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ENVIRONMENTAL IMPACT ASSESSMENT: ENHANCED OIL RECOVERY BY COMBINATION THERMAL DRIVE, PARIS VALLEY, CALIFORNIA

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August 15, 1978

Prepared for U. S. Department of Energy under contract No. W-7405-Eng-48.

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ABSTRACT

The U.S. Department of Energy has contracted with Husky Oil Co. to share the cost of a field experiment of the *in situ* combustion oil recovery process. This contract is one of 21 awarded to oil producers by DOE to demonstrate various techniques of enhanced oil recovery (EOR). The goal of the EOR program is to develop a process or processes that may be employed in various environments with predictable results, a requisite condition for wide-scale industrial use.

The purpose of this assessment is to describe activities proposed by Husky Oil and to evaluate any resulting environmental disruption. The experiment will take place in the Paris Valley oil field, upper Salinas Valley, California, an area that is mainly agricultural. The nearest industrial developments are at the San Ardo oil field, 10 miles south, and at King City, 10 miles north. Key issues involve air pollution, for which some mitigating measures have been taken, and surface waste-water disposal.

ENHANCED OIL RECOVERY PROGRAM

The Department of Energy has awarded 21 contracts to oil producers as of April 1, 1978, to partially fund field experiments with various methods of enhanced oil recovery. The goal of this program is to develop one or more processes that can be employed in a variety of environments with predictable results. Oil and gas may accumulate (with some other materials) if the following are present to create a potential trap: reservoir rock (containing interconnected pores), impervious rock above, and closure (a geological configuration which prevents the lateral escape of fluids). The latter may be either a structural trap (anticlinal, fault, or salt dome) or a stratigraphic trap (lithologic change). Gas and water may be present in the oil.

To produce oil from the reservoir, well pressure must be lower than reservoir pressure. The rate of production depends on the viscosity of the oil, the ease with which fluids can pass through the reservoir towards the well (formation permeability), and the pressure within the reservoir. The pressure is influenced by the gas and water present in the reservoir. Although a reservoir may contain a mix of these drives, usually one predominates: water drive, where water brings pressure to bear from below or from a lateral direction towards the oil; gas cap drive, where gas above the oil expands pushing gas ahead of it downstructure; depletion drive (solution gas); and gravity drainage, which is particularly influenced by the dip, oil viscosity, and formation permeability.[1]

Primary recovery uses initial natural flow and pumping to draw oil from the reservoir. The amount removable by this method varies with the pressure within the reservoir, the permeability of the reservoir rock, the viscosity of the oil, and the driving mechanism. Between 10 and 30 percent of the oil is usually recoverable by primary methods.[2] As oil is withdrawn from the reservoir, the pressure decreases, and the producing capacities of the wells decline. To enhance production, the reservoir pressure can be increased by secondary recovery methods.

Secondary recovery methods, such as waterflooding or gas repressuring, are used to extend flow from reservoirs once their rate of primary recovery becomes uneconomical. From 8 to 13 percent of the oil in place is typically recoverable by secondary methods,[2] but up to 30 to 40 percent can be obtained under good conditions.

Enhanced oil recovery (EOR) methods that not only increase reservoir pressure but also reduce oil viscosity have been developed because secondary recovery methods are not particularly effective with very viscous oils. Thermal methods include injection of either hot steam, hot water, or air, which is then ignited for *in situ* combustion. Injection of carbon dioxide or of micellar-polymers are tertiary recovery methods which lower the oil/water interfacial tension.

DOE's program for enhanced oil recovery is intended to slow the oil production decline in order to extend the time available to the United States for developing energy alternatives to oil, and to decrease reliance on imported oil in the interim. DOE estimates that there are 290 billion barrels of conventional oil and 130 billion barrels of heavy oil and tar sands, none of which can be profitably recovered with conventional technology. By the use of enhanced recovery techniques, such as those being partially funded by the aforementioned contracts, DOE estimates that 40 to 60 billion barrels of this oil may be recoverable.[3] Costs of the experimental projects are shared by DOE and the producer, and all published results are in the public domain.

A number of enhanced oil recovery techniques have been developed. These include miscible fluid injection, micellar-polymer flooding, and several thermal methods such as cyclic or continuous steam injection, and *in situ* combustion, also known as "fireflooding."

California's crude oil is generally high in napthenes, with asphaltic matter usually present in large proportions. This results in a highly viscous type of crude which is difficult to remove from the reservoir. Heating the oil-bearing formation (by injecting hot water, steam, or by *in situ* combustion) lowers the viscosity of the oil and makes production easier.

Husky Oil Co., in producing from the Paris Valley field, requires a recovery method which both increases oil mobility in the vicinity of the producing wells, and which replenishes the depleted portions of the reservoir while heating the main body of the reservoir. The chosen method is a combination of several processes: 1) combustion thermal drive, a "wet" modification of forward *in situ* combustion, and 2) cyclic steam stimulation of the producting wells. The following is a description of a standard forward *in situ* combustion project (see Fig. 1).

Compressed air has been injected into the producing formation, and the formation is then ignited. Combustion usually continues as long as the airflow is maintained by injection. At the site of the air injection well, the oil and coke (carbonaceous material) content has been burned and the oil displaced. The burned region is composed primarily of clean, fine-grained sand. The temperature is lower in this area than at the combustion front, where the temperature ranges between 600 and 1,200^{O}F. A coke zone lies beyond the combustion front. In that zone, carbonaceous material is deposited as a result of cracking of the crude oil by the burning front. Lighter oils are either vaporized or move ahead of the burning region, displacing oil ahead of them. The hot water or condensing steam zone, is the next zone. The temperature there is between 200 and 350^{O}F (depending on the pressure), and warm fluids precede the steam plateau. A light hydrocarbon zone follows, which is pushed ahead by the burning front. The zone beyond the oil bank is relatively undisturbed. The water, oil, gases, and the temperature are close to that of an undisturbed reservoir until the steam plateau and combustion front reach it.[4]

Wet combustion is a modified form of forward *in situ* combustion. Of the total heat generated underground in standard forward combustion, more than half remains between the air injection well and the burning front. To move this heat forward in front of the burning zone, water is injected. Part or all of the water vaporizes when it hits the hot burned-out sands, then passes through the burning front and transfers the heat to the area ahead of the flame. This reduces the viscosity of the oil ahead of the steam/hot-water zone. Water flooding also provides a number of technical advantages for the operators such as the possibility of reducing fuel needs, reducing operating pressure, and reducing air-oil ratios. See Fig. 1 for a comparison of the heat distribution in normal vs wet combustion.[4]

PARIS VALLEY PROJECT DESCRIPTION

The DOE-Husky Oil Co. contract calls for a combination thermal drive experiment: that is, one that combines *in situ* combustion with cyclic steam injection. This fireflood experiment will take place in a rural area some 10 miles south of King City, California, on the western slopes of the Salinas Valley. The experimental area is a 25-acre site located in sections 2 and 3 of T22S, R29E on the side and crest of a small anticline.

