and elevations of salinity at which reproduction is quenched completely. The synergistic effects of temperature variation will be incorporated into the above studies.

Heavy and Trace Metal Contamination of Pileworms. Annelid polychaetes were employed in a variety of studies on the uptake, accumulation, and sensitivities to heavy and other potentially toxic metals. Studies by Hogg²⁷ on organochlorine pesticides and by Young³⁰ on K, Cs, and Rb indicate that pileworms take up such substances from the detritus in the Salton Sea, that they concentrate these substances to varying levels,

and that fish feeding upon the worms may concentrate these substances even more. *Based on these studies and our own experience with the pileworms, we conclude that pileworms in the adult stage are useful indicators of localized metal concentrations in the Salton Sea and that egg and larval stages are useful in defining environmental stress by their reproductive mortality.*

Quarterly samples of pileworms were obtained from four sites around the Salton Sea: Mecca Beach, Desert Shores, Elmore Ranch, and the South Shore Wildlife Refuge. These represent a well-placed geographic spread and should be continued for baseline input on the availability and numbers of the worms as well as background metal concentrations in their tissues. In conjunction with the sampling of adults, a quarterly sample of larvae should be taken by a plankton tow. The numbers of larvae thus obtained will be useful in extrapolating the biomass and the fecundity of the worms.

Additionally, new sites will be chosen emphasizing the southeastern shore and corresponding to the Salton Sea KGRA. These sites will include the Wildlife Refuge, Red Hill Marina, Wister Wildlife Area, Niland Marina, and Bombay Beach. This new emphasis will provide closer monitoring of

localized concentrations of trace elements that are related to geothermal brines and better surveillance for leaks or other unapparent intrusions of heavy metals around the Salton Sea KGRA. Sampling will not only include an ample supply of adult pileworms for trace metal analysis, but also a sediment sample from each location and a measurement of water such as salinity, conductivity, temperature, oxygen tension, and pH. We hope that this type of monitoring will help establish positive correlations among geothermal brine leakage, metal concentrations in worm tissues, deposition of heavy metal in sediments as well as information on the transport of such metals in the counterclockwise current flow of the Salton Sea.

Food-chain Transfer of Metals.

Experimentation is needed to determine the degree of concentration of heavy metals attained in the detritus-to-worm-to-fish food chain. *Bardiella* and young corvina feed extensively, if not exclusively, upon pileworms.²⁹ Worms placed in a sublethal environment of increased heavy metals tend to conform to that stress by concentrating these metals in their tissues.⁴¹ Young fish should be fed upon worms that are adapted to elevated sublethal levels of a trace element such as Zn that is known to occur

in geothermal brine. A tracer study with ⁶⁵Zn would determine the extent of concentration by the fish.

Indices of Environmental Stress in Pileworms. Environmental stresses are measured accurately by reproductive success. Sexually ripe heteronereids should be gathered and fertilization affected in the laboratory. The trochophore (egg) and neotochaeta (larval) stages of the pileworm can be cultured and subjected to a variety of stress situations. *We recommend a study of the toxic effects of different heavy metals, singly or in combination.* Additionally, contributions of synergistic effects of environmental factors such as salinity and temperature upon the toxicity of heavy metals should be examined, as suggested by Jones *et al.*⁴² Experiments with egg and larval stages would be realistic and valid indicators of the impact of elevated loads of trace elements related to geothermal energy production.

Salton Sea Fishes

Baseline Study of Salton Sea Fishes. The development of a geothermal power plant in the Imperial Valley might have adverse effects on fish populations in the Salton Sea. *Spills of geothermal brines into the sea might have acute or long term*

chronic effects on the fish. The baseline study will involve "fingerprinting" trace element concentrations in various organs of the fish, i.e., kidney, muscle, liver, gonad, bone, skin, and heart. Trace element concentrations in the tissues are being followed because many trace elements are concentrated in the geothermal brines.⁴³ Fish species that are sampled are the orangemouth corvina (*Cynoscion xanthulus*), gulf croaker (*Bairdiella icistia*), sargo (*Anisotrenius davidsonii*), *Tilapia zillii*, and the Mollys (*Molliensie latipinna*). Fish are collected by the standard gill net except for Mollys, which are collected by hand net in the irrigation ditches near the Red Hill Marina. Other fish are collected at the Salton Sea State Park at two locations. All fish are collected quarterly (October, January, April, and July). At each collection site, abiotic data gathered include water temperature, dissolved oxygen, and salinity. The trace element composition of Salton Sea water at the Salton Sea State Park is being determined.

Along with trace element "fingerprinting," morphometric measurements on each fish sample are made. Morphometric data include age, length, weight, gonadosomatic index, fin-ray count, liver weight, and stomach contents.

Toxicity Studies of Salton Sea —
Current Program. Geothermal brine spills will cause increased salinities in the Salton Sea, although the immediate increase in salinity will be only local. Increased salinities (those above 35%) are detrimental to the eggs and larvae of most teleosts.^{28,29,44,45} *Eggs and larvae of teleosts are more susceptible to salinity variations than are adults, because of underdeveloped organs for osmoregulation, i.e., gills and kidney.*

Experiments will be conducted to study the effects of salinity and geothermal brines on the eggs, larvae, and juvenile orange-mouth corvina. A study of salinity toxicities will enable differentiation between purely osmoregulatory problems caused by the geothermal brines and toxicity resulting from elevated levels of trace elements in the brines. Toxicity to fertilized eggs at different salinities and geothermal brine concentrations will be determined by percentage hatch similar to the study by May.⁴⁵ Toxicity in the larval and juvenile corvina will be determined by mortality. Salt concentrations in the experimental media for the salinity and geothermal brine studies will be kept equal. Experiments with eggs and larvae will also be performed at different temperatures.

Chronic studies should follow acute toxicity studies. A chronic geothermal brine study of juveniles should include trace element analysis of tissue digests of dead fish. Trace element accumulation by various organs of the corvina can then be determined.

Temperature and Oxygen Effects. Temperature variations in the Salton Sea are large.³¹ Synergistic effects of temperature and salinity on the eggs and larvae of the gulf croaker *Bairdiella icistia* were demonstrated by May.⁴⁵

Respiratory experiments on juvenile corvina should also be planned to determine the effects of sublethal salinity and geothermal brine concentrations on the metabolic rate (determined by oxygen uptake) and on the critical oxygen tension. In other words, will salinity or components of the geothermal brines affect the oxygen tension of the water at which the respiratory rate of the fish begins to decline. Oxygen concentrations vary hourly in the Salton Sea and may become extremely low in the water column.³¹

Heavy Metal Effects. *Trace elements found in cooling tower discharges or geothermal residuals such as Zn^{++} might be problems.* Geothermal brines contain high concentrations of Zn^{++} .⁴³ The gills of the New Zealand

rainbow trout, *Salmo gairdneri* have approximately 12 times the Zn^{++} concentration of its muscle.⁴⁶ Since the gills of fish are important in electrolyte balance, Zn^{++} accumulation in this organ might interfere with osmoregulation and water balance. Therefore, an experiment should be performed with sublethal concentrations of Zn^{++} to determine if this element is accumulated in the gills of juvenile corvina. At the same time, plasma Cl^{-} concentrations should be determined. The accumulation of Zn^{++} in the gill may alter plasma Cl^{-} concentrations, and consequently interfere with osmotic balance.

