GL03122-4 of 9

CIVIL ENGINEERING FEATURES OF A GEOTHERMAL POWER PLANT

Simon Peters, F. ASCE

Presented at the January 21-25, 1974
ASCE National meeting on Water
Resources Engineering at Los Angeles,
California

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CIVIL ENGINEERING FEATURES OF A GEOTHERMAL POWER PLANT[a]

Simon Peters[1], F. ASCE

INTRODUCTION

The United States is experiencing an urgent energy supply problem. Our country needs new energy sources. One of the most intriguing possibilities is geothermal energy, which is derived from natural heat beneath the crust of the earth.

Our earth's interior is like a great furnace. From an environmental standpoint, geothermal energy might be among the most acceptable of all new energy sources available in the future.

This report describes the Civil Engineering features of The Geysers geothermal power project developed by Pacific Gas and Electric Company. The report outlines the geology, seismicity, and reservoir mechanism of the Geysers area. Site selection, materials of construction, and the design of the principal Geysers Power Plant structures are also described.

GEOLOGY AND STEAM RESERVOIR THEORY

The Geysers is located in the Mayacmas Mountains, south of Clear Lake, near Cobb Mountain, about 75 air miles (121 Km) north of San Francisco, California (Fig. 1). The area is characterized by rugged topography with about 2500 - foot relief and by highly folded, fractured, and sheared rocks.

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[a] Presented at the January 21-25, 1974 ASCE National meeting on Water Resources Engineering at Los Angeles, California.

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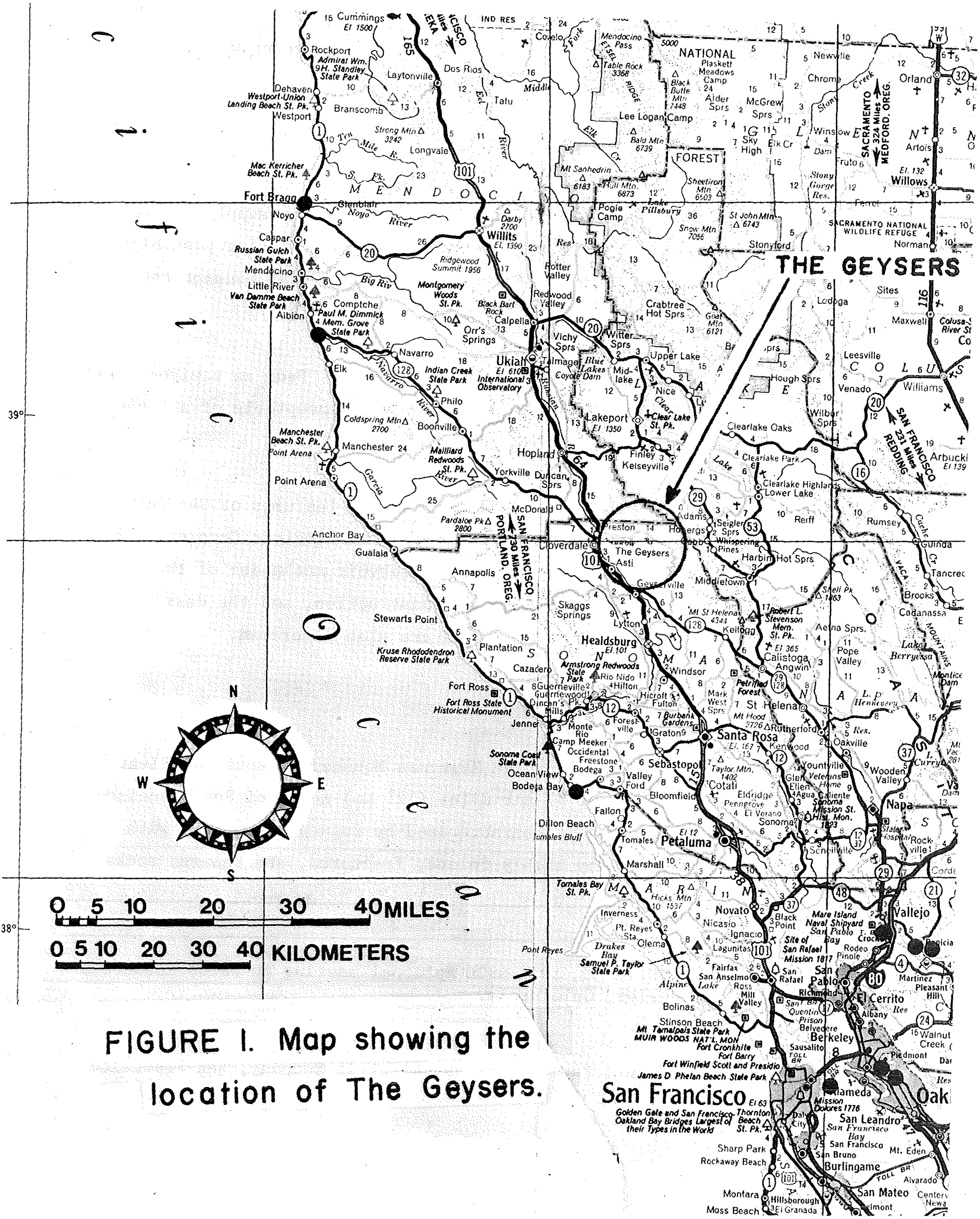


FIGURE 1. Map showing the location of The Geysers.

The Geysers steam field is one of the three major geothermal resource areas in the world that commercially produce dry steam, technically known as a vapor-dominated geothermal system. The other dry steam fields are in Larderello Travale, Italy, and Matsukawa, Japan.

At present, the ten completed generating units produce 390 MW of electricity (Table I) making The Geysers the largest geothermal electric generation installation in the world. After completion of the 5 other planned units, 11 through 15 in 1977, the total capacity will be 908 MW. The capacity of The Geysers steam field cannot be determined with certainty at present. Some geologists and reservoir engineers estimate that its ultimate capacity may be two thousand MW or more.

With present technology, a successful steam producing geothermal field has to possess the following four features (Fig. 2):

1. A heat source at a depth of 6 to 12 miles (10 to 20 Km). For example, an intruded stock.

2. A permeable zone of rock which will allow formation of steam. This steam zone should be located at drillable depth.

3. An impermeable solid rock close to the surface to form a cap or barrier to prevent escape of heat to the outside.

4. Adequate rainfall or ground water system to recharge the reservoir.

Geologically, recent volcanic activity in the region of The Geysers indicates the source of heat is a molten magma chamber at shallow depth. The fractured nature of the Franciscan graywackes provides the required permeability. The hydrothermal alteration of surface rock provides the necessary seal. And finally, abundant rainwater percolates underground refilling the deep geothermal reservoir, which is heated by contact with hot rock at lower depths.