Oil production at Paris Valley comes from the Ansberry formation, which lies at an average depth of 800 ft with a gross thickness of about 100 ft. The Ansberry formation is an unconsolidated sandstone. The sand is nonhomogeneous and is medium to coarse in texture. The net oil sand thickness varies between 5 and 90 ft. The crude oil is viscous with a gravity of about 10.5° API (American Petroleum Institute), and an average oil viscosity of 150,000 cp at the reservoir temperature of $87^{\circ}F$.[5]

The Paris Valley reservoir has some problem characteristics that hinder response to thermal stimulation. The oil viscosity is very high; the oil has little gas in solution to provide gas drive; the water present is not sufficient for water drive; the reservoir pressure is low; and the productive intervals are thin enough to result in heat losses to adjacent beds. All these factors reduce the response duration.

The Paris Valley field was first drilled in 1922. In the 1940's and 1950's, the structure and extent of the field was delineated through additional drilling. Wells drilled in the late 1950's had little production

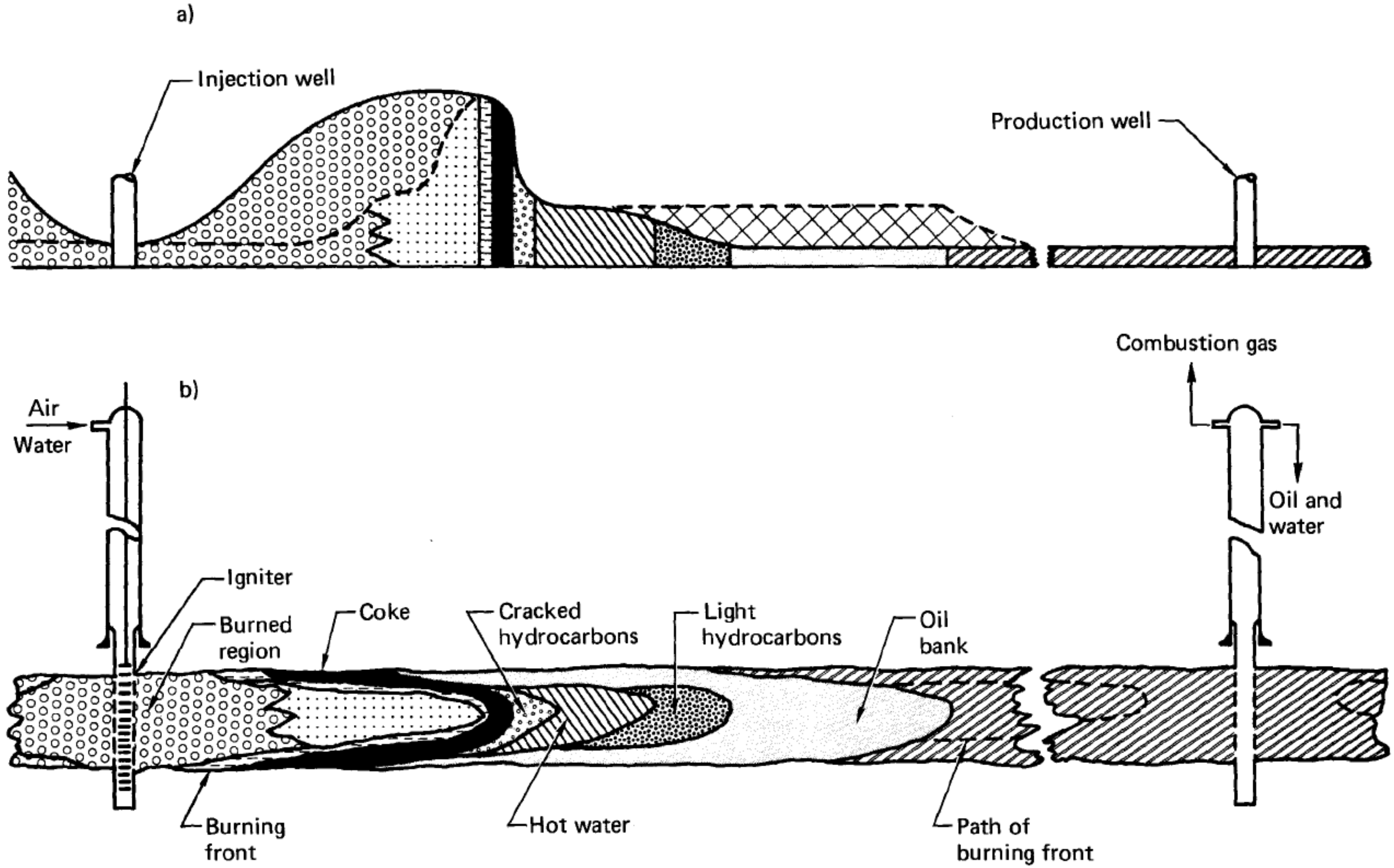


Fig. 1. Mechanisms of the *in situ* combustion process: a) temperature distribution, b) a cross section of the formation.[6]

and were shut down. In 1961, Getty Oil Co. acquired the Ansberry Lease portion of the field and began cyclic steam drive tests to increase production. However, the project was considered unsuccessful, and it ended in 1964. Getty Oil continued to produce some oil at Paris Valley until Husky Oil acquired the Ansberry Lease. The oil in place in the Ansberry sand for the Paris Valley field is currently estimated to be approximately 50 million STB.[6] Some oil can be, and has been, removed by conventional thermal stimulation techniques such as cyclic steaming, but the response lasts only a short time due to the high oil viscosity and low reservoir pressure, as well as to the relatively thin zones of productive sands. The current combination thermal drive experiment is an attempt to increase this rate of production.