Biomass as an Indicator of Productivity. Estimates of corvina biomass in the Salton Sea might serve as an important index of change in the productivity of the Sea with respect to the development of geothermal power in the Imperial Valley. Data on corvina biomass are needed to compare present productivity with estimates for the future. Biomass data are also needed for predictive models of the effected goethermal development and is desired by the California Department of Fish and Game for fisheries management.

Estimating fish biomass is extremely difficult. Patchiness, the main problem in this estimation, requires numerous sampling stations.

Corvina biomass will be estimated by a survey of eggs and larvae and by adult fish densities at selected stations on the Salton Sea.

Current Program for the Survey of Eggs and Larvae. A survey of the eggs and larvae will determine the number of each per unit volume of Salton Sea water. This along with fecundity, average hatch time of the eggs, average number of batches of eggs produced each year, and length of the spawning season will allow an estimate of corvina biomass.

Experimental design and techniques for collecting, preserving, and counting the eggs and larvae follow the protocol set by Kramer *et al.*⁴⁷ Oblique plankton tows are performed with a 1-m, 505- μ mesh plankton net. Thirty-six sampling stations running along three transects (12 stations per transect) the length of the Salton Sea are designated for plankton tows. Four additional sampling stations, two each at the mouths of the New and Alamo Rivers will be used to determine if spawning takes place in these areas. Walker³¹ reported that corvina gather near the mouths of the New and Alamo Rivers in the spring, and spawning usually occurs in the late spring or early summer months.

The data gathered at each sampling station will include:

- The number of eggs per unit volume of Salton Sea water, and
- The number of larvae at different stages of development in a unit of Salton Sea water.

Direct Assessment of Adult Fish Densities. The second method for estimating corvina biomass involves capture of adult corvina at four California Fish and Game sampling stations on the Salton Sea. This estimate of corvina biomass was performed only once, at the peak of the corvina spawning season. Samples are taken by the standard gill net, and the data gathered at each station are:

- The number of male and female fish captured,
- The number of eggs per unit body weight per female corvina, and
- The number of fish per station per unit of fishing effort.

Freshwater Ecosystems

The Imperial Valley is located in the drainage basin of the Colorado River Valleys to the Salton Sea. It is one of four major agricultural valleys within the Colorado River Basin (others are the Bard, Palo Verde, and Coachella Valleys). The land within the Colorado River Basin is generally flat in the agricultural areas with outlying mountain ranges.

Water is provided to the agricultural areas by the Colorado River. The All American Canal transports water across the desert to the Bard, Coachella, and Imperial Valleys. Farm drainage waters originating in the Imperial Valley are conveyed to the Salton Sea by the New and Alamo Rivers. The Coachella Valley Stormwater Channel conveys agricultural waste waters from the Coachella Valley to the Salton Sea. The total watershed draining to the Salton Sea is sometimes called the Salton Basin, which is contained within the Colorado River Basin of California and the Mexicali Valley in Mexico. The Salton Basin comprises an area of about 7500 mi².

Freshwater Aquatic Resources

The need for protection of the freshwater aquatic habitat was established by the California Department of Fish and Game records of fish kills.²⁶ The California Department of Fish and Game indicated that major freshwater wildlife resources live in or are associated with canals, rivers, and drains in the Colorado River Basin Region. The Department of Fish and Game further stated that those aquatic resources are threatened by pollutants from agricultural sources (pesticides and herbicides). The addition of geothermal brines and heavy metals

from the development of geothermal energy in the Imperial Valley increases the possible overall threat to both freshwater and marine fauna of the Colorado River Basin.

The freshwater aquatic resources of Imperial Valley lakes are largemouth bass, channel catfish, threadfin shad, sunfish, and bluegills. The canal and lateral systems usually support largemouth bass, channel catfish, bullhead, bluegill, carp, and minor fish; occasionally striped bass and black crappie populations are significant.

Most of the freshwater sport-fishery occurs in these systems. The New and Alamo Rivers may also contain smaller numbers of these species, but the water-quality management of these rivers is primarily directed toward them as an agricultural drainage system, so that levels of pesticides, phosphates, nitrates, and other residues are not optimized for sportfishery.

The agricultural drains support the economically important herbivorous fish, *Tilapia*, and fish such as carp, mosquitofish, mollies, other minor fish, and occasional smallmouth bass.

In general, the inventories of fish are inadequate in the freshwater system and the populations are very patchy.

Fish Likely to be Impacted by Discharges

The California Department of Fish and Game clearly established that important fish populations are present in Imperial Valley drains. These populations are severely limited by pollutants from agricultural sources. The Department of Fish and Game did not estimate dollar equivalents of the value of this wildlife resource, and, in fact, the Department considers dollar equivalents inadequate to describe the true value of this resource.

*The IVEP proposed the use of the mosquitofish, *Gambusia affinis*, an important member of the aquatic community (rivers and drains) of the Imperial Valley as an indicator of dangerous levels of pollutants.*

Gambusia, sometimes also called the top minnow, is an excellent indicator of aquatic contamination, especially of pesticides, herbicides, and heavy metals in fresh water.^{48,49}

The mosquitofish, family *Peocilidae*, was introduced into the Imperial Valley sometime before 1929. It is native to the eastern United States, but was widely distributed during the early part of this century to aid in mosquito control. It is common in the fresh waters surrounding the Salton Sea, particularly the drainage systems and the two rivers (New and

Alamo). This habitat makes them ideal indicators of not only pesticide and herbicide contamination, but also salinity and heavy metal increase in the numerous drains in the Imperial Valley.

Bioassaying for Pesticides and Herbicides in Freshwater. A series of 48- and 96-h LD₅₀ bioassay methods are being used to determine the acute toxicity of selected pesticides and herbicides currently used in agriculture in the Imperial Valley. The pesticides to be tested are Parathion, Lindane, Dieldrin, and Sevin. The herbicides to be tested are Decamba, 2,4,5-T and 2,4-D. These bioassay procedures will be designed for static- and continuous-flow systems and conducted as outlined by Spague.⁵⁰

Bioassays for Tolerance to Salinity and Heavy Metals. A series of 48- and 96-h LD₅₀ bioassays methods will determine the salinity tolerance and toxicity of selected heavy metals found in blowdown water and geothermal brines. The metals that are tested are Fe, Mn, Zn, and Cu. Bioassay procedures will be improved for both static- and continuous-flow systems as outlined by Sprague.⁵⁰ Combinations of pesticides, herbicides, and heavy metals will be tested for synergism and antagonism.

Bioassays are conducted with varying fish densities to determine

changes in measurable tolerances and toxicities with heavy or light fish loading.