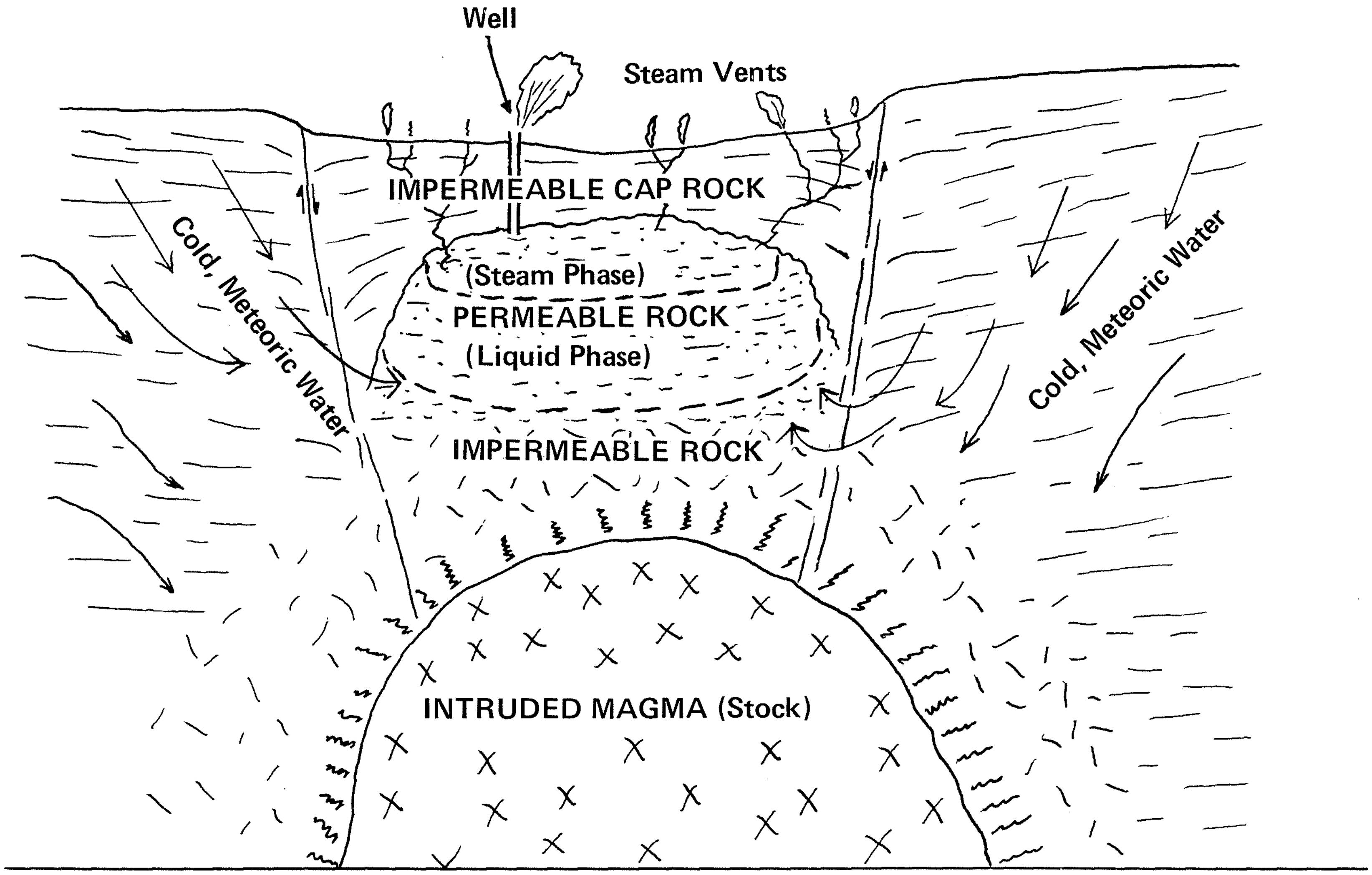


FIGURE 2.
GEOTHERMAL SYSTEM

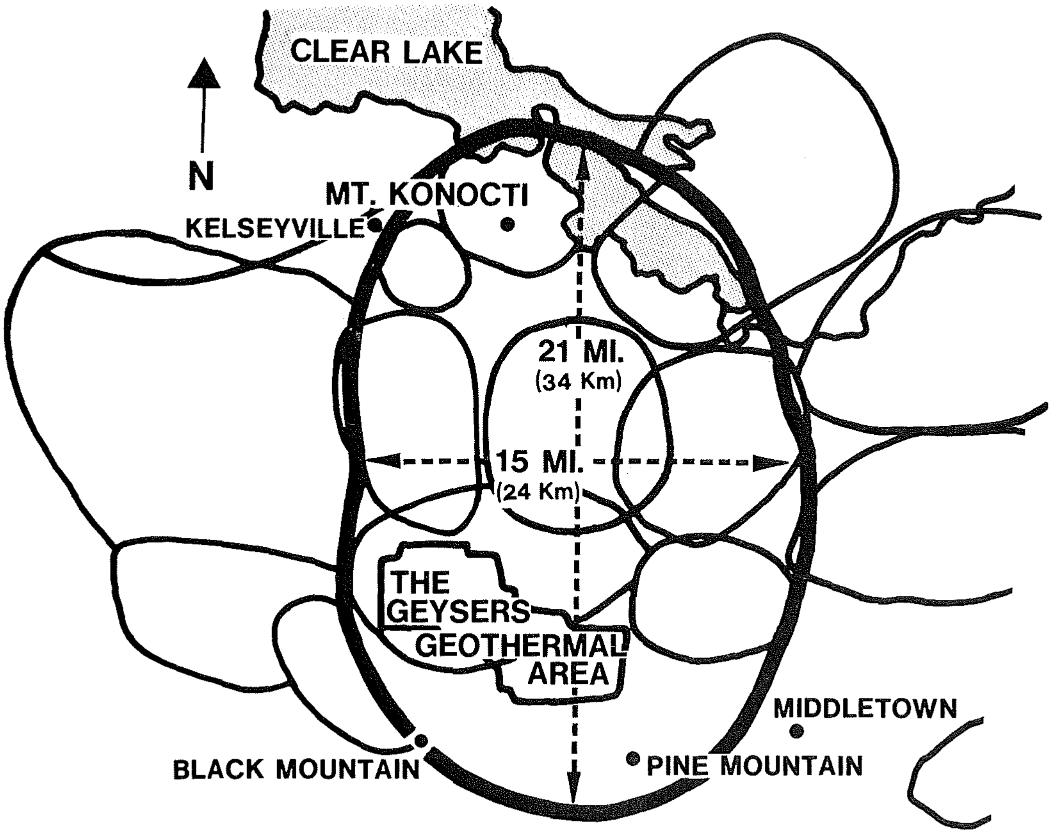

CLEAR LAKE
N
MT. KONOCTI
KELSEYVILLE
21 MI.
(34 Km)
15 MI.
(24 Km)
THE GEYSERS GEOTHERMAL AREA
MIDDLETOWN
BLACK MOUNTAIN
PINE MOUNTAIN

Figure 3.

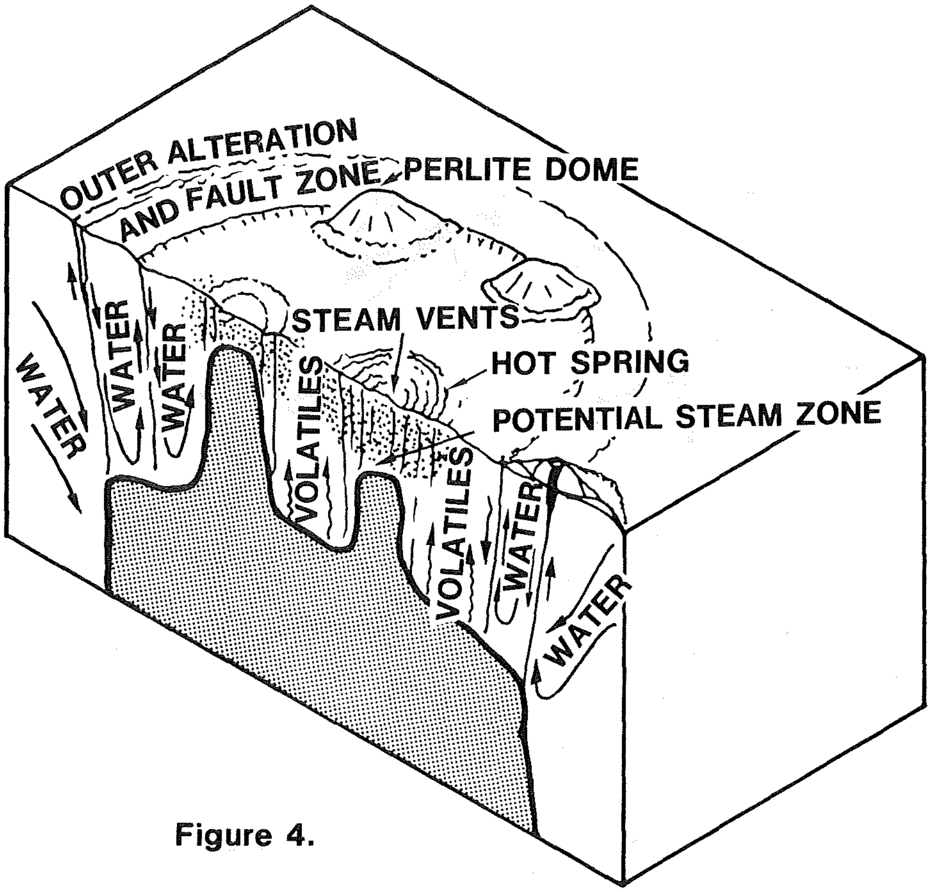

OUTER ALTERATION
AND FAULT ZONE
PERLITE DOME
STEAM VENTS
HOT SPRING
POTENTIAL STEAM ZONE
WATER
WATER
WATER
VOLATILES
VOLATILES
WATER
WATER

Figure 4.

It is interesting to note that on a global scale geothermal activity occurs in the zones of young valcanism and mountain building and is localized along the margins of major crustal plates. The Geysers is "granitic stock," a geothermal deposit type in which the heat source is an intrusion of non-basaltic magma at relatively shallow depth. Mapped from aerial photographs, Figure 3 shows the locations of the surface expressions (often elliptic) of the underlying intrusions or "stocks." Figure 4 shows the three dimensional picture of the elliptical alteration pattern of the main cell and several local cells indicating fracture, alterations, intrusion and collapse patterns. From a gravity survey of the Geysers area a negative gravity anomaly was mapped. This anomaly, shown by contour lines on Fig. 5, is indicative of a magma chamber at a relatively shallow depth in the earth's crust beneath the vicinity of the Clear Lake volcanic field. The comparison of the USGS geoelectrical investigations and the gravity and restivity maps, shows a coincidence of gravity lows and resistivity anomaly. This suggests a relationship between the causes of the two anomalies, Stanley, et al (Ref. 23). Both Fig. 3 and Fig. 5 point to the possible location of an enormous geothermal steam field within an elliptical area 15 miles (24 Km) wide and 21 miles (34 Km) long.

The Geothermal Steam Act of 1970 passed by Congress included the following provision:

> Sec. 2(e). "Known geothermal resources area" means an area in which the geology, nearby discoveries, competitive interests, or other indicia would, in the opinion of the Secretary, engender a belief in men who are experienced in the subject matter that the prospects for extraction of geothermal steam or associated geothermal resources are good enough to warrant expenditures of money for that purpose.

Figure 6 is a map showing lands classified as The Geysers' KGRA (known geothermal resource area). Notice that The Geysers' KGRA encompasses the main elliptical surface expression (Figure 3) and the negative gravity anomaly (Figure 5) as described above.