At Paris Valley the production wells are cyclically steam stimulated until the combustion front arrives. When steam is injected into a well, a steam saturated zone forms around the outlet. Temperature decreases away from the injection point. In the steam-invaded area, steam distillation of the oil takes place. Some oil is displaced by gas drive effects, and oil viscosity and saturation is reduced, improving the sweep efficiency by increasing the mobility ratio. Because of condensation, a hot-water flood develops beyond the steam zone. Beyond this, a cold water flood zone develops which also contributes to oil recovery by flushing action [5] (see Fig. 2).

The Paris Valley project uses a "staggered line drive" well pattern in a 5:1 ratio. The wells are parallel to the Ansberry Sand structure contours to promote uniform distribution of injected air. The injection wells are placed down dip from the pattern center in order to compensate for the expected up dip air flow. Ideally, each well in a row has a similar structural position, net pay, and formation dip[6] (see Fig. 3).

The following are the components of the project's surface facilities. The configuration of each is shown in separate figures.

<u>Wells</u> (see Figs. 4 and 5)

- 5 injection wells.
- 17 production wells.

<u>Central Tank Battery</u> (See Fig. 6)

- Incoming oil production flowlines.
- Emulsion treater for tests, 6 × 15 ft.
- Wash tank, 2,400 bbl capacity where oil is floated into sales tanks and water is drained to the produced-water cleanup facility.

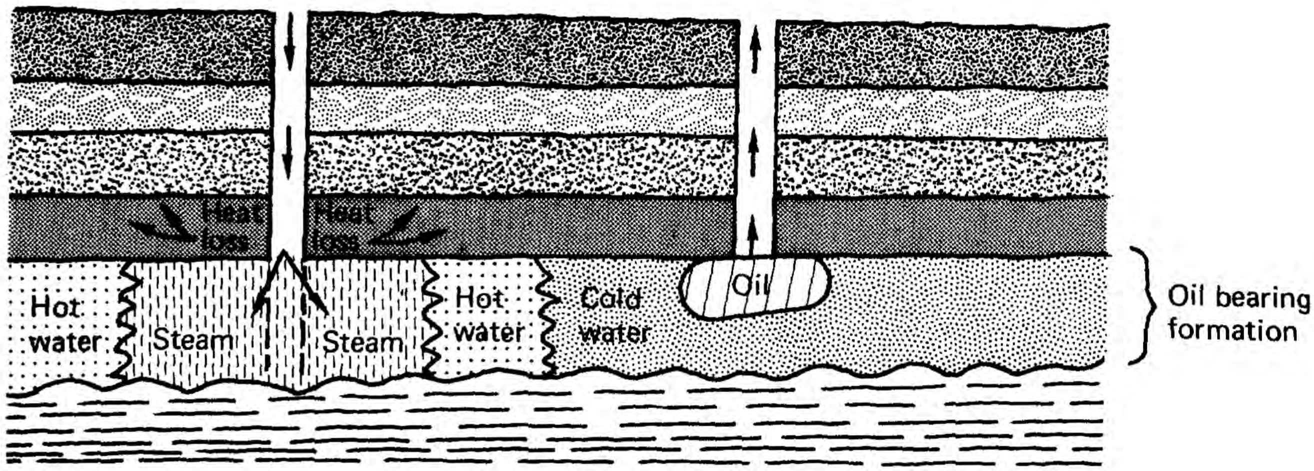


Fig. 2. The steam injection process.