Dilution water for these tests is Salton Sea water, drainage water from the Imperial Valley's agriculture drains, and water from the New and Alamo Rivers.

A Standard Bioassay Procedure for Gambusia. *Collection.* *Gambusia* are best collected in relatively shallow water. Using a pair of waders, the collector walks in waist to knee deep water 6 to 8 ft from the shore with a fine mesh dip net. *Gambusia* can be scooped up easily and transferred to holding jars for transport to the laboratory. The length of the fish that were collected ranged from 20 to 60 mm.

Laboratory care. After collection the fish are treated for 24 h in 2.5% nonionized NaCl to remove fungus and tail rot (only fish collected from the heavily polluted water should need treatment for tail rot). The fish are then placed in fresh water and held 1 to 5 da before preliminary testing. Fish are fed oatmeal flakes daily. Water temperature in the holding tanks should be adjusted to room temperature (21°C). Controlled red light and aeration are unnecessary if the tanks are large enough.

Guidelines. *Gambusia* is one of the hardiest fish known. It flourishes

in a very stagnant water, providing, of course, that a proper amount of food is available. It thrives in the aquarium, and lives equally well in salt (up to 40%) as in fresh water. It may be plunged directly from one into the other without any apparent harm. These

characteristics make it ideal for bioassays of the pesticide and herbicide threat to aquatic life of the drainage systems in the Imperial Valley as well as to the heavy metal and salinity problems that could result from geothermal energy production in the area.

POTENTIAL EFFECTS OF AIR POLLUTION FROM GEOTHERMAL ENERGY CONVERSION

Effects of Air Pollutants on Vegetation from Geothermal Energy Conversion

The noncondensable gas fraction of geothermal steam usually consists of about 80% CO_2 and lesser amounts of H_2S , H_2 , CH_4 , N_2 , and NH_3 , as well as minor trace gases.⁵¹ The concentration ratios of minor gases to CO_2 apparently vary from well to well, depending on geophysical factors and well depth. *However, based on data on liquid-dominated fluids from the best documented sites we will assume a ratio of 15 CO_2 :1 H_2S with approximately equal amounts of H_2S , CH_4 , H_2 , and N_2 .*^{51,52} We expect particulate air pollutants to be primarily in the form of salt-aerosol drift from cooling water plumes. The aerosol will evaporate to solid particulate form

as the plumes entrain drier air, so that drift deposition will be liquid spray only at distances that are relatively close to the source. The particulate composition will be largely NaCl , but will also include elements either from geothermal brine or corrosion inhibitors. The composition of the mix will vary with each cooling water site.

An economic assessment of air-pollution effects on vegetation must consider the geothermal source-term emission rate and atmospheric transport to ground level. However, these are beyond the scope of this discussion. We will assume that the ambient concentration of pollutant gas is satisfactorily obtained by either prediction or measurement, and will discuss other requirements for an

economic assessment of possible air-pollutant damage to plants. We should consider problems in yield estimates, methods of controlled fumigation to determine plant response, ecological interactions of plants with other species, methods of quantifying response, and finally the inventories of crops and native plants.

Deposition of Pollutants

Estimation of the responses of agricultural and native plants to potential stress by geothermal air pollutants should begin with considerations of the rate of uptake (dry deposition) of the gases by the plants and the biological factors that are rate limiting. A given ambient concentration of gas and a given set of meteorological conditions (wind speed and thermal stability) are rate-limiting factors only when the vegetation is a perfect sink. Hill⁵³ showed that deposition rate depends on the solubility of the gas in cell sap. The fraction of gas that is reactive on the external leaf surfaces and the composite resistance to gaseous diffusion across the leaf boundary layers and the stomatal pores are also important factors.⁵⁴ The stomatal resistance to diffusion of water vapor from ambient air to internal leaf cells is approximately inversely proportional to the net radiant energy absorbed by the leaf.^{55,56}

The leaf boundary-layer resistance is approximately inversely proportional to the square root of the wind speed.^{57,58} The factors influencing air-pollutant uptake by plants was reviewed recently.⁵⁹ *A given ambient concentration of air pollutant may produce different responses at different times.*

Yield Estimates

To evaluate yield losses over a region with a pollutant gradient, a large-scale yield model should be used. At selected sites along the gradient, controlled plots are needed with adequate biometeorological monitoring equipment. Yields are then compared with that of a nonfumigated plot, and the yield loss is predicted from a multiple regression model containing the uncontrolled variables. This approach was successful in the California South Basin in evaluating the role of oxidants in the reduction of alfalfa and tomato yields.⁶⁰⁻⁶² It will not be directly applicable in the IVEP until electrical power production begins, but a preliminary study would establish a baseline for later comparison in a before-and-after study.

Life-stage Dependencies. *Different developmental stages in the life cycle of plants might be affected by various degrees of noncondensable geothermal gases. Other air pollutants such as ozone and peroxyacyl*

nitrate cause selective injury to tissues at specific developmental stages.^{63,64} Besides CO_2 , H_2S might be the most abundant, noxious gas resulting from geothermal energy conversion and its effects on various stages of plant development must be studied in detail.

Studies on successive stages of development are needed (suggested methods are discussed later). As seeds germinate and emerge, symptoms such as changes in the duration of developmental stages, reduced germination, high mortality, fungal "damping-off," and either necrosis or premature senescence of juvenile and expanding foliage should be anticipated. As the plant enters the reproductive stage, reduced incidence of flowering, necrosis of flower parts, and abortion of entire blossoms should be anticipated. The effect on the leaf area and biomass should be measured. Some pollutants cause reduced pollination. Viability of pollen should be determined. If nectar production is halted, beneficial pollinating insects will avoid the flowers. Even if pollination occurs, other effects might cause reduced fruit or seed production.

Gas Mixtures. *In addition to the effects of H_2S alone, the total mixture of geothermal gases (CO_2 , H_2S , NH_3 , etc.) should be investigated to*

determine the effects on vegetation in a given area. Preliminary studies show that CO_2 ameliorates the effect of H_2S acting alone.^{65,66} At low concentrations of a simulated geothermal gas mixture, growth of several Imperial Valley crop plants was enhanced in two independent studies. This approach should be expanded to determine fully the effects of pollutants before the actual development of a given geothermal resource.

Determination of the Response of Plants to Air Pollution

The effects of H_2S on vegetation were studied earlier by exposing selected species to high concentrations, i.e., 40 to 400 ppm for periods that were as short as 2 to 4 h.⁶⁷⁻⁶⁹ Young foliage was injured; but until recently H_2S was considered as relatively nontoxic, because these levels were so much higher than suspected ambient levels and greater than levels of other highly injurious pollutants.

Present studies show that continuous exposures to 0.30 ppm H_2S will cause injury to a number of plant species. Because many plants respond to the total dosage of pollutants, several regimens of exposure will be tested. We must determine the effects of short-term, high-level, repeated exposures as well as of long-term,

low-level exposures and intermittent, low-to-moderate levels of exposure.