The available geotechnical data indicates that The Geysers area is at an early stage of the geothermal cycle. This initial phase involves continued heating of The Geysers magma chamber with further fracturing, faulting, and alterations taking place throughout the area.

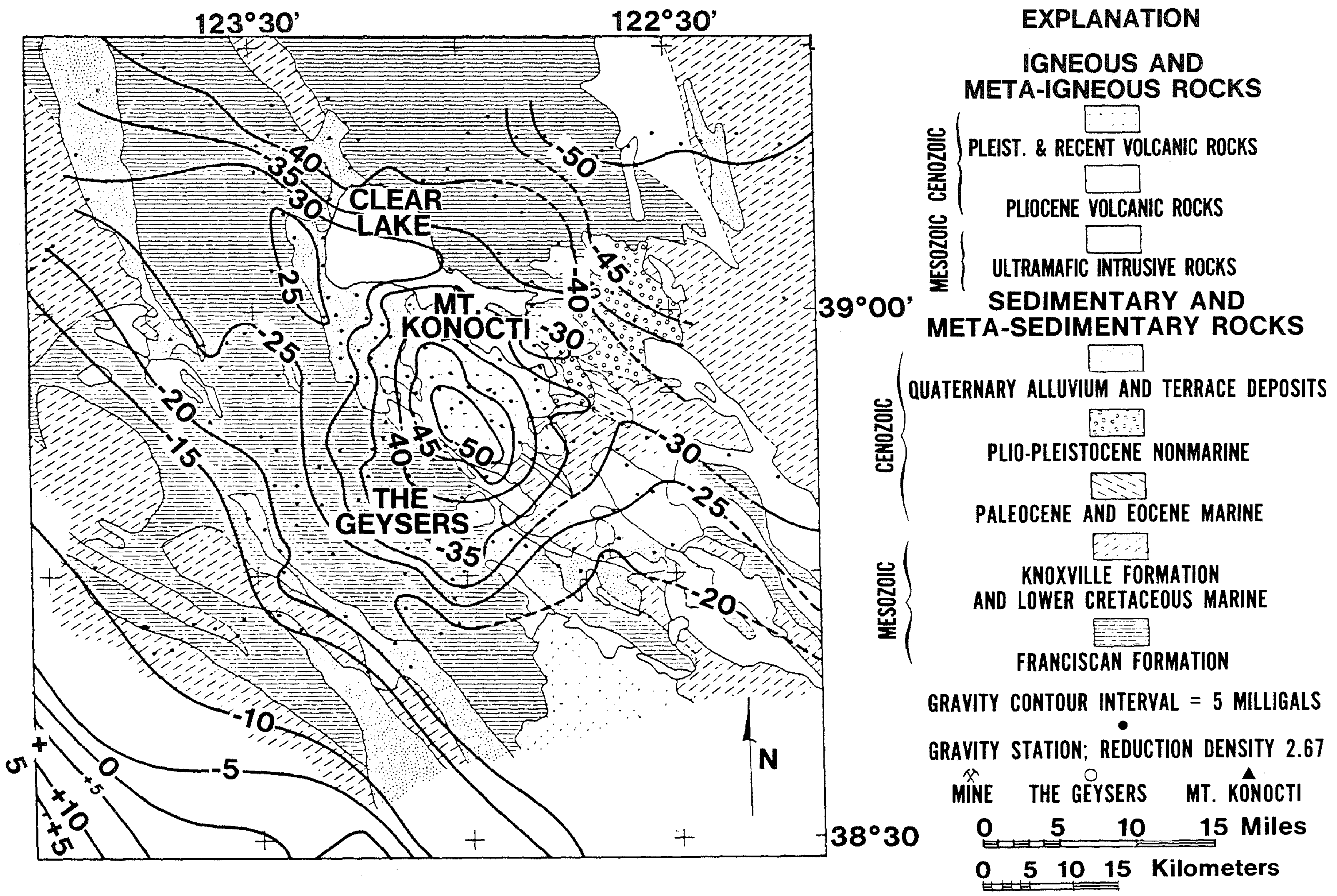

123°30'
122°30'
39°00'
38°30
CLEAR LAKE
MT. KONOCTI
THE GEYSERS
-50
-45
-40
-30
-40
-35
-30
-25
-25
-20
-15
-10
-5
0
+5
+10
+5
5
-45
-50
-40
-35
-30
-25
-20
N
EXPLANATION
IGNEOUS AND META-IGNEOUS ROCKS
CENOZOIC
PLEIST. & RECENT VOLCANIC ROCKS
PLIOCENE VOLCANIC ROCKS
MESOZOIC
ULTRAMAFIC INTRUSIVE ROCKS
SEDIMENTARY AND META-SEDIMENTARY ROCKS
CENOZOIC
QUATERNARY ALLUVIUM AND TERRACE DEPOSITS
PLIO-PLEISTOCENE NONMARINE
PALEOCENE AND EOCENE MARINE
MESOZOIC
KNOXVILLE FORMATION AND LOWER CRETACEOUS MARINE
FRANCISCAN FORMATION
GRAVITY CONTOUR INTERVAL = 5 MILLIGALS
GRAVITY STATION; REDUCTION DENSITY 2.67
MINE
THE GEYSERS
MT. KONOCTI
0 5 10 15 Miles
0 5 10 15 Kilometers

Figure 5.

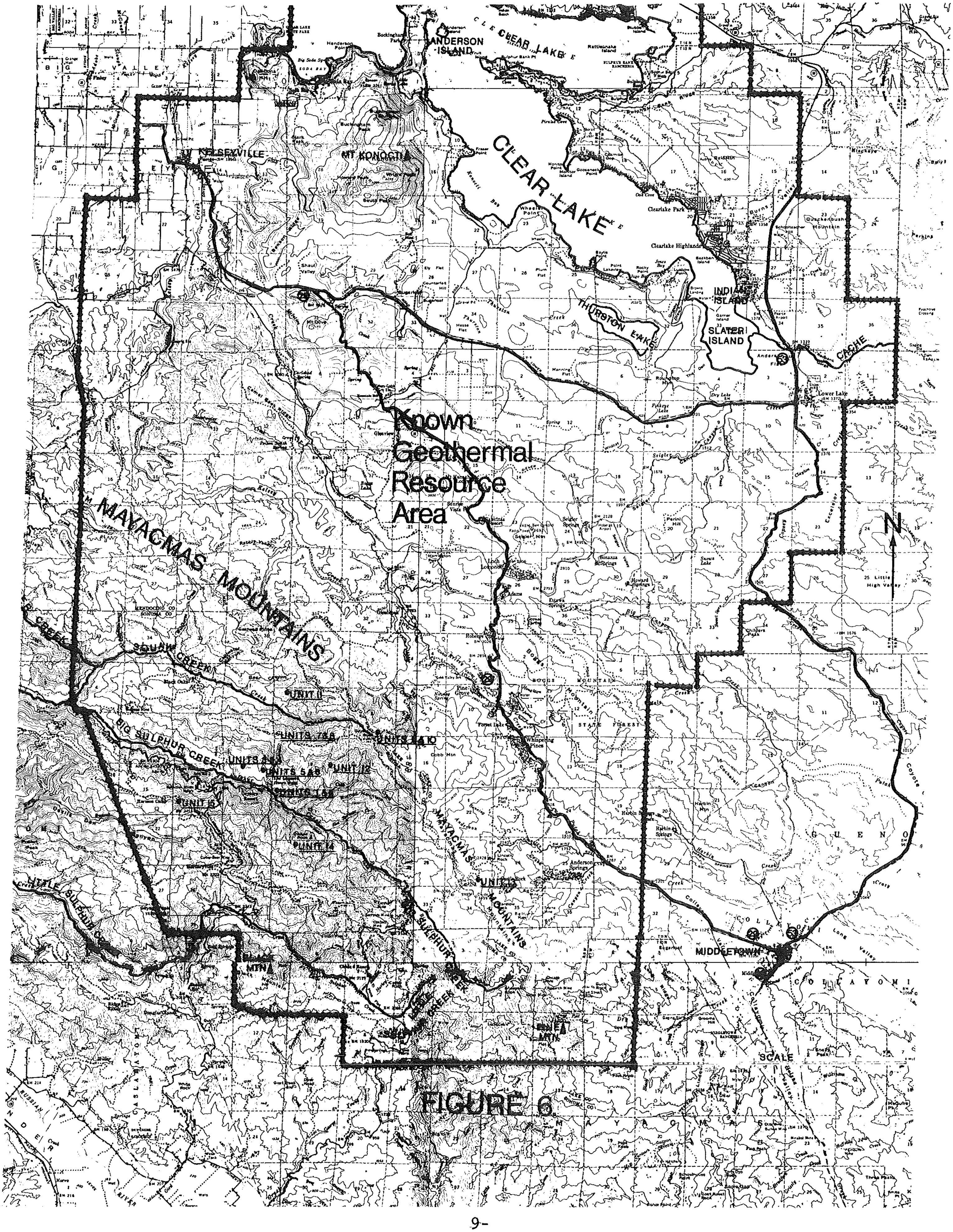

Known Geothermal Resource Area
CLEAR LAKE
ANDERSON ISLAND
KELSEYVILLE
MT KONOCTI
THURSTON LAKE
INDIAN ISLAND
SLATER ISLAND
CACHE
MAYACMAS MOUNTAINS
SQUAW CREEK
BIG SULPHUR CREEK
UNIT 11
UNITS 7&8
UNITS 9&10
UNITS 3&4
UNITS 5&6
UNIT 12
UNITS 1&2
UNIT 15
UNIT 14
UNIT 13
LITTLE SULPHUR CR.
SULPHUR CREEK
BLACK MTN
PINE MTN
MIDDLETOWN
N
SCALE

FIGURE 6

SEISMICITY AT THE GEYSERS

Seismic activity in a typical geothermal area can be generally classified into three types:

1. Ground noise--a more or less continuous phenomenon related to underground thermal activity, steam escaping through wells, or possibly even to amplification of microseisms in layers of low rigidity within the geothermal regions.
2. Microearthquakes--small earthquakes of magnitude less than 4, that occur in connection with no identifiable tectonic structures.
3. Larger earthquakes--earthquakes detectable by strong motion seismographs, usually typified by the sequence of a few foreshocks, one mainshock, and many aftershocks.