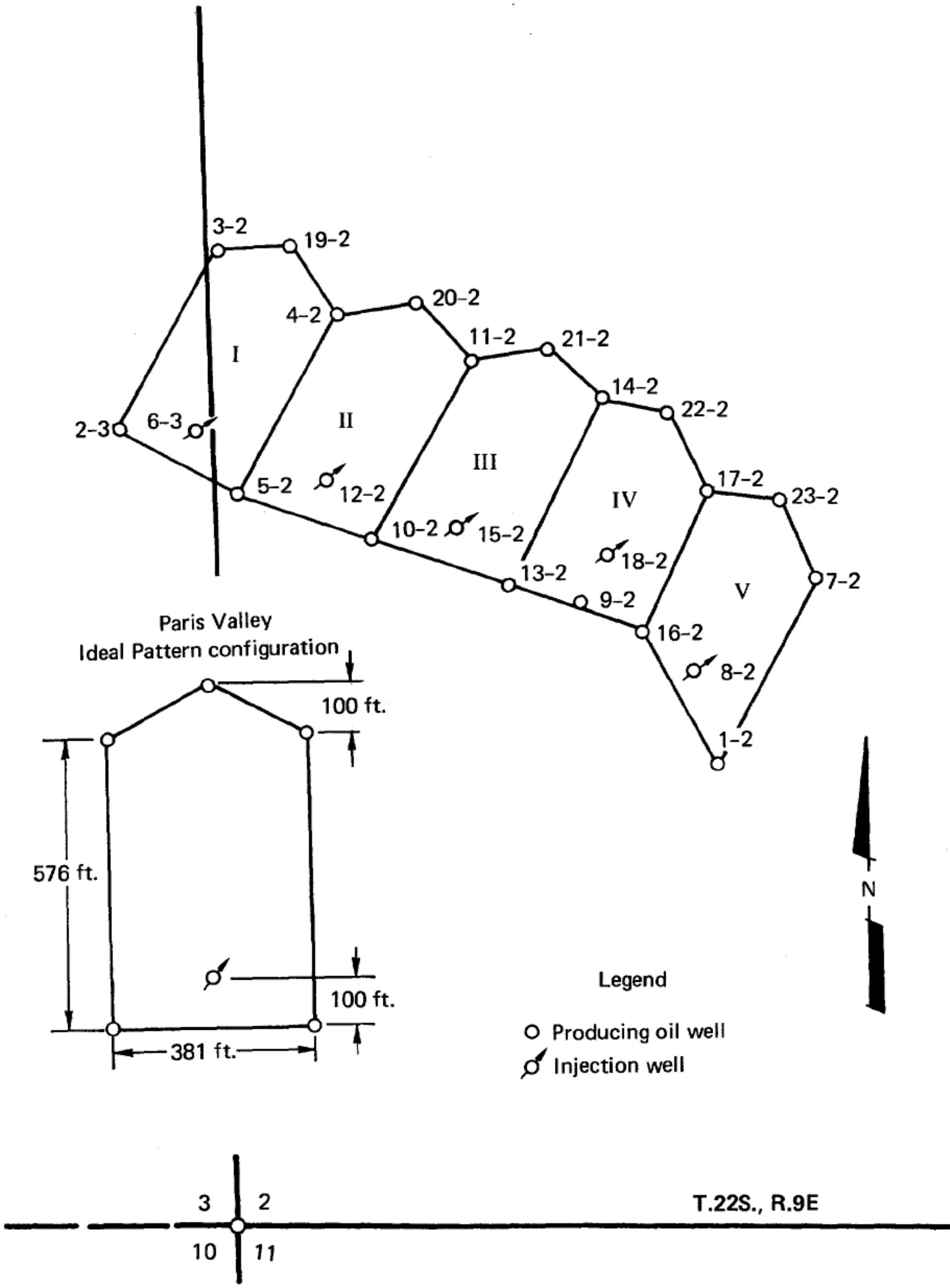


Fig. 3. Well pattern geometry, Paris Valley field.[6]

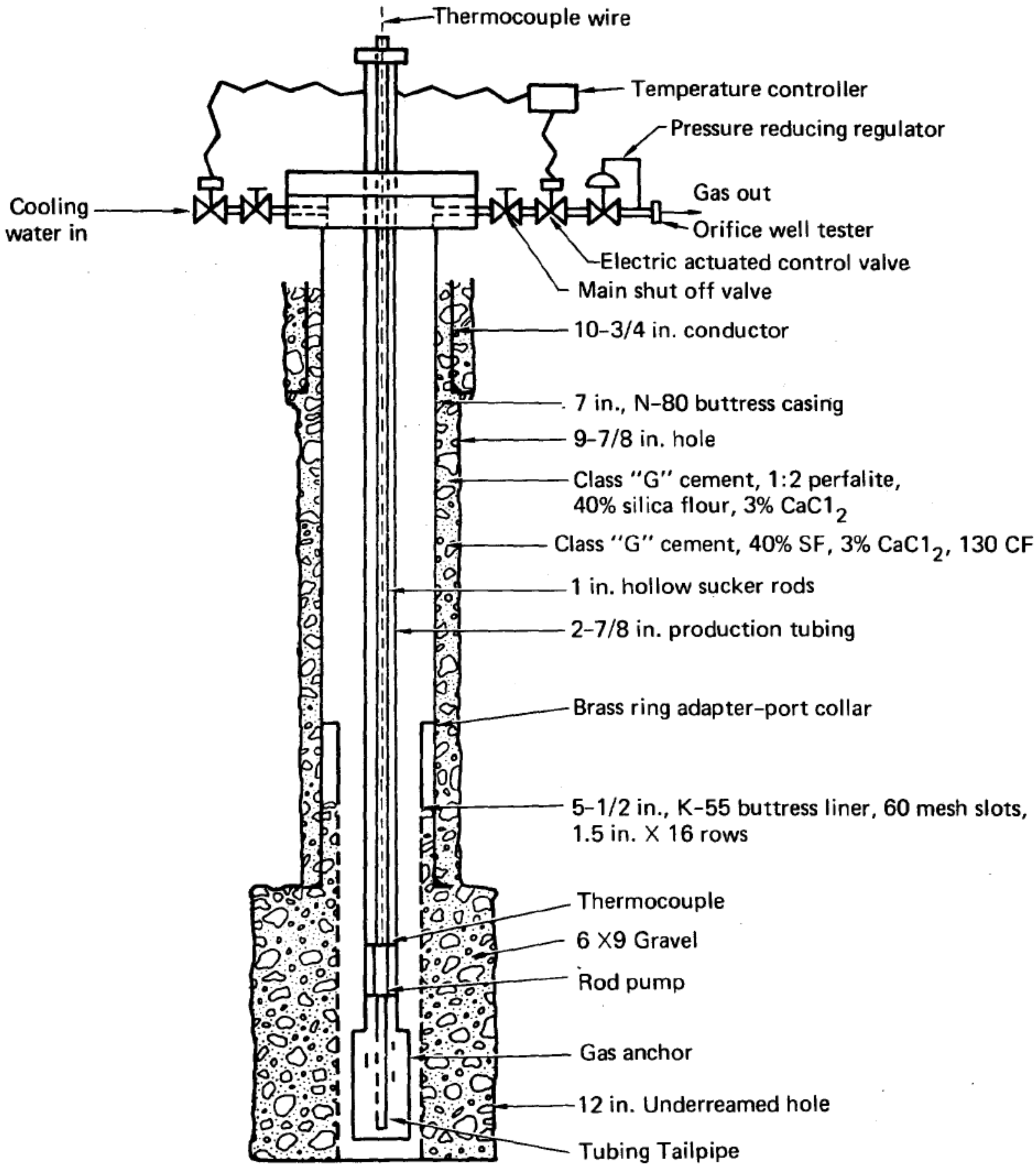


Fig. 4. Typical producing well, with specifications, Paris Valley field.[6]