Controlled Fumigations. *Studies on the responses of plants to geothermal air pollutants should simulate the conditions in the field as much as possible.* Studies should include short-term, high-dosage exposures that would occur close to a source where a plume falls to the surface. This could be simulated in an exposure chamber by daily programming of a dispensing system of a mixture of pollutants. A suggested schedule is 7.2 ppm H_2S for 30 min beginning at 09:00 a.m. followed by a second 30-min exposure to the same concentration at 11:30 a.m. At other times clean air would be provided to the test plants. This total daily dosage would be equivalent to a continuous dosage of 0.03 ppm, which previously reduced growth and produced lesions in alfalfa, grapes, Douglas fir, and lettuce. The addition of CO_2 at 15 times the amount of H_2S plus a volume of NH_3 roughly equivalent to the H_2S should simulate the total mixture of noncondensable gases that are emitted at many geothermal sites.^{51,52} Plants could be exposed to continuous low concentrations of pollutants by procedures similar to those described above. This would simulate the exposure of vegetation

at some distance from a source where prevailing winds cause a somewhat continuous exposure for several hours during the day. During the night, low inversions and static conditions might cause the accumulation of higher levels of pollutants. Suggested levels of H_2S such as 0.010 ppm for 8 h from 10:00 a.m. to 6:00 p.m. followed by 16 h at 0.040 ppm again equals the total daily continuous exposure of 0.030 ppm that was described previously. Plant response would be evaluated as before.

A third mode of exposure would simulate the condition in which plants grow in an area close to a concentrated source and are exposed continuously for several hours or days before a weather change dissipates the pollutants. In this kind of exposure the vegetation would be subjected to 0.060 ppm H_2S for 3 d followed by zero concentrations for a similar period, etc. This dosage again equals that used previously, but will also test the recovery mechanism of the exposed plants.

Effects of Fumigation on Ecology.

To evaluate the *full* impact of geothermal emissions on higher level interactions in agricultural systems that are representative of the Imperial Valley, several other ecological concepts should be considered. *We should know the effects of high levels*

of H_2S and CO_2 on host-parasite relationships of important agricultural pests, on important plant pathogens and interaction with disease syndromes, on plant competition with weed infestations, on the interactions with current herbicide and pesticide use, and finally on any density-dependent population-control mechanisms in the plant populations themselves. Some of the effects of single pollutant gases on these interactions were studied, but the results are equivocal and cannot be generalized. Since ozone is already present in Imperial Valley, synergisms between O_3 and H_2S might exist; therefore, appropriate mixtures must be included in our studies. A project of this type has already begun within the IVEP.

Quantitation of Plant Response.

Economic impact can also be facilitated experimentally using controlled fumigations, if a quantitative analysis can be made of whole plant response to pollution stress. Measurements of plant response should include relative growth rates, crop growth rates based on ground area, canopy size relative to ground area (Leaf Area Index) and biomass (Leaf Area Ratio), net assimilation as a function of leaf area, leaf weight per unit leaf area (Specific Leaf Weight), weight partitioning ratios

and coefficients, including the ratio of economic yield to total biomass yield (Harvest Index), internal water balance (ratio of dry weight to fresh weight), the ability of the crop stand to intercept radiation and convert it into dry matter (light utilization efficiency, percent cover, etc.), the efficiency of the light receptor system in the leaves (chlorophyll a/b ratio), and nutrient uptake efficiency (N, P, K, and particularly S levels in the leaves). Crop physiologists and ecologists have studied these variables in great depth to correlate them with yield. A few studies of the effects of ambient levels of O_3 on growth of clover, ryegrass, and carrots show significant changes in canopy size and light utilization efficiency thus changing partitioning within the plant.^{70,71}

While total yield may be unaffected, economic yield can be significantly reduced. It is then possible to predict loss in economic yield as a function of dose or synergistic actions of pollutants by statistically relating dose to the weight partitioning function.

Pollution stress might be ameliorated in Imperial Valley by agricultural practices, such as changing fertilizer use, if nutrient uptake increases as a result of fumigation and yield loss is insignificant.

Nutrient and fumigation interaction must be studied also.

Vegetation Inventories and Average Yield. After obtaining adequate measurements of the response of plants to air pollutants, additional data are required before an economic assessment of vegetation damage can be made. If an hourly assessment is required and the detail of meteorological data permits, *downwind inventories of vegetation must be obtained on a field-by-field basis so that each crop or native plant population can be assessed separately.* On the other hand for long-term, annual averages, a mean, regional crop-distribution list may suffice. The average yield of each crop must be known to determine relative economic loss.

Special Considerations

Particle drift. Cooling water drift provides a special problem for economic assessment. *Wet deposition of liquid aerosols causes much more salt damage to local vegetation than the more distant deposition of dry particles.* In the Imperial Valley dry particles greater than a few micrometers in diameter probably will be transferred rapidly to the soil where, in agricultural areas, they are likely to contribute insignificantly to the total saline material

normally managed by flood irrigation methods. However, small, dry particles can be taken up by the plants through the stomata. *The collection efficiencies of these submicron-sized particles by plants is not very well known.*

Nonagricultural Vegetation. The estimation of air-pollutant effects on native plants can parallel that on crop plants *but quantitation of responses is more difficult in native plants because of the heterogeneity of the standing biomass and the natural variability in the unevenly aged, multispecies plant communities.* In principle the same methods of controlled fumigation may be applied, but the experimental conditions might require closer definition than in crops, and the interpretation of the results might require the aid of a model of species interaction.

Effects of Geothermal Gases on Pollinator Insects

Apiary production in Imperial Valley is a significant secondary component of the agricultural economy. In the reference period 1973-1974, honey production from 41,000 colonies averaged 57 lb/colony (25.9 g) for a total of 2.3×10^6 lb (1.06×10^6 g). Another 29,000 colonies were used to pollinate economically important crops.

Available literature on the response of insects to geothermal gases is sparse. Weedon showed that houseflies have nearly the same mortality as rats and mice when exposed to high concentrations (1000 ppm) of H_2S .⁷² The more extensive literature on rats and mice shows that repeated 12-h exposures to H_2S concentrations as low as 0.7 ppm causes functional and morphological changes.⁷³ Preliminary studies show that pollinator insects might be sensitive under certain conditions that are described later.

Economical assessments of possible damage from air pollution resulting from geothermal energy conversion should include secondary effects such as the loss of seed-producing crops because of reduced pollination, as well as a loss of honey production in fields adjacent to power plants. Initially we will assume that the analysis of geothermal gas source term and atmospheric transport is sufficient to allow a prediction of concentrations at distances from the geothermal source.

Gas Deposition to Pollinators

We can assume that behavioral and physiological avoidance mechanisms are unimportant to the honeybee to reduce its exposure to gases. Preliminary tests of continuous exposure

of caged honey bee workers to various concentrations during mortality and longevity studies indicate that they apparently have no avoidance or other discernable behavioral responses. Honeybees are capable of closing their spiracles quickly for short periods (about 15 s) to acute stresses such as noxious gases and small dust particles.