Ground noise at The Geysers is unrelated to seismic hazard.

Earthquakes with magnitude greater than about 4.5 are rarely observed in geothermal areas around the world. The largest shock ever detected near a geothermal area was the 1940 Imperial Valley (El Centro) earthquake, an event of magnitude 7.1 on the Richter scale. Located approximately 15 to 20 km southwest of The Geysers area, the Healdsburg fault had 5.6 and 5.7 magnitude earthquakes in 1969. Only three earthquakes with magnitudes over 4 (i.e., 4.6, 4.2, and 4.4) have occurred in The Geysers' immediate vicinity since 1934. The magnitude 4.6 and 4.2 earthquakes probably occurred in the northern portion of The Geysers area. In The Geysers' area, the fault system paralleling Big Sulphur Creek is believed, by a few geologists, to be active although there is no specific evidence to indicate such.

Microearthquakes in the Geysers region are characterized by:

1. Small magnitudes, from -2 to 4.
2. High frequency of occurrence.
3. Being confined to well-defined areas.
4. Shallow focal depths.

Microearthquakes, which occur in or near most geothermal areas, have received very little attention until recent years when increasing exploitation of geothermal energy prompted research work in microearthquakes and related phenomena. Because exploitation of geothermal energy might lead to disturbance of the earth's crust, the possible consequences have become a matter of concern. These possible consequences are:

1. Effects on local seismicity due to steam extraction from wells and fluid injection into wells;
2. Effects of earthquakes on the power generating facilities;
3. Effects of earthquakes on the operational life of a geothermal steam field. A related concern is the relationship between microearthquakes and large earthquakes.

The limited data available seem to support the hypothesis that microearthquakes are primarily caused by the relief of local tectonic stresses along faults. Bolt, et al. (Ref. 3), have determined a strike slip mechanism for an earthquake which had its epicenter just south of the Geysers. They suggested that this earthquake, and most of the microearthquakes later observed by Hamilton and Muffler (Ref. 4), had the effect of relieving local stress.

The effect of steam extraction on seismicity was investigated by Ward and Bjornson (Ref. 5). They reported that varying the flow of a large well in Iceland did not appear to affect the frequency of microearthquakes occurrence significantly.

The most widely accepted mechanism for the effect of fluid on earthquakes involves pore pressure. When increased, the fluid pore pressure is believed to reduce the frictional resistance to slippage by decreasing the normal stress across the fault. The possibility of triggering earthquakes by fluid injection into wells at The Geysers is ruled out by Muffler (Ref. 4). Because of the vapor-dominated characteristic at The Geysers, which is unique among geothermal fields in the U.S., the injected condensate cannot possibly increase the pore pressure to an appreciable degree.

The correlation between microearthquakes and large earthquakes remains undetermined. Only detailed study of microearthquake activity can provide insight into the physical processes responsible for the generation of damaging earthquakes. The occurrence of great numbers of microearthquakes does not preclude the possibility of large earthquakes. There are two reasons for this: first, the energy released by an earthquake of magnitude 6 is about 1000 times greater than the energy of an event of magnitude 4. Normally, only about 100 events of magnitude 4 can be expected to occur for each event of magnitude 6. Second, a geothermal area constitutes a small part of the tectonically active zone and the energy released by microearthquakes is a small fraction of the total strain energy stored in the zone.

In connection with a microearthquake study of the San Andreas fault system in southern California, Brune and Allen (Ref. 7) conjecture that a "section of active faults characterized by occasional very large earthquakes, may, in the intervening periods, be characterized by extremely low seismicity, possibly due to some 'locking' mechanism, whereas sections of the fault characterized by lack of very large earthquakes may in turn be characterized by more or less continuous seismic activity on a small scale."

Based on historic earthquakes affecting The Geysers area, the seismic coefficient for the power plant currently being designed was set at 20% of g, with vertical acceleration equal to 2/3 horizontal.

SELECTION OF THE PLANT SITE

The first task a Civil Engineer faces in the design of a geothermal power plant is site selection. At least three potential sites are evaluated, based upon the following considerations:

1. Proximity to producing steam wells. Because of heat dissipation in piping, geothermal steam can only be economically transported a maximum of two miles. Beyond this distance, its distance is severely diminished.

   This vital constraint constitutes the principal difference between site selection procedure for geothermal plants and fossil and nuclear fuelled plants.
2. The layout of surface features must be planned for blending harmoniously with the environment (Fig. 7). Fig. 8 demonstrates the study of the visibility angles of different alternate sites. In the rugged terrain of The Geysers, suitable sites with minimum exposure are very limited and a thorough evaluation of alternate sites is necessary; such an evaluation is shown in Table I.
3. The power plant should be located on a competent foundation material away from surface faulting and existing or potential slide hazards. Thorough geological and soil investigations

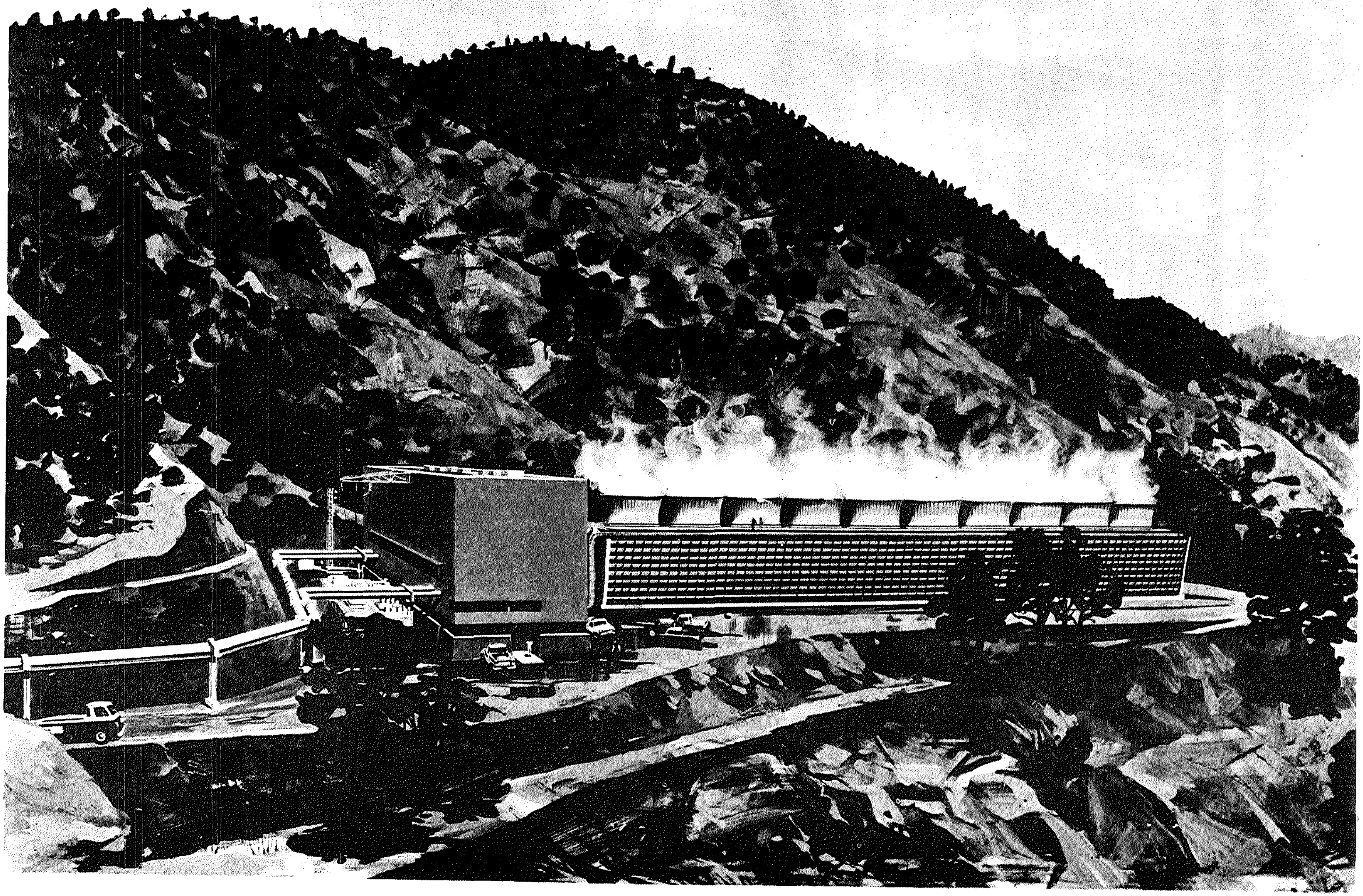


Figure 7.