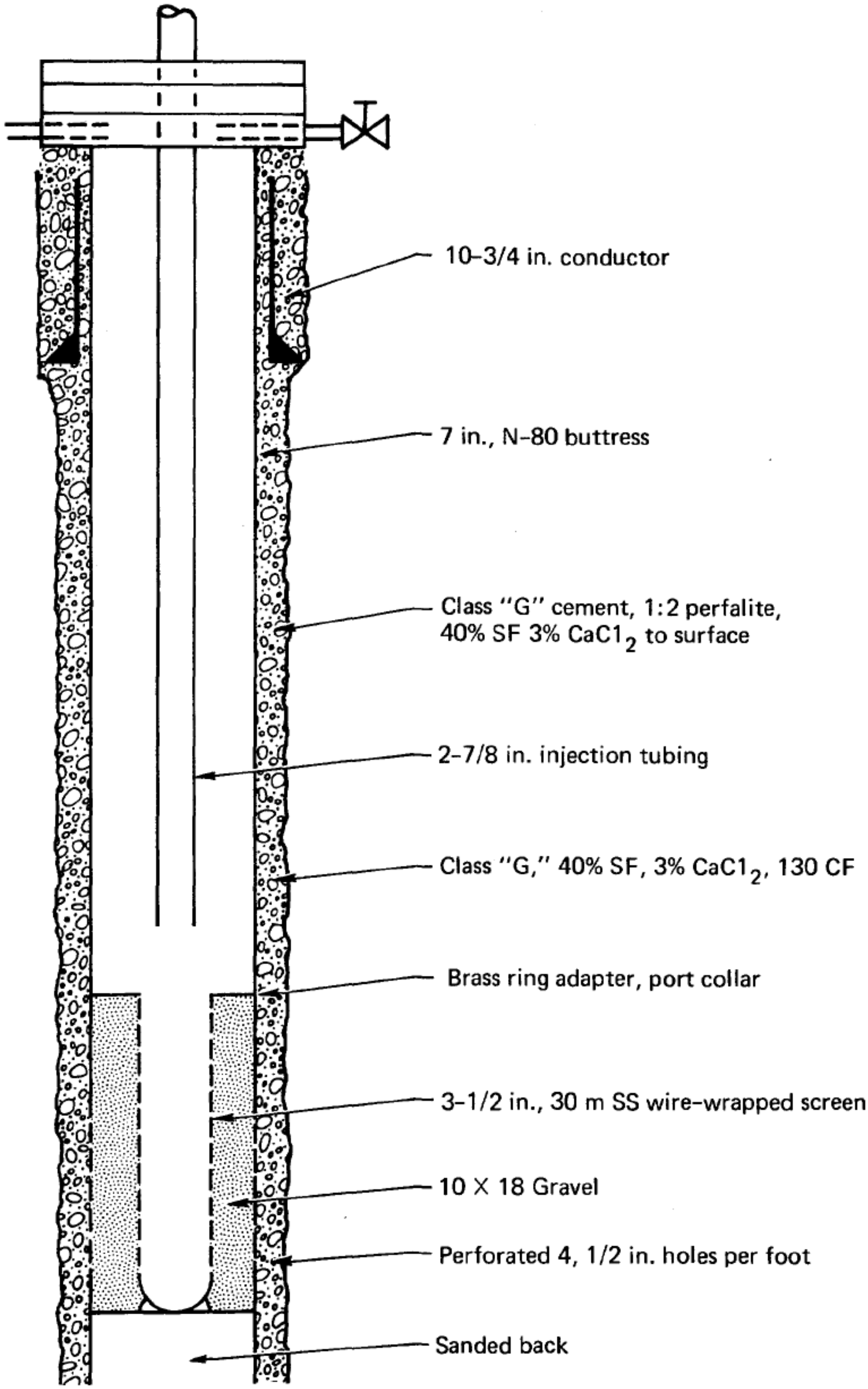


Fig. 5. Typical injection well, with specifications, Paris Valley field.[6]

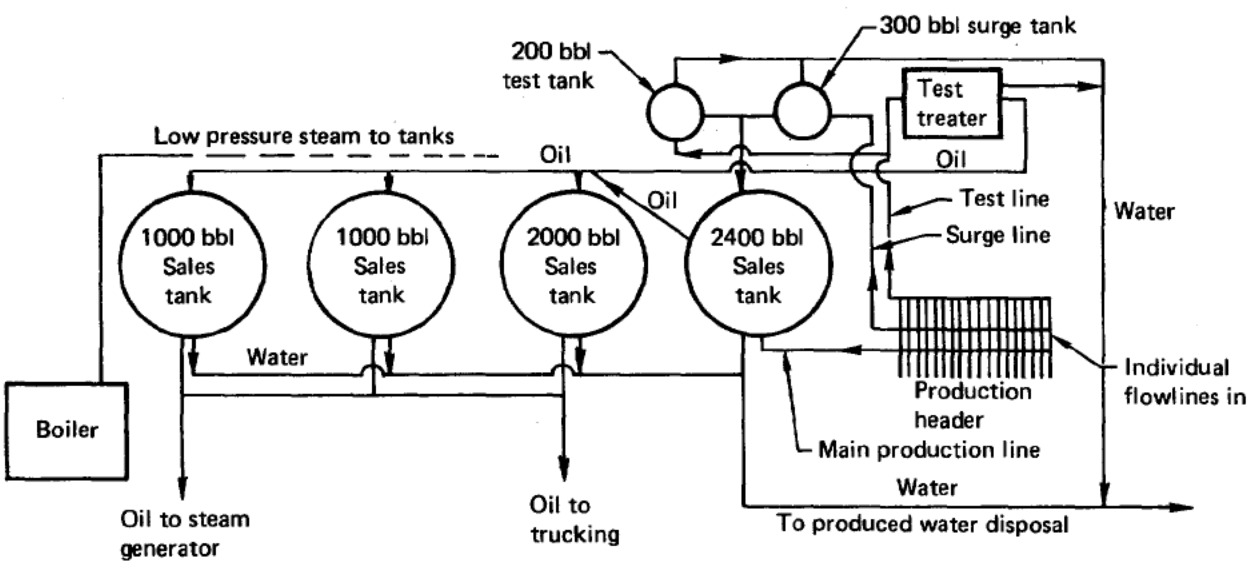


Fig. 6. Central tank battery, Paris Valley field.[6]

- One 15-psig dual-fired boiler for steam generation to heat the wash tank and sales tanks.
- Two 1,000-bbl and one 2,000-bbl sales tanks where water is removed again from the produced oil to reach the allowable basic sediment and water percentage of 3%; oil for trucking out and to fuel the steam generator are drawn off from these tanks.
- 2,000-bbl test tank.
- 300-bbl surge tank.

<u>Produced Water Cleanup Facility</u> (See Fig. 7)

This facility is for removing oil and solids from the produced water in order to maintain injectivity in disposal and air injection wells and to provide clean water for other uses such as the cooling water system and the steam generator fluegas scrubber.

- 500-bbl skimming tank.
- 100-bbl overflow tank.
- 100-gpm air flotation cell.
- 100-bbl sludge tank.
- 1,000-bbl clear water tank.
- Scrubber blowdown pit.
- Flowlines to carry water to uses or to disposal.
- Disposal wells.