Productivity of Honeybee Colonies

Temperature Stress. The erection and maintenance of permanent or temporary sunshades for honeybee colonies is common practice in the Imperial Valley since ground-surface temperatures often reach or exceed 150°F, the approximate temperature at which beeswax melts. It is also imperative that water, of a quality that bees will use, is available continuously to enable bees to cool their brood nest to 94°F. *The relationship between the stresses of temperature and air pollution is yet unknown.*

Quantitation of Responses. Honey production is influenced by the following factors:

- Condition of colonies, which can be measured by colony weight gain per day.
- Density and number of colonies per acre. If too many bee colonies are located in an area

for the amount of available forage, there will be no surplus honey stored, resulting in a net loss because bees will use up hive stores.

- Amount of cotton, hay, alfalfa, and the few acres of citrus in the Valley, which are primary nectar sources for honey production.
- Amount of native plants, such as mesquite and tamarisk, that are also primary nectar sources for honey production and colony sustenance.
- Plant nectar availability, which varies with temperature and water stresses. Seed alfalfa and cotton cease nectar secretion completely near mid-day.⁷⁴

Honeybee Pollination. Pollination efficacy is characterized by:

- The duration and frequency of visits to plants. These data are called foraging profiles. Some data are available now under typical conditions.⁷⁵
- The acreage of seed alfalfa, seed onions, and cantaloupe. These are important crops in Imperial Valley for which pollinators are contracted. Seed alfalfa and seed onions both require honeybees for effective cross-pollination to set seed,

while cantaloupe requires cross-pollination to improve quantity and quality of fruit.⁷⁶

Honeybees are the only significant, manageable pollinators in the Imperial Valley. The hot, dry climate essentially eliminated the survival of other manageable pollinators such as the alfalfa leafcutter bees, *Megachile pacifica* (Panzer), and the alkali bee, *Nomia melanderi* Cockerell.

Usually little or no honey is produced while bees are used intensively to pollinate agricultural crops. In fact, if a sufficient number of colonies of adequate strength are provided, the number of foragers will usually prevent the gathering of any surplus of honey. This is used as a guideline on the adequacy of bee pollinators.

Enough nectar must be available from flowering crops to sustain the pollinator bees and to assure adequate cross-pollination. Enough pollen must be stored or be available to sustain brood rearing and thereby maintain a continuing supply of pollinators.

A large portion of the honeybee colonies used in Imperial Valley are present only during the growing of crops that are attractive to honeybees. Most of these colonies are transported to the Valley from San Diego County.

Apiary Response to Air Pollution

Previous research on O_3 and fluorine as air pollutants showed that these gases affect honeybees.⁷⁷

The effects of H_2S on caged honeybee workers are being studied to determine longevity and mortality. Tests are conducted at the Statewide Air Pollution Research Center in greenhouses where five replicate cages of worker honeybees are exposed continuously to filtered air containing 0.03 ppm, 0.10 ppm, or 0.30 ppm H_2S , or to 0.30 ppm H_2S + 50 ppm CO_2 . *These studies indicate that bee longevity increases and mortality decreases at 0.030 ppm and 0.10 ppm H_2S ; but at 0.30 ppm H_2S + 50 ppm CO_2 , mortality increases.*

Indirect Effects. Honeybee diseases and parasites will probably not be affected by air pollution. An alteration in the incidence of diseases or parasites of the brood or adults by geothermal development is not indicated.

The success of honeybees as pollinators of agricultural crops and as honey producers depends upon the condition of the plants. If bee-attracting plants are growing under optimum conditions, honeybees should continue to be efficacious pollinators and honey producers.

Baseline data on honeybees are available from studies on the effects

of pesticides in Imperial Valley.

These data may be utilized to determine adverse effects from gaseous pollution during geothermal energy conversion.

Quantification of Responses.

The effects of air pollution on honeybees caused by geothermal energy conversion can be measured by one or more of the following:

- Life span of the worker bee.
- Worker bee mortality.
- Honey production and seed or fruit production. Honey production per colony can be measured by the amount of surplus honey produced by the colony or on a short-term basis by gain or loss by weight of the colony. Seed and fruit production can be measured by the quality and quantity of the seed and fruit produced per colony of bees and strength of colony of bees.
- Colony quality as determined by the number of square inches of brood (eggs, larvae, and capped brood), the number of worker bees, and the amounts of pollen (protein food) and honey stores present (carbohydrate food).
- Removal of food sources. If geothermal energy conversion causes the displacement of plants that are bee forage, we

can measure how many fewer colonies of bees are needed in the area. An increase in acreage of a forage plant for bees should be allowed so that an increased number of colonies can be provided.

Special Consideration: Disturbance and Inventories

Honeybee Disturbance at Critical Periods. Noise does not usually have continuing importance since bees adjust to it. However, intermittent high-level noise will stop bees temporarily from foraging. Pesticide sprays or chemical odors (except low levels of H_2S) will suppress bee foraging for 1 to 4 da.⁷⁸

Inventories of Crops and Native Plant Food Sources. These inventories will be used to determine if significant shifts in plant species resulting from cultural or other requirements indirectly effects apiary productivity in the Imperial Valley.

Effects of Gases Produced from Geothermal Energy Conversion on Vertebrate Animals

Based upon a survey of the literature, we decided that gases resulting from geothermal energy conversion would not have sufficient impact on native and domestic animal populations

in Imperial Valley to warrant expanded discussion and research at this time.

We assumed that the exposure of domestic animals would not be any greater than the occupational exposure of humans. We will consider H_2S as the major pollutant. Animals respond to H_2S similarly to humans.⁷³ Significant responses were not obtained to repeated, continuous exposures of H_2S of 1 to 10 ppm, which is about 100 times the California air quality standard (0.03 ppm). We concluded that only crop fields and pollinator insects should receive significant exposures in areas adjacent to geothermal sources where emissions might exceed the air quality standard; these were discussed previously.

Exposure of native animals to H_2S should occur only infrequently and in geothermal development areas that are near wildlife habitats. Each of the areas under geothermal development in Imperial Valley could conceivably contain wildlife habitat. These populations and their potential exposure to noncondensable gas emissions were discussed in the section on Agricultural Ecosystems.

Another potential problem yet unresolved is the possible interactive or synergistic effects of gas emissions resulting from geothermal energy conversion and the already existing stress of heat on the

physiology of cattle. Because cattle are usually confined to feed lots,

proper selection of power plant sites could avoid this problem.

ECOLOGICAL PROBLEMS IN THE DESERT ECOSYSTEMS RELATED TO DEVELOPMENT OF GEOTHERMAL RESOURCES AT EAST MESA

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Development of Geothermal Resources in the East Mesa

Geothermal resources in the East Mesa KGRA are being developed by various groups including Federal and private agencies. The present development concept is to build modular units spaced throughout the KGRA, each covering an area with a 1-mi radius. The environmental impact of these units would depend on the environmental constraints placed on the constructing agency. The statements and recommendations made in this section are based on one modular unit.