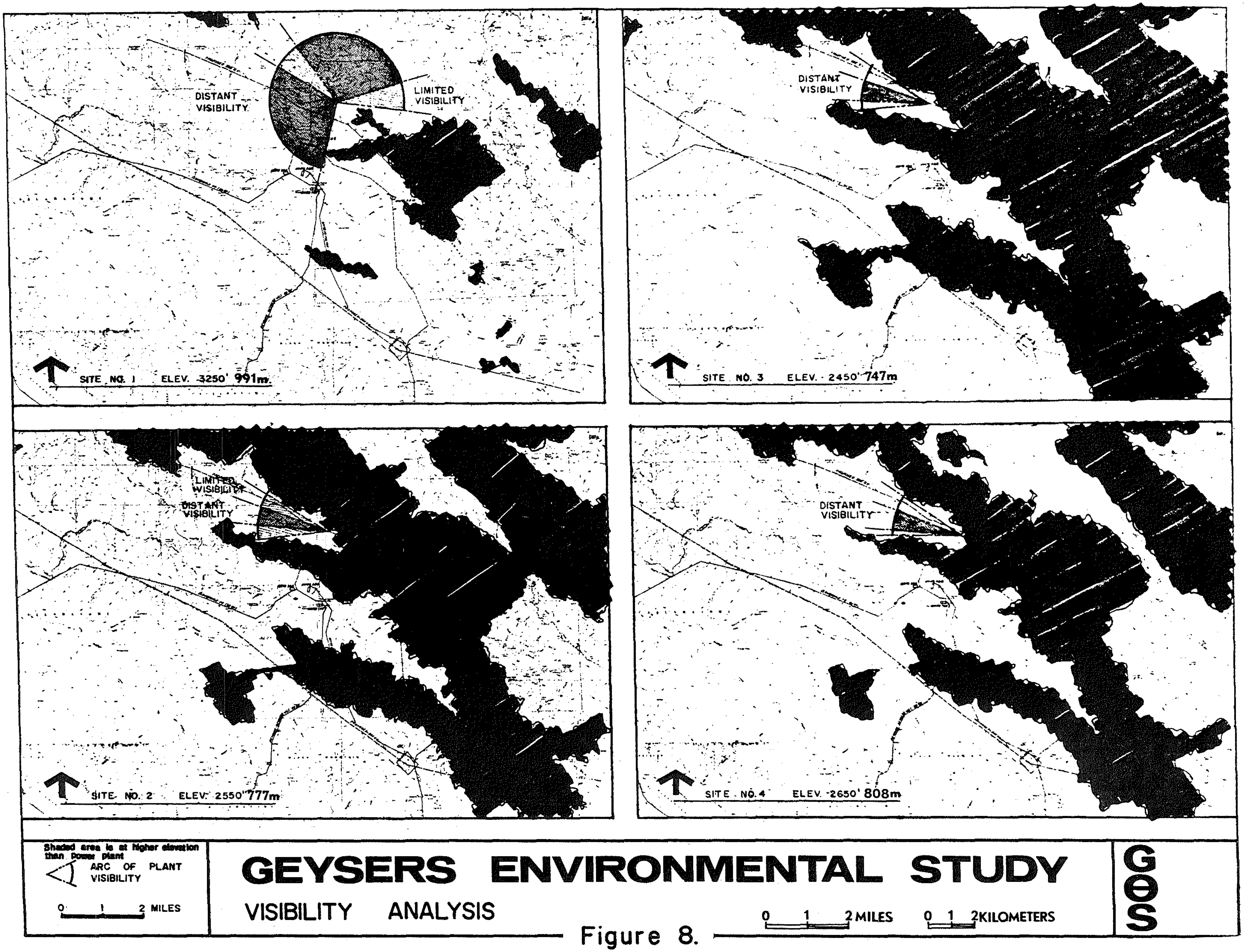

DISTANT VISIBILITY
LIMITED VISIBILITY
SITE NO. 1 ELEV. 3250' 991m
DISTANT VISIBILITY
SITE NO. 3 ELEV. 2450' 747m
LIMITED VISIBILITY
DISTANT VISIBILITY
SITE NO. 2 ELEV. 2550' 777m
DISTANT VISIBILITY
SITE NO. 4 ELEV. 2650' 808m
Shaded area is at higher elevation than power plant
ARC OF PLANT VISIBILITY
0 1 2 MILES
GEYSERS ENVIRONMENTAL STUDY
VISIBILITY ANALYSIS
0 1 2 MILES 0 1 2 KILOMETERS
GES

Figure 8.

TABLE I

ENVIRONMENTAL SITE ANALYSIS

	Site 1	Site 2	Site 3	Site 4
Geology and Foundation	2	2	3	2
Terrain and slope	2	1	2	3
Vegetation	2	2	2	3
Wildlife	2	2	2	3
Access Road	3	1	2	3
Adequate Site	2	2	1	2
Expansion (4 Units)	3	3	1	2
Transmission Corridor	1	3	1	3
Visual from Public Road				
(a) Background	1	3	2	2
(b) Well concealed	1	3	3	2
(c) Silhouette	1	3	2	2
Total	20	25	21	27

Rating: Lowest total indicates a degree of preference for environmental considerations.

Excellent	1
Good	2
Poor	3

must be performed with holes drilled to a depth below proposed foundation levels. The technical advice of geologists is vital at this step.

4. The site should have the most economical overall site development evaluation. This requires provisions for:
    a. Easy accessibility by all weather roads with not over 10% grade, without excessive cuts into steep ridges, and in stable material.
    b. Availability of land which does not conflict with interests of government agencies or private parties.
    c. Proximity to a transmission corridor.
    d. Minimum excavation.

In principle, the site selected should represent an optimum solution of a cost/benefit analysis, wherein costs and benefits of construction and costs and benefits of environmental factors are weighed and balanced. There is insufficient information to evaluate fiducial costs and benefits to the environment, and the costs and benefits of those factors which relate to public concern and length of time for licensing. The best that can be done is to identify, on the basis of experience and judgment, those factors which are the most important in a cost/benefit analysis, and to develop a scale of ratings that will permit a reasonable and feasible determination of an acceptable and optimal site.

REGULATORY INTERFACES

The construction and operation of geothermal power is under the regulatory jurisdiction of State and County governments. Regulation of geothermal power generally has been a series of prohibitions. This is to be expected since geothermal power generation is still in its infancy. To facilitate geothermal development within a reasonable time period, many in-depth studies are needed. These studies should cover the physical, economic and sociological aspects of geothermal resource production.

At present nine permits/licenses are required in order to construct and operate a geothermal plant at The Geysers.

1. First, an application accompanied by an Environmental Data Statement has to be filed with the California Public Utility Commission one year ahead of the start of construction.
2. The California Air Resources Board requires a report indicating conformance with air quality standards.
3. The California Department of Fish and Games requires a report on the effect of the proposed action on wildlife habitat and the rivers and creeks adjacent to the plant site.
4. A report must be filed with the California North Coast Regional Water Quality Control Board which sets up water pollution and waste discharge requirements for P.G.&E. geothermal plants.
5. The County Water Agency investigates the stream crossings and issues permits for use of water.
6. The County Air Pollution Control Board is concerned with air quality at the plant site.
7. The County Board of Zoning Requirements issues the use permit.
8. The County Public Works Department requires drawings and structural computations before issuing grading and building permits.

9. The County Public Health Service must approve septic tank location and the noise level at the plant site.

Elapsed time from the start of design to the date the geothermal plant is put into operation is 48 months.

STEAM GATHERING SYSTEM

The gathering system of a geothermal field is comprised of several wells which deliver steam through a network of 12" to 42" diameter pipes to the generating plant. On an average, one well is capable of producing 8 MW of electric power. Therefore, to supply the necessary steam for a plant of 110 MW capacity, about 14 wells would have to be drilled.

Economic selection of the diameter for the pipes is a function of several parameters, such as, friction pressure loss, heat loss due to length, perimeter and material of pipe and well production costs. The final pipe sizes are determined by optimizing all of the above variables. The pipes are anchored at intervals of 200 feet, with intermediate sliding supports spaced at 40' to 60'. Temperature expansion loops 16' high and 40' wide are provided to accommodate 2½" per 100' horizontal movement due to 300°F differential temperature, Fig. 9. The loops are often placed in vertical configuration when slope of the terrain does not allow horizontal placement.

All pipes are insulated on the outside with 3" of fiberglass material compacted to 1½" thickness and wrapped (jacketed) with an asbestos nylon reinforced cloth which, on the inside, has an aluminum color coating and, on the outside, a bayberry colored finish to blend with surrounding natural landscape.