<u>Fresh Water Treating Facility</u> (See Fig. 8)

This facility treats water produced from two fresh water wells on the Ansberry Lease for steam generator conversion to steam. The water is both filtered and softened, and scale inhibitor and oxygen scavenger are added.

- 500-bbl hard water tank.
- Pump.
- Filter.
- Softener.
- 500-bbl soft water tank.

<u>Steam Generator Facilities</u> (See Fig. 8)

- 22-MMBTU/HR (million BTU per hour), 2,500-psig steam generator, fired with local crude.
- Natural gas fired heater for fuel oil tank.
- 300-bbl fuel oil tank.
- 500-bbl soft water tank.
- Combustion air preheater (natural gas).
- Emissions scrubber, generator fluegas.

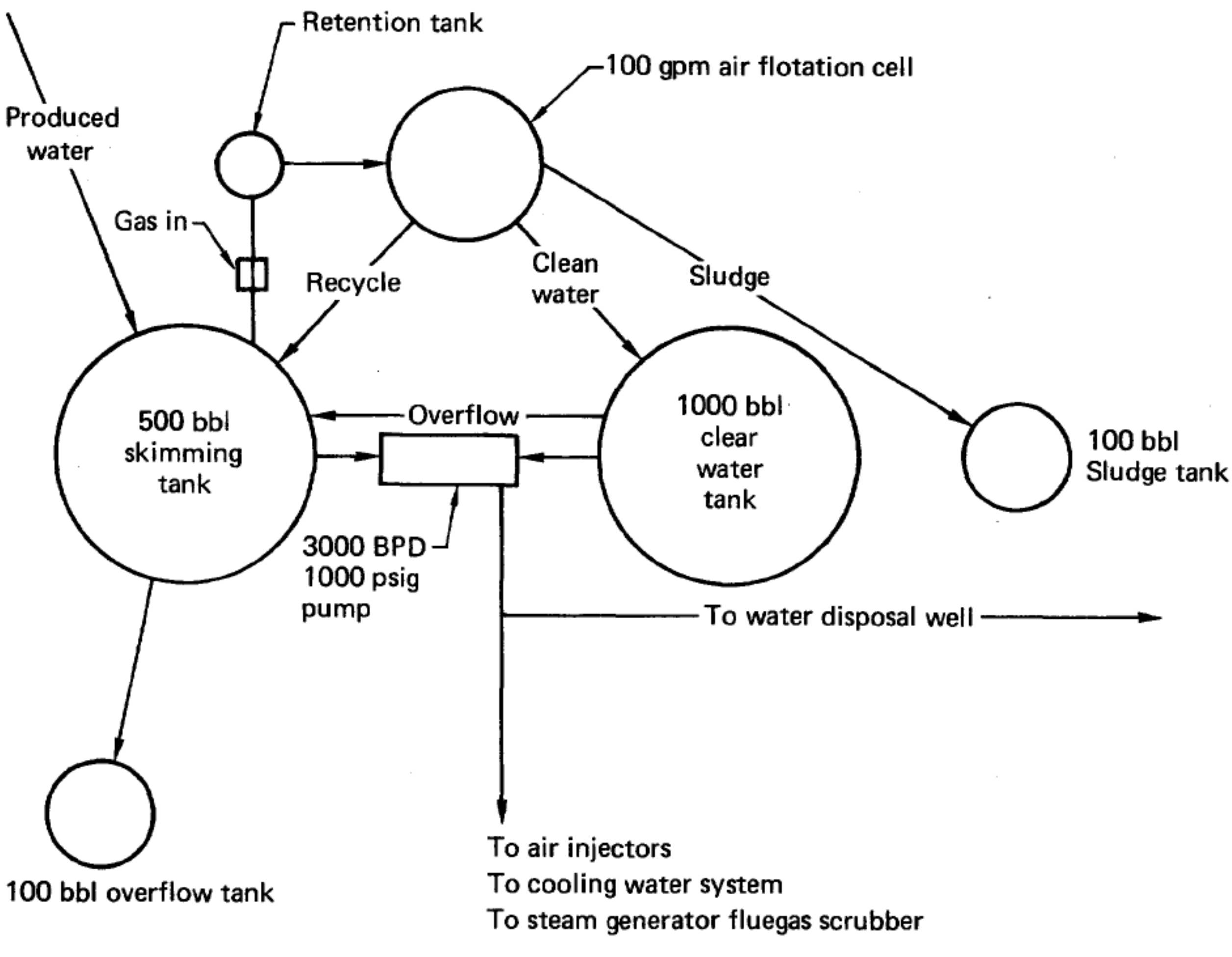


Fig. 7. Facilities for cleanup of produced water, Paris Valley field.[6]