The program for the development of geothermal resources now underway at East Mesa involves the determination of the technological feasibility and subsequent installation of a desalinization facility for reclaiming water. Plans also include the development of a 50-MW power generator to sustain

the local power needs of this facility.^{79,80} Such an industrial complex might involve heat-source inputs from as many as 18 geothermal wells, feeding a central system through transmission pipelines that are up to 1 mi long. Included, therefore, within an area of about 1-mi radius will be environmental insults from transmission pipelines, well-head sites, service roadways, power-plant and desalinization-plant facilities, cooling tower installations, power-transmission lines and transformers, yards, and support buildings. *The ecological impact within an industrialized area of 1-mi radius might be so severe that the site would be an ecosystem write-off for all practical purposes.* Within this industrialized area, one could expect environmental impacts such as those that are outlined below.

Potential Environmental Impact from Development of Geothermal Resources at East Mesa

Habitat Destruction

Within the confines of the industrialized area, the ecosystem will be insulted by noise and physical disturbance from human and vehicular traffic. Grading and land movement to accommodate roadways and pipelines, well-head operations, and plant installations will destroy the natural vegetation and edaphic features. Surviving fauna will probably leave the disturbed habitat and move to an undisturbed area. Insults from accidental and controlled brine releases are expected, and the area will receive drift from cooling towers. Wind movement of soil and sand from denuded areas will be a nuisance to site workers and should be stabilized to prevent erosion. *The philosophy of industrial development acknowledges that certain land areas will be sacrificed. This sacrifice is recognized by ecologists as necessary in exchange for benefits from energy production.*

Impacts from Effluents Resulting from Geothermal Energy Conversion

All of the above listed perturbations to the natural environment could result in habitat deterioration or destruction in the ecosystem surrounding the development site. Noise

should not be a continuing major problem except from vehicular traffic along access roadways. (See section on Wildlife Resources.) Insults from accidental and controlled brine releases might extend to undetermined distances into the ecosystem. There might be off-site wind erosion and resuspension of salt particles from local brine spills unless they are cleaned up or covered, in which case underground water supplies might be affected. *The main problems foreseen for the surrounding ecosystem are those resulting from the deposition of fall-out materials, i.e., noncondensable gases, trace metals, and salt particles from brine-holding ponds and cooling tower facilities.*

Requirements for Baseline Studies

The extent of such effects during the geothermal program development can best be determined by comparison with baseline ecological data characterizing the undisturbed desert ecosystem. Base-line studies to be described in the following sections involve soil sampling as well as sampling of prominent plant and animal species and are essential to establish reference data. *Concomitant problems for which specific research is required include studies on ecosystem components affected by salt imbalances in soil resulting*

from fallout or effluent contamination from accidental spillage of brines on the land surface or from well blowouts. The removal of shrub species from sites within the industrialized area will alter the site for decades because the natural establishment of these woody species in the desert is slow and unpredictable. Natural revegetation of certain shrub species will be too slow to meet aesthetic needs; therefore, husbandry methods must be applied to restore vegetation. Such methods were developed for many Mohave Desert shrub species.^{81,82}

The structure and function of the desert ecosystem and interactions between fauna and flora must be understood so that environmental impacts may be evaluated. Recent work on desert biomes, sponsored by the International Biological Programs, provides information that will assist in the ecosystem studies of the East Mesa desert. Methods of ecosystem analysis that were developed in the northern Mohave Desert ecosystem at Rock Valley, Nevada are applicable immediately.^{83,84}

Effects on the Community and Ecosystem

Plants, animals, and micro-organisms in the East Mesa coexist in a system integrated by complex

biotic and physical interactions. Ultimately, any effect of the development of geothermal resources on one part of the system will affect the others by shifting the pattern of interactions. Hence, environmental insults resulting from the development of geothermal resources will affect the components directly by toxic and noise effects and indirectly by altering the structure of the communities.

The changes that are likely through both direct and indirect effects are most readily measured by changes in community structure or composition with time. If such measurements were made at selected points within a 3.1-mi² circular area surrounding the power plant at points downwind from this circle and at nearby control areas, the changes effected by the development and operation of the plant can be documented. Measurements over a 2-yr period before development of the plant in both control and probable areas of impact will provide baseline data on divergence between the impacted and control communities.

Baseline Studies on Community Structure

Appropriate measurements will be:

- Density, frequency, dominance, and size- or age-class distribution of perennial vegetation.

- Density and biomass distribution by species of annual plants along with appropriate diversity and equitability indices.
- Relative abundance, relative biomass, and appropriate diversity and equitability indices measured at key periods during the year for:
 - insect fauna,
 - soil arthropods,
 - small mammals,
 - breeding birds and wintering species, and
 - the herpetofauna.
- The effects of different brine and heavy metal concentrations on germination and seedling survival of key perennial and annual species.
- The effects of different brine and heavy metal concentrations on egg, larval, nymphal, and pupal survival of key invertebrate species.
- Diet preferences and heavy metal content of dietary uptake of selected species of vertebrates.

Baseline Studies on Key Effects

The elucidation of the mechanisms by which these parameters change with time is a far more complex task than merely the measurement of their changes. *To analyze all of the impact mechanisms for all species in the desert community will be obviously beyond the resources of this study.* However, major impacts that are expected from pollutants and disturbance can be investigated in selected species. Some examples of studies that can be performed in the laboratory are:

- Photosynthetic rates in key perennial species subjected to realistic, simulated levels of H_2S and other noncondensable gases in experimental chambers.
- Reduction in phytomass resulting in reduction of insect populations, which in turn might lead to reductions in nesting bird and reptile populations.
- Reduction in seed production especially that of annuals through reduction in plant populations that might reduce small mammal populations and possibly those of ants and wintering birds.
- Reduction in phytomass leading to increased wind erosion of soil, including dune formation and movement.

Indirect Effects to the Community

Cause and effect of indirect influences on various taxonomic groups are more difficult to demonstrate. Some examples are:

- Reduction in phytomass leading to a reduction in soil invertebrate densities through reduction in soil organic matter.
- Reduction in small mammal populations through either direct or indirect causes, almost certainly resulting in a reduction in populations of carnivorous mammals and raptors.

All of these indirect effects are likely; but without meticulous research to establish cause and effect, they can only be correlations. The implication of causality can be strengthened by measuring periodically some of the elements in the chain such as soil seed reserves, movement and deposition rates of sand, and organic matter in the soil in impacted and control areas.

Effects on Cycles and Functions

The functional changes described so far have focused largely on species, populations, or major functional groups. Whole ecosystem processes such as energy flow and nutrient cycling have not been discussed. Changes in energy flow are implied in the discussion on the reduction of vegetation and animal populations. So far we have considered only probable negative effects. Water-vapor and steam release, depending on extent and duration, might increase or

decrease plant growth in the downwind direction. This effect can be measured by the annual measurements on plants described above combined with measurements of annual net primary production of perennials in impacted and control areas.