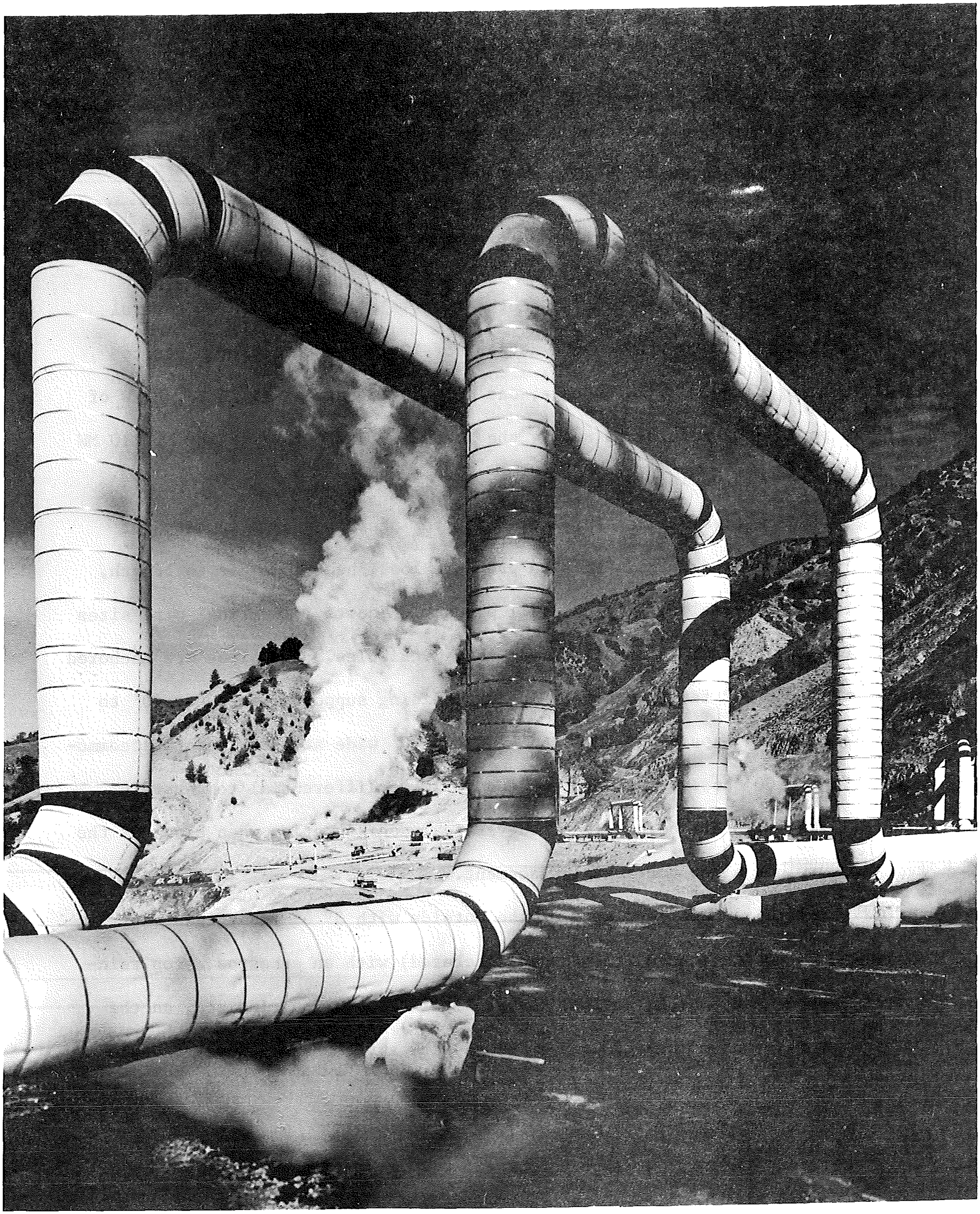


FIGURE 9.

MATERIALS OF CONSTRUCTION

Because of the corrosive action of steam and condensate, extensive studies were conducted in The Geysers area to determine the suitability of various materials. The studies were conducted by placing test coupons inside the condenser and exposing various metal samples to the outside atmosphere. These test samples were placed in special racks built in close proximity to the plant site.

The results of these studies indicate that:

1. The steam, as it comes from the wells with a slight amount of superheat, is relatively noncorrosive. Therefore, carbon steel is used for piping and turbines. Chromium steel has been used for turbine blading to minimize the corrosion from the particulate matter in the steam.
2. Corrosiveness of steam and condensate increases on leaving the turbine and entering the condenser. Austenitic stainless steel, aluminum or epoxy-fiber glass are satisfactory materials for this portion of plant equipment.
3. Outdoors, heavy galvanizing gives good results and epoxy paints provide the necessary protection against ambient ground-level emission of hydrogen sulphide.
4. As a remedy to corrosion, metals are often replaced by plastic products.

POWER PLANT STRUCTURES

Because the steam does not have to be produced in a boiler, The Geysers units are simpler to design than are other thermal plants. There are no boiler structures, exhaust stacks, heat exchangers, fuel tanks or fuel loading facilities, and the size of cooling water intake and discharge structures are grossly reduced. In fact, the plant consists of two principal structures: a generator turbine building that includes the condenser and a cooling tower.

Because of a rugged hilly nature of the terrain, the flat area required for a plant site must be created by excavations, cuts and fills. For convenience of operations and servicing of the equipment, all plant facilities should preferrably be located on one level. This makes the excavated bench of considerable extent.

The layout of the plant in the form of a "T" with the turbine-generator building occupying the cross bar of the "T" and the cooling tower occupying the stem. This configuration has been used for Units 3, 4, 5 & 6, 11 and 12, (Fig. 10). When the plant is located on the side of a hill or on the top of a ridge, the configuration is that of two parallel bars (Fig. 11) as has been done with Unit Nos. 1, 2, 7 & 8, and 9 & 10.

The power building houses the turbine-generator, condenser and associated equipment. The steel frames are spaced between 8 ft. high precast concrete wall elements, which are made to accommodate perimeter ventilation. The rest of the walls are covered with metal siding panels. The roof consists of a built-up roof over a 3-inch folded metal deck with 1 5/8 inch fiberglass insulation between.

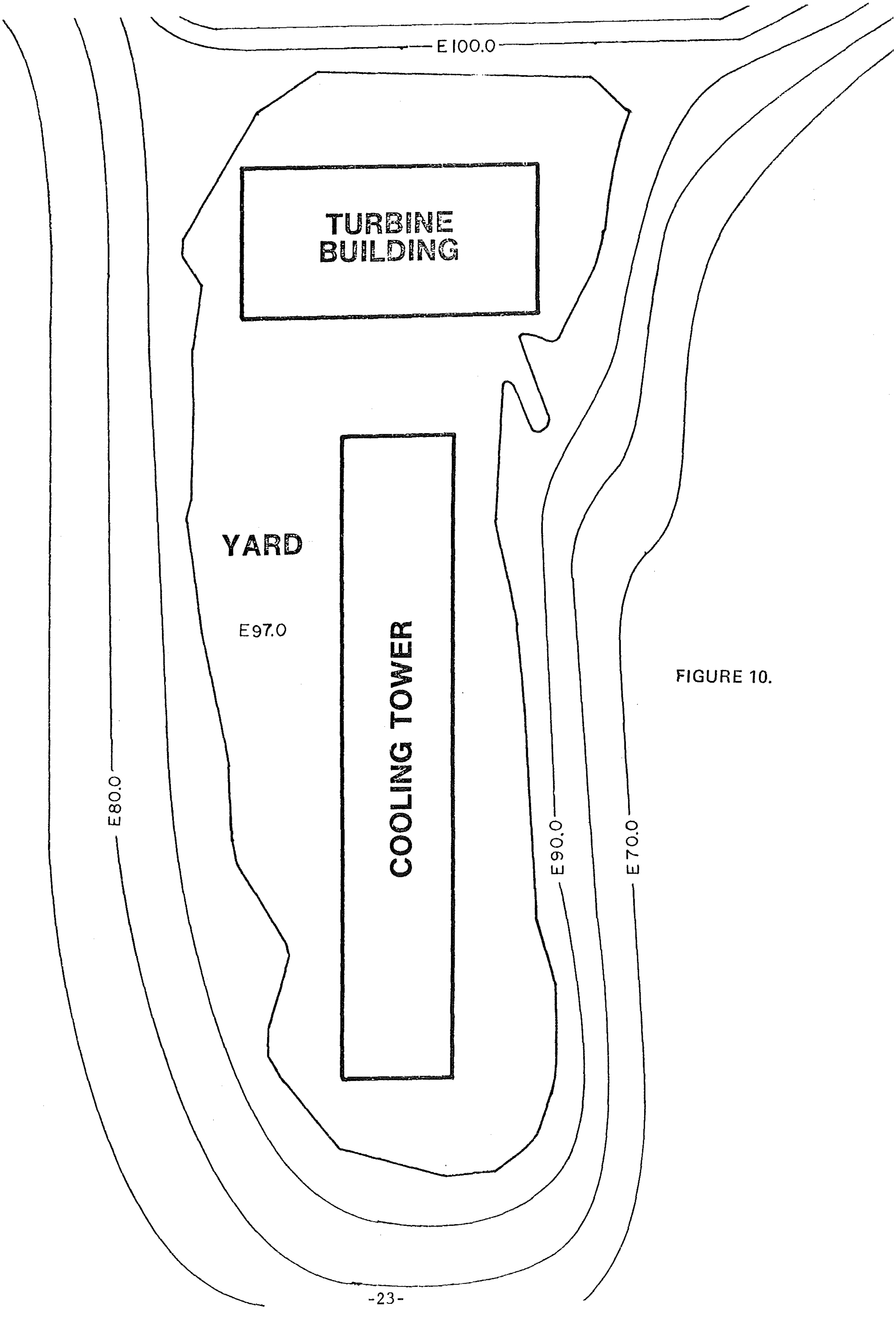

E100.0
TURBINE BUILDING
YARD
E97.0
COOLING TOWER
E80.0
E90.0
E70.0

FIGURE 10.