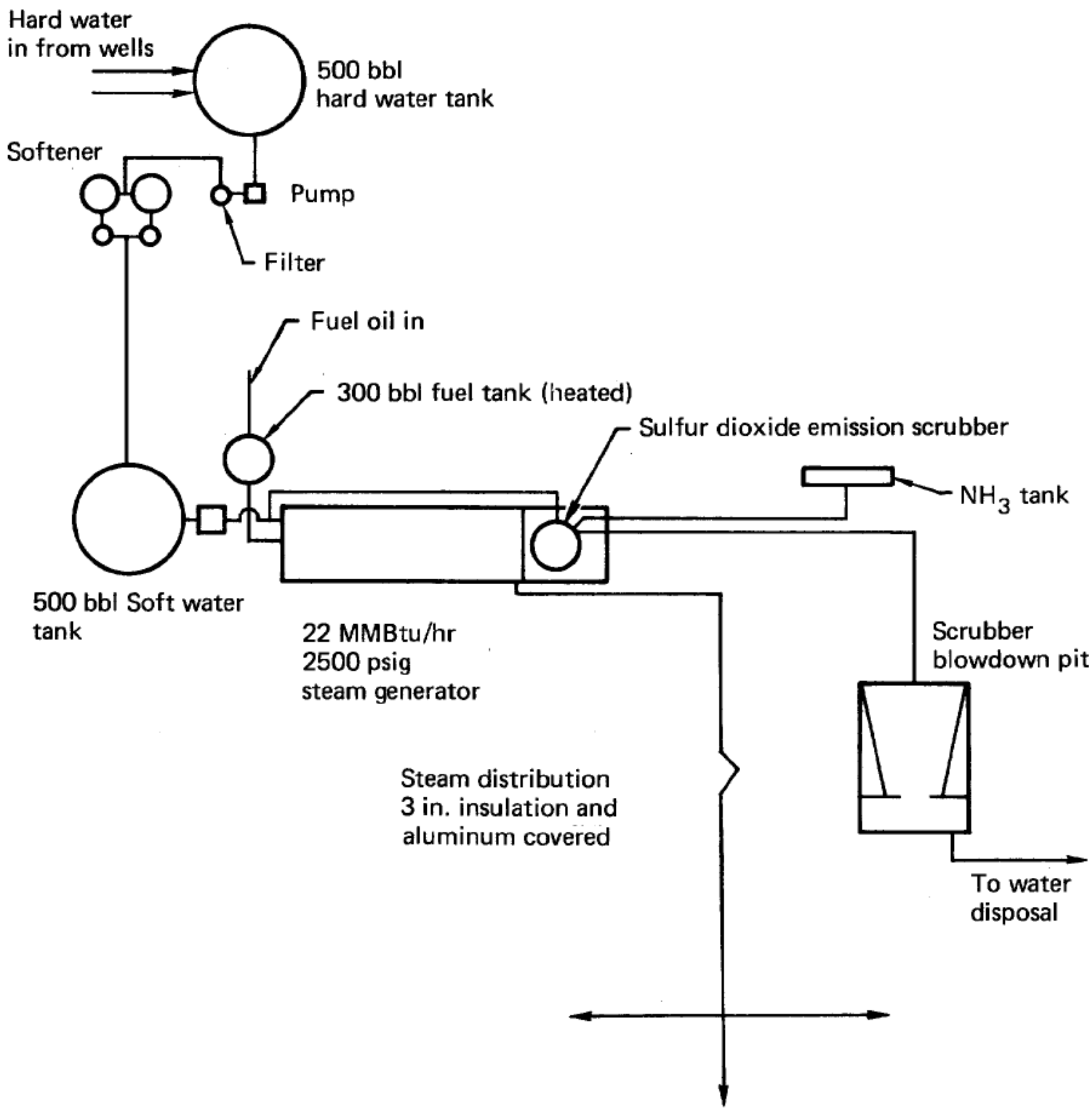


Fig. 8. Facilities for steam generation and distribution, Paris Valley field.[6]

- Ammonia storage tank supplying NH_3 to scrubber.
- Flow lines for steam to wells, above ground and insulated.

<u>Air Injection Facilities</u> (See Fig. 9)

- 5.25-MMSCFD, 750-psig, 1750-hp reciprocating air compressor.
- 60/12-kV, substation to supply air injector.
- Water addition facility for injection during combustion thermal drive (2,000-BPD (barrels per day) 1000-psig pump).
- Metering and control manifold.

GEOLOGY

The Paris Valley field is located in foothills at the upper end of the Salinas Valley on the southwestern side. The experimental project is located on a small hill in sections 2 and 3, T22S, R9E. The Salinas Valley, like many others in the Coast Ranges, has been an area of downwarp and sedimentation through the Tertiary and Quaternary geological periods. Four of the reentrant valleys of this sort – the Los Angeles basin, the Ventura basin, the Salinas basin, and the Santa Maria basin – contain productive oil fields.

Such basins were washed by shallow seas rich in aquatic life during much of the Tertiary and, in places, into the Quaternary. Clastic sediments, including potential reservoir sands, were being washed in from nearby mountains, forming in time many oil rich formations.[7] The oil-bearing Upper Miocene sandstone beds, part of the Santa Margarita formation, are associated with a ridge-like feature on the overlain basement complex. The Ansberry sands transgressively lap over the basement complex, and they were subsequently forced into compressional folds paralleling the Salinas basin shoreline. The thrust faulting which parallels the shoreline resulted in additional folding. The beds consist of fine to coarse-grained unconsolidated sands and shale (see Fig. 10). The Santa Margarita formation is found either overlying the Monterey formation or conformably on the basement, deposited against the ancient shorelines of the Salinas basin.

The Miocene Monterey formation is composed of silicious mudstone and shale with porcelaneous and cherty type rocks. The pre-Miocene basement formation is a conglomerate of clasts, weathered basement complex, bluish-grey shist, granitic rocks, and quartz biotite gneiss. Overlying the Santa Margarita formation are the Pleistocene Paso Robles and the Pliocene Pancho Rico formations.