Brine and heavy metal emissions might affect nutrient cycles by their toxicity to important organisms in the cycles: detritivorous anthropods, important decomposing and mineralizing microorganisms, and nitrogen-fixing forms. Some measure of these effects can be provided by periodic measurements of phosphate, ammonium, nitrate, and nitrate ions on impacted and control areas.

Anticipated Effects on Specific Ecosystem Components

Vegetation

Cooling Tower Effluents.

Vegetation downwind from cooling towers will probably be affected adversely by airborne water droplets containing solutes. Initially vegetation will show primarily foliage effects. Soil effects are anticipated downwind from cooling towers because:

- Water used for cooling is limited by the amount of irrigation water available to the valley. Hence cooling waters

will be recycled, which will result in the concentration of solutes in the water.

- As dilute salt water evaporates in cooling tower plumes, salts reach high concentrations in the small droplets.
- Antifouling agents, possibly biocides or anticorrosive agents, will be added to the cooling water. They too will be concentrated for reasons given above.

These solids, which are generally very soluble, will be deposited downwind from the cooling tower at distances determined by weather, primarily wind speeds, and will be diluted with distance from their source.

Baseline analyses of vegetation (creosote bush) are being made (Fe, Na, Cl, S, K, B). In addition, periodic measurements should be made of vegetation downwind to any cooling towers that operate in East Mesa area.

Anticipated Effects of Cooling Water Deposition. Short-term (2 to 5 yr) effects might be:

- Some defoliation and reduced productivity.
- Little effect on soils as such, but conductivity should be measured to provide warnings of effluent effects on the soil.

Long-term effects might be:

- Defoliation and death of some shrubs at distances closer to sources. More tolerant species will remain.
- Increased salinity of soils, spreading of salt tolerant species, and disappearance of intolerant species.

Attempts are being made to analyze cover measurements on selected sites from aerial photographs. This is done to provide "historical" basis from systematic photo coverage, particularly for areas where effects may not be anticipated. (Aerial coverage is funded by ERDA, DBER as a service to the IVEP program.)

Geothermal power development has accelerated in Imperial Valley. More specifically, a large number of wells have been and are being drilled. These wells have already been tested for flow rates and have probably been vented into the atmosphere. In at least a few cases, brine was poured into open pits and allowed to creep out among the dunes in the East Mesa KGRA. These sites offer an opportunity to examine short-term consequences to project the outcome of future activity. This information will allow us to take measures to prevent or to mitigate damage to the desert ecosystem before actual damage occurs.

Brine Spills Effects on Vegetation-Shrubs. Aside from direct effects to plants, redistribution of brine on the surface by winds may lead to significant effects. Salt particles will settle on foliage by wind distribution similarly to direct deposition of cooling tower effluents. Anticipated effects are similar to that of cooling tower effluents.

Research on these effects is anticipated:

Vegetation should be analyzed in areas suspect of having redistributed materials, e.g., elemental analysis along roadsides through and adjacent to spills and visual examination for salt-burn effects.

Physical Disturbances of Vegetation. *Physical removal of vegetation for the development of geothermal energy conversion sites will no doubt be the single largest perturbation of the desert system.* In contrast to other impacts, the return to natural state is prevented almost completely whereas areas affected by other causes related to development can be reestablished when the insult is removed or mitigated.

Experience at the Nevada Test Site showed that site development disrupted significantly natural systems in the Nevada desert. We estimated that within 3-km radius of a nuclear

test on Pahute Mesa 0.65% of the area was cleared for roads, drill-pads, and other physical surface modifications required for tests.⁸⁵

Many requirements for geothermal energy conversion in the East Mesa area parallel those at the Nevada Test Site. The extent to which vegetation in such areas must be removed or otherwise disturbed seriously should be estimated.

Total areas that will be disrupted by geothermal development must be determined by aerial photos before and after development. We can thereby measure total areas that are taken up by roads, drill pads, steam lines, cooling ponds, and eventually power lines to conduct power to centers of use.

Special Species Considerations.

One specific species interaction, because of its dominance at the East Mesa site, should be mentioned at this time relative to the above environmental effects. *Larrea tridentata* is the dominant plant at East Mesa, comprising over 90% of the perennial ground cover and thus serving as a major element at the beginning of food chains. *Any baseline study of short- or long-term effects of geothermal energy development on the desert ecosystem must depend heavily on influences to Larrea.*

Of the possible environmental perturbations that were considered, three might be critically important to the productivity and even existence of *Larrea*: noncondensable gases, cooling tower drift, and brine spills. Enhancement of atmospheric CO₂ might well increase CO₂ fixation, although effects of CO₂ on stomatal resistance also might occur. Water vapor in the cooling tower plume might affect stomatal resistance as well as change the concentration gradient of water vapor from the leaf to air. Changes in transpiration will affect the energy balance of leaves via the latent heat term. Other gases such as H₂S and NH₃ might have effects on productivity that are difficult to assess *a priori*. Possible synergistic and antagonistic effects of all the above gases on transpiration and photosynthesis must be investigated.

Brine spills present another series of problems. Data from Rock Valley, Nevada Test Site indicate that Larrea is sensitive to soil salinity. However, very little is known about the root system of Larrea. Because brine spills are acute insults, studies should be made on the interaction between the duration of exposure and the level of salinity.

Invertebrates

The effects of geothermal energy production on invertebrates must be considered. However, because of their importance over other invertebrate groups, we will focus our consideration on arthropods.

We will assume that the main purpose of this study is to assess the effect of geothermal development on the invertebrates and the effects on the ecosystem as a whole if invertebrates are damaged.

It is often held that animals as a group have but little significance for the functioning of an ecosystem. *However, many soil invertebrates play an important part in litter decomposition by breaking down particles to a size that may be acted upon rapidly by microorganisms.* Several reviews, e.g., Edwards *et al.*,⁸⁶ give evidence of this, but all refer to nondesert systems.

Assuming such importance of arthropods, the second question that arises is: How are arthropods affected by the kind of pollutants that we expect? The scanty information that exists suggests that many soil arthropods, particularly predators, accumulate heavy metals, while other arthropods invertebrates do not, and that in several instances the numbers of arthropods were reduced in proximity to heavy metal

sources, e.g., a zinc smelter⁸⁷ and lead mining and smelting operations⁸⁸; but in other cases the reverse was true.⁸⁹ Again, desert systems were not studied.

Edney *et al.*⁹⁰ recently studied the nature, distribution, and abundance of soil microarthropods in the Mohave desert. They obtained preliminary evidence on the deleterious effect of salinity on these organisms.

Probable Effect on Invertebrates.