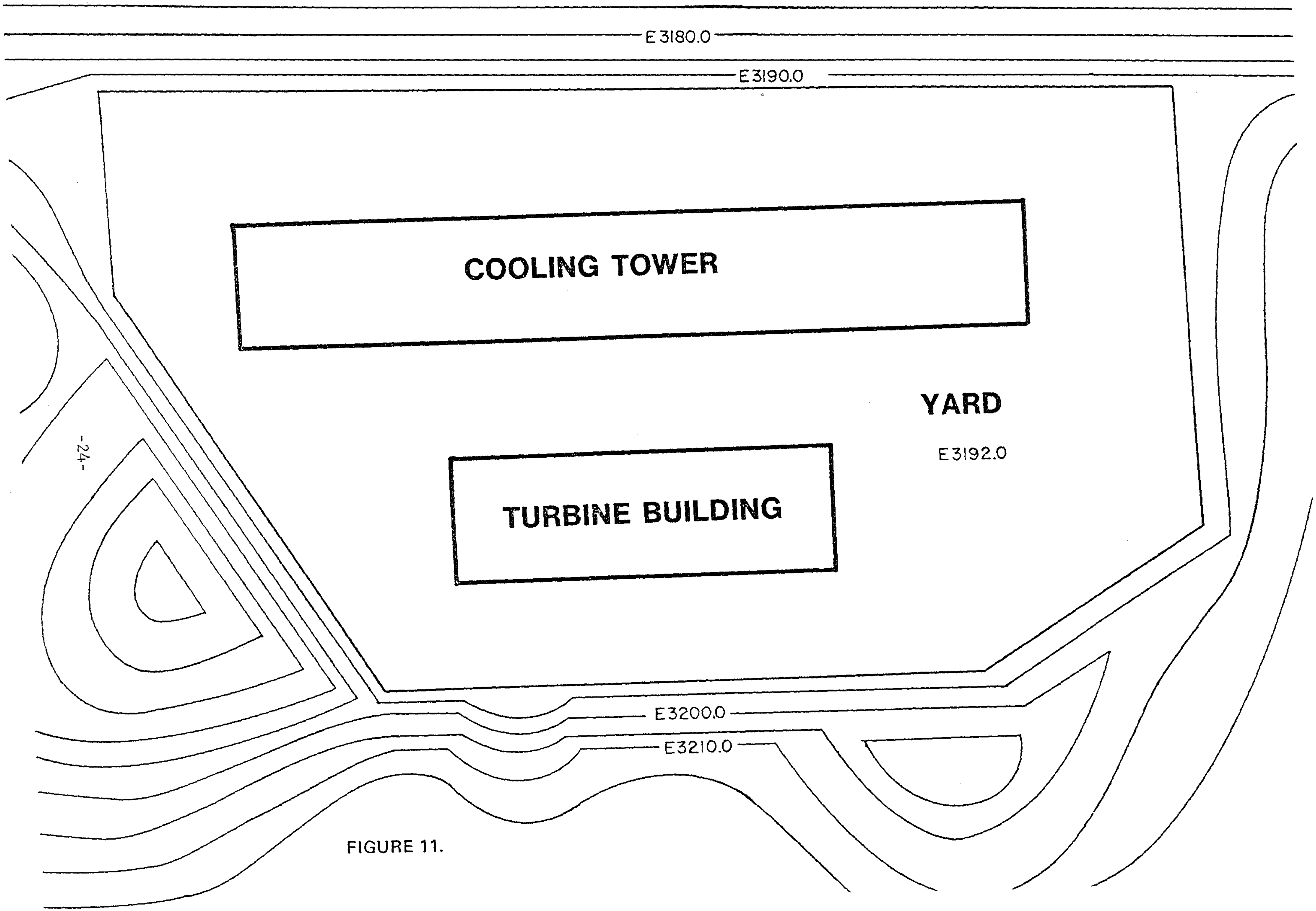

E3180.0
E3190.0
COOLING TOWER
YARD
E3192.0
TURBINE BUILDING
E3200.0
E3210.0

FIGURE 11.

Concrete turbine pedestals are normally designed as low tuned structures. The width and height parameters of the condenser preclude design of a high tuned foundation. A foundation pedestal is classified as "low tuned" when its fundamental vertical mode is lower than the normal operating speed by at least 20%. The natural frequencies and mode shapes are determined by means of a three dimensional lumped mass dynamic analysis using the "Strudl" program developed at MIT. This three dimensional model includes pedestal, foundation mat and soil springs. Once the frequencies and mode shapes of the structure are determined, a Fortran IV program is employed to compute response to harmonic loading applied normal to the rotor along its length throughout the range of frequencies. This harmonic loading represents force due to mass imbalance. The calculated response is used to determine whether or not the basic requirements have been met. Resonance at frequencies other than normal operating speed must also be avoided. These frequencies are twice operating speed, oil whirl, and rotor criticals. Alignment of the rotor under operational loading and temperatures must be maintained to close tolerances. These are set by the manufacturer. Once the geometric form of the foundation has been established in accordance with these resonance and deflection requirements, design of the members for stress can proceed.

Static loads, temperature loads, and dynamic loads act on the foundation. Theoretically, it would be possible to use the actual maximum out of balance forces to determine the dynamic loading but these forces are difficult, if not impossible, to obtain from the manufacturer. Thus, use of static equivalent forces for dynamic loading is forced upon the designer. Service loads are factored and combined in accord with the strength design method of ACI (318-71), Requirements for Reinforced Concrete. The "Strudl" space frame program is used to determine the envelope of maximum forces along the members and they are reinforced in compliance with the strength design method. Biaxial bending stresses are checked using a small computer program.

Cooling towers are of induced draft, cross flow type. One of the principal objectives of the site development is to orient the cooling towers to take best advantage of prevailing winds to maximize performance. At the same time the steam vapor should not be dispersed in the direction of the turbine building or transmission line corridor.

The correct design of the structural framework of a cooling tower is an intricate task. The tower must not only be structurally stable, but the design should be compatible with thermal, aerodynamic and economic considerations. The tower must be able to support not only the weight of the basic components such as mechanical equipment, fill louvers and casing, but also the weight of the cascading water, a wind load of 30 lbs per square feet, and earthquake forces. In a very severe operating environment, all of this should be accomplished while providing long and trouble-free service life.

Tower configuration conforms to water and air flow requirements, with particular attention to keeping the restrictions of air flow to a minimum. Efficient performance depends on thorough mixing and prolonged contact of water and air. This is accomplished by use of splash fill. The air intakes on the side walls are covered with screens to prevent entry of leaves.

The tower framework is composed of redwood members, with bolted connections. Wind and earthquake forces are transmitted by diagonal bracing to the foundation. Plywood shear diaphragms carry the transverse forces to the foundation.

The cooling tower fill is made of polyvinyl chloride because of its high resistence to deterioration and fire.

The bottom basin is a reinforced concrete slab with 4 ft. curb walls all around. Because of its size (50 ft wide, 400 ft. long) the concrete is poured with an expansion joint every 30 feet, with rubber water stops to prevent leakage. The concrete is coated with coal tar epoxy to inhibit the corrosive action of the condensate water. The basin serves to collect the water as it falls to the base of the tower.

DOMESTIC WATER

Drinking water at the plant is supplied by **imported, bottled water.** The domestic water needed for initial fill of the cooling tower basin, use in wash rooms, toilet factilities and fire and compressed air cooling systems is supplied from a well system or from adjacent creeks. The domestic water system is designed for a flow of 20± gpm for short periods of time. The use of a water truck to supply a plant storage tank is being studied.

ECONOMICS OF GEOTHERMAL GENERATION

The following data are estimates which are valid for comparative purposes only and are subject to change.

Pacific Gas and Electric Company's role in geothermal development is the construction and operation of generating plants, leaving exploration and development of steam to others. The cost to the principal steam suppliers (Magma Power Company, Thermal Power Company, and Union Oil Company of California) of drilling a well is about $400,000 for 8,000 ft. depth. Depletion allowance is 22% of gross income, but not greater than 50% of net income, with depreciation calculations on straight-line over 14 years.

The principal steam suppliers own leases on about 20,000 acres. The current lease rental for flank acreage to The Geyser's field is about \$10.00 per acre per year and 10% of gross revenue from the sale of steam. Under an agreement with Pacific Gas and Electric Company, the financial responsibility for and income from the first 200 MW capacity belongs to the Magma-Thermal coalition. The second 200 MW is to be divided 25-25-50 among Magma, Thermal and Union Oil, and the third 200 MW will be entirely Union's. Thereafter, development and revenues will again be shared 25-25-50.

The cost of constructing geothermal capacity is about \$150 per KW which compares very favorably with \$400 per KW for fossil-fuel plants, and \$600 per KW for nuclear units. These cost figures should be considered taking into account the time from the start of design to the start of operation, which is 4, 7, and 11 years for geothermal, fossil-fueled, and nuclear-fueled plants, respectively.

The service life of the plant is taken as 35 years. Because of detrimental effect of discontinuous flow on well efficiency and the involved procedure for phasing out steam well production during shut downs, The Geysers units are operated base-loaded, to the extent it is feasible to do so. During 12 years of operation, geothermal power generation costs have averaged about 5.5 mills per KWHR. The price for steam is tied to PG&E's other fuel cost by special formula and is thus uncontrolled.

The turbines are designed to operate at 100 psig pressure, 355°F temperature, and 4 inches Hg absolute exhaust. The well testing procedure to determine if necessary steam flow is available before plant construction is approved, has been replaced by theoretical reserve estimates based on criteria developed in natural gas fields.

500 MW

X

5×10^5

$\times 1.5 \times 10^2$

7.5×10^7

75 M Bucks

400,000

40 M Bucks

Productivity of the steam field could be evaluated with just a few wells drilled in the region of the potential power site.

Steam productivity of the well is expected to decline with time and new wells are drilled to maintain the steady supply of steam for the plant. By drilling wells at one well per 40 acres the production rate of the wells is better maintained.

INJECTION WELL

Geothermal plants do not require a supplemental source of cooling water. The natural steam, after passing through the turbine, is condensed, piped to the cooling tower, and then recirculated back to cool the exhaust steam in the condenser. By this method the field at the Geysers produces about 20% more condensate than is evaporated. This surplus is reinjected into unproductive wells, which accomplishes two purposes:

1. The reinjection of the condensate presents the most efficient way of waste water disposal. The surplus condensate cannot be disposed of on the surface, because it contains ammonia, boron, sulphates and other ingredients harmful to fish and plant life.
2. The useful life of the field might be prolonged by returning the condensate to the reservoir, where it originated.

NOISE AND HYDROGEN SULPHIDE

Noise from well operation has been recognized as an environmental problem. Steam suppliers have been persistently working on this problem and notable improvements have been achieved in recent muffler design.

The emission of hydrogen sulphide from the cooling tower operation is under study by Pacific Gas and Electric Company. Hopefully the results of these studies will enable us to reduce these emissions.

HYDRAULICS OF COOLING WATER CYCLE

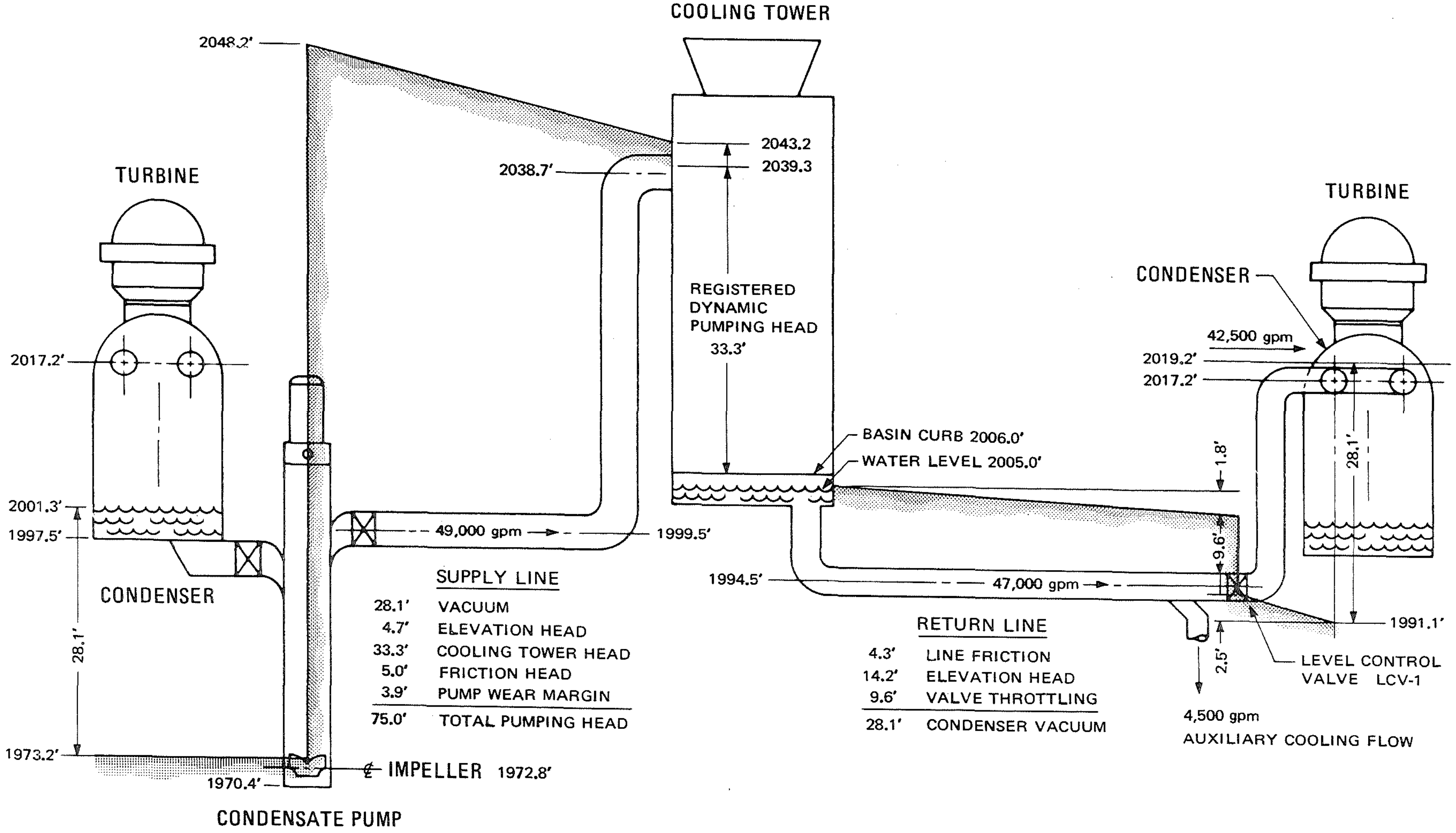
The flow diagram shown in Fig. 12 indicates the energy grade line of the cooling water cycle. The condensate in the condenser hotwell is pumped to the top of the cooling tower by the circulating water pump. The cold water from the tower basin is gravitated back to the top of the condenser to complete the cycle. Starting up the cycle first requires partial filling of the condenser with water and then lowering the water level to create the necessary vacuum. When the turbine is started, the valve that regulates water flow from the condenser is put into automatic operation.

CONCLUSION

Geothermal energy generation has a vast potential. Some hopefuls believe that in 50 years it will be recognized as a greater energy source than petroleum. Geothermal resource development has been significantly hampered by the fact that geothermal science and technology are generally in their infancy. In this respect, the outstanding success of the geothermal exploration and power production at The Geysers serves as a guide and a model for future world development of vapor dominated geothermal resources. A remarkable evolution takes place in the design of every new unit which serves as a laboratory for research and practical application of the inventiveness and the ingenuity of engineers and scientists. An outstanding achievement has been attained in the ecological field and research in this direction is vigorously being pursued.

ENERGY GRADE LINE

FIG. 12 CONDENSATE PUMP DESIGN CONDITIONS



SUPPLY LINE

28.1'	VACUUM
4.7'	ELEVATION HEAD
33.3'	COOLING TOWER HEAD
5.0'	FRICTION HEAD
3.9'	PUMP WEAR MARGIN
75.0'	TOTAL PUMPING HEAD

RETURN LINE

4.3'	LINE FRICTION
14.2'	ELEVATION HEAD
9.6'	VALVE THROTTLING
28.1'	CONDENSER VACUUM

HIGH BAROMETRIC CONDITIONS	28.8 in. Hg. (STANDARD BAROMETRIC 27.8 in. Hg.)
NORMAL TURBINE BACK PRESSURE	4.0 in. Hg. Abs
CONDENSER VACUUM	24.8 in. Hg. = 24.8 x 1.33 = 28.1 ft. QF H_2O

ELEVATION SCALE: 1" = 1'0" HORIZONTAL SCALE: NONE

(SI CONVERSION FACTORS: 1' = .305m and 1gpm = 0.004m^3/min)

ACKNOWLEDGMENT

This paper was possible only with the cooperation, suggestions and review by my many friends and colleagues. Particular acknowledgment is due to Richard V. Bettinger, Ray Blum, Lynn Breger, Andy Chou, John P. Finney, Curtis E. Hendrick, Winifred Hutton, Seow Kew Kho, Mark Mathiesen, Harry McMasters, Tom Robyns, Otto Steinhardt, and Mike Storchillo.

Special thanks are expressed to G. W. Leonard of Naval Weapons Center, China Lake, California, for giving me permission to use several illustrations from "Geothermal Science and Technology, A National Program" publication.

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