- Noise. There is no evidence that noise will affect East Mesa invertebrates. We do not recommend a study of this factor.
- Heavy metals. The effects of heavy metals on invertebrates should be studied. In the laboratory we will subject microarthropods and certain beetles to soils containing heavy metals at concentrations that occur in geothermal fluids (brine).
- Salinity. Although a great deal of information on the physiological mechanisms of salt and water balance in invertebrates is available, virtually none is available on the effects of different salinity levels on the viability of soil arthropods. We

are therefore investigating salinity effects on soil microarthropods and tenebrionid beetles, an important component of the larger arthropod fauna. We will assess the effects of spills at the East Mesa site on the arthropod fauna by measuring populations and their fluctuations throughout a year at two or more sites, one of which will probably not be affected, while the others may be exposed to either a natural or an artificial brine spill. The significance of soil arthropods in the ecosystem will be explored by studying their role in the cycling of materials and energy. Involved in such studies will be measurements on biomass of certain species of tenebrionid beetles in the natural environments.

- Noncondensable gases. Noncondensable gases will probably be present in significant quantities from vents anywhere in the physical structure of the energy conversion facility. We do not have the knowledge to undertake research in this area, although it is clear that such research should indeed be done.

(See previous section.)

- Physical disturbance. The very existence of buildings, pipes, roads, and construction practices will undoubtedly affect the invertebrate in its immediate neighborhood; but with limited budgets, research on these effects do not seem justified.

Recommendations for Invertebrate Studies. Of course, numerous groups of arthropods besides those discussed above are present. Clearly ants, termites, and several other hexapods may be involved significantly in the ecosystem and these eventually should be considered. The research proposed above will at least permit assessment of the main deleterious effects, and at the same time will yield information of general scientific value.

Finally, we believe that if invertebrates are killed by geothermal development, this will occur in limited areas in the vicinity of major power or desalination installations. If the damage is temporary, invertebrates will surely reinvade the harmed area from nearby areas. If the damage is permanent, it will be limited in area and to that extent may be acceptable.

Vertebrates

The development of geothermal

areas for generation of electrical energy imposes various environmental stresses. Some of these impacts will be most pronounced during the production-testing phase; others will persist throughout the operating lifetime of the facility.

All of the following problems are of potential ecological significance to vertebrate populations: physical disturbances of habitats resulting from construction and excavation, noise, release of noncondensable gases, e.g., CO_2 , H_2S , NH_3 , CH_4 ; releases of hot brines containing salts and toxic trace elements, e.g., F, B, As, Hg; condensation of downwind plumes from cooling towers; releases of radioisotopes, particularly Rn; and indirect effects stemming from damage to other ecosystem components, e.g., plants.

Physical Disturbances. All vertebrates occupying East Mesa (reptiles, birds, mammals) are vulnerable to habitat disruptions associated with construction and maintenance of roads, excavation of wells and drainage canals, and the erection of buildings, fences, and power transmission facilities. We believe that these activities collectively will constitute the greatest impact of the development program. In general, the largest species and those with the most extensive activity ranges will

be most sensitive to such disturbance. Some animals will be killed by vehicles and construction operations. Birds might be electrocuted by transmission lines and other animals might be displaced for varying distances. Local abundances and diversity of vertebrate species might decline, but species will differ in their tolerances to these stresses. Hence, the relative abundances of some species might increase because of the creation of new habitats and shifts in competitive balances. These types of changes are generally predictable, but specific details can only be ascertained through *post facto* observation or appropriate experiments.

Noise. Noise, *per se*, should not have important effects on reptiles, but could have distinctly deleterious impacts on populations of birds and mammals near the power plant or well heads.

Noise might drive some species from the area, disturb normal predator-prey relationships, interfere with communication, affect mating and rearing behavior, or even have direct physiological consequences.⁹¹⁻⁹⁵

Because noise is usually associated with construction or other physical disturbances, the separation of effects resulting from noise might be difficult. As discussed in the sec-

tion on Wildlife Resources, the extent of the excessive noise range in Imperial Valley should be small.

Noncondensable Gases. Releases of some amount of noncondensable gases are unavoidable in the development and operation of a fluid-based facility. However as discussed in the section on Air Pollution, the amount and kinds of noncondensable gases released will vary among fields, depending on local circumstances. Some noncondensable gases will be poisonous to vertebrates if sufficiently concentrated.⁹⁶ H_2S is slowly oxidized to SO_2 , and may ultimately be converted to H_2SO_4 . Again, these substances can be immediately toxic to animals,⁹⁷ but such concentrations are not expected over any substantial area at East Mesa.

Brine Releases. Discharges of brines should not have important direct effects on vertebrates unless releases are great enough to cause extensive inundation and flooding of burrows. Smaller releases might result in localized redistribution of some terrestrial vertebrates. The greatest potential effects of brine releases on vertebrates are indirect.

Trace Elements. A number of trace elements might be released into the environment by condensing steam or brine releases, e.g., B, Li, F, Br, As, Hg, Ag. These elements could

then become incorporated into the diets of vertebrates. As with non-condensable gases, any ecological consequence will be dependent on the degree of exposure, for in sufficient amounts many of these elements are toxic to vertebrates.^{97,98}

Water Vapor from Cooling Towers.

No direct effects on vertebrates resulting from condensate from cooling tower plumes are foreseen.

Releases of Radioisotopes. Some discussions of radioisotope releases with emphasis on ²²Rn and its decay products appeared recently,^{99,100} but the situation on East Mesa remains undefined. We do not believe that geothermal releases of radionuclides will have any ecological effect on vertebrates if discharges of steam and water are controlled as expected.

Indirect Effects. Indirect ecological effects are probably the most important for vertebrates, but at the same time are the most difficult to define. We will, however, comment on some possibilities.

- Depletion of Food Resources.
Depending on their food habits, vertebrates will obviously be influenced by any direct effect on the abundance and quality of vegetation or on numbers of invertebrates (especially insects).
- Changes in Vegetation of Habitats.
Reduction in the stature or via-

bility of shrubs could adversely affect vertebrates by reducing nesting sites or available cover.

Priority Recommendations

Perhaps the Imperial Valley ecosystem, more so than others, requires a longer term understanding of the community relationships and ecologically complex interrelationships in the desert which are now incompletely understood or anticipated only in part. These are essential to a better understanding of the environmental impact of geothermal energy development in the East Mesa KGRA.

Short-term baseline studies, most of which are now underway, are needed immediately. This research is directed toward preliminary investigations at those facilities that are now being developed in the East Mesa area by commercial companies, e.g., drilling operations, well development, pressure and temperature determinations, and consequent brine dispersal or disposal into the environment. The current exploratory developments are a significant part of the Imperial Valley geothermal resource development. These provide an important opportunity to investigate immediate ecosystem effects. Better utilization of new drilling and testing methods, now scarcely or not at all

used, might indicate things to come in Imperial Valley. They will also suggest areas of future ecosystem research more clearly than the most foresighted academic approach to these problems can now envision.

Current research should also in-

clude a broad area study on the degree of ecological homogeneity in the East Mesa KGRA. This will establish the applicability of data obtained from one site to another during the various stages of geothermal development at different production sites.

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