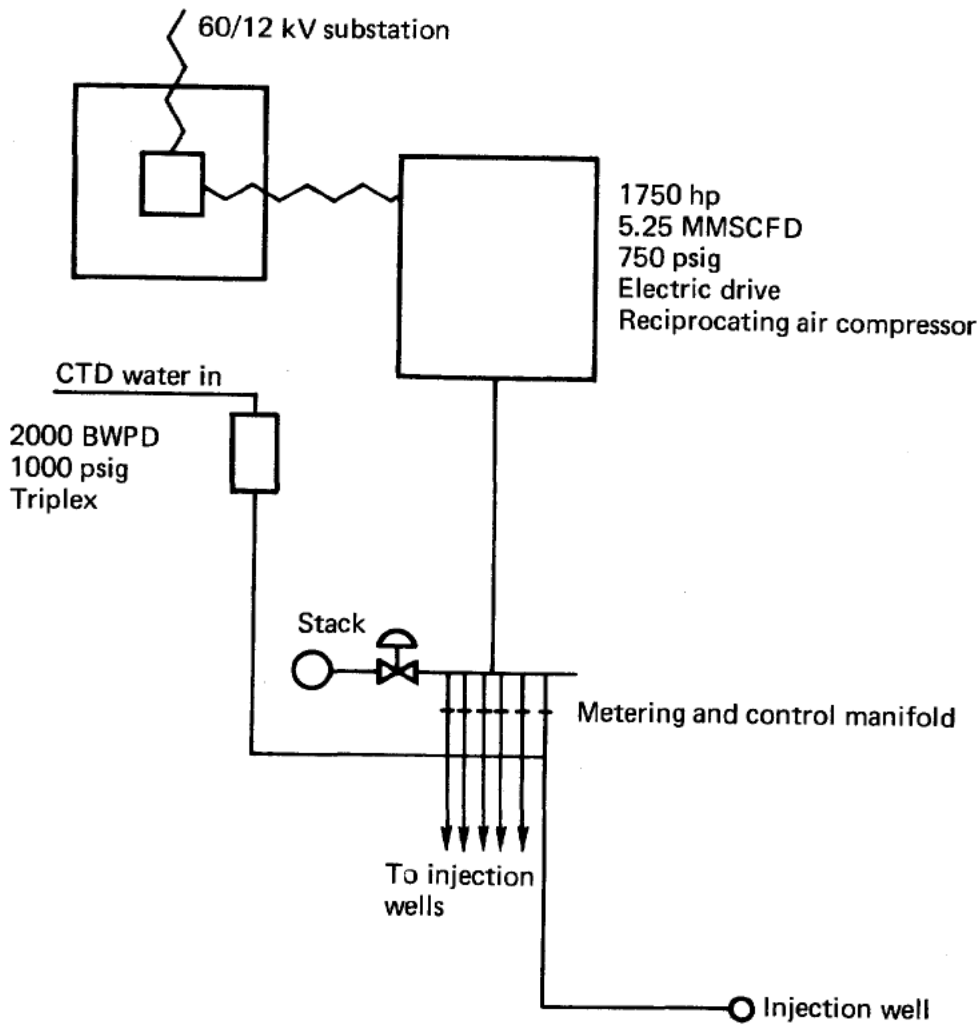


Fig. 9. Air injection system, Paris Valley field.[6]

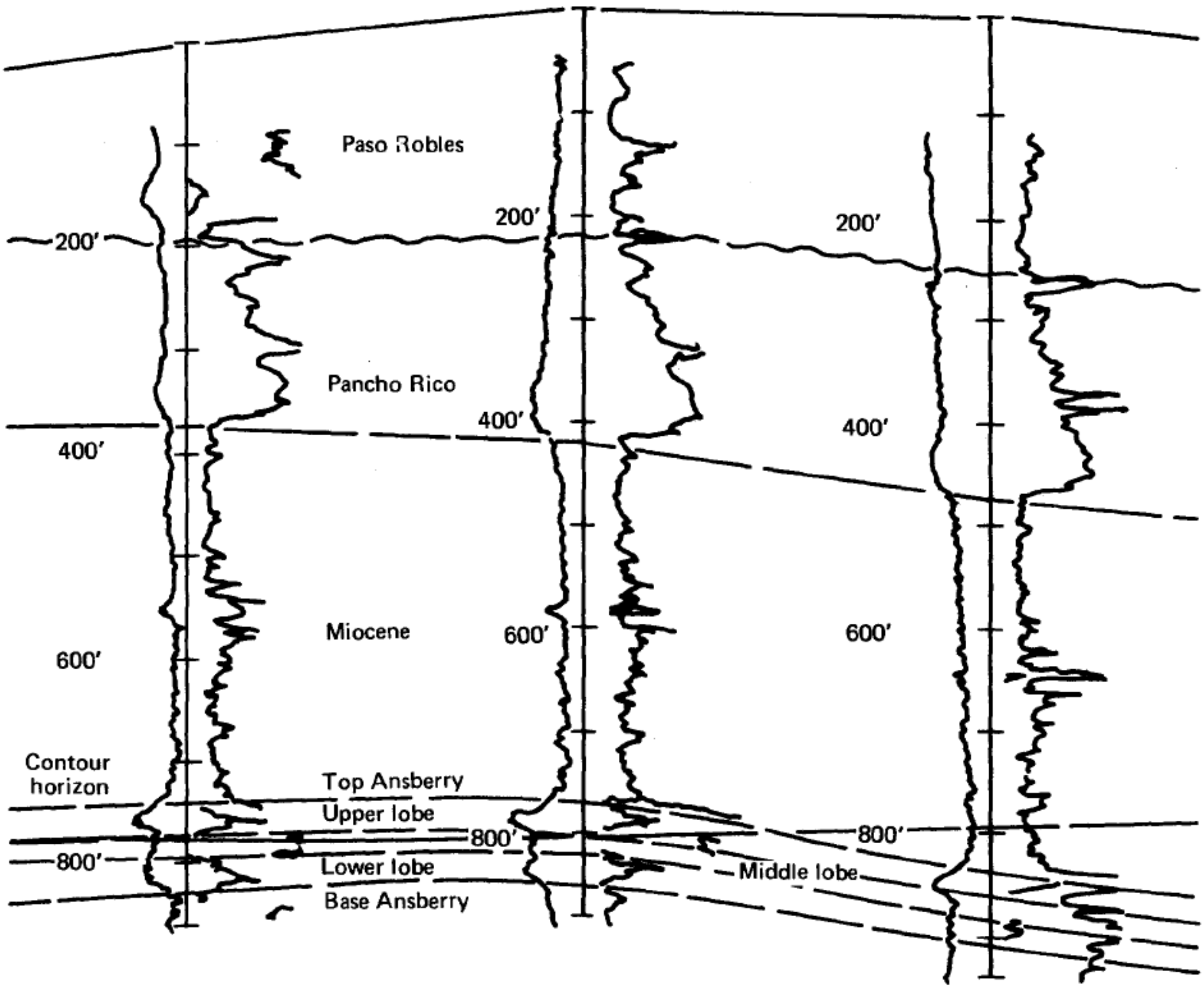


Fig. 10. Sample geological cross section, Paris Valley field; superimposed are log readings for each drilling. (Repr. by permission, Husky Oil Co.).

The Pancho Rico is grey-green or grey-brown silty shale and clay. The formation contains fresh water. The Paso Robles unconformably overlies the Pancho Rico and is nonmarine in origin and is composed of gravels, sands, and clays.[6]

The Paris Valley project is located on the side and top of the small Ansberry Anticline where oil accumulation is controlled to some degree by structural traps due to the anticline, to faulting along its edge, and to stratigraphic variation. The major fault is the Ansberry Thrust Fault to the northeast of the anticline. Two less significant faults traverse the anticline and are truncated by the thrust fault. The average depth to the top of the formation is 800 ft. The Ansberry sand is divided into three lobes, with varying reservoir properties. The upper lobe is controlled stratigraphically, and its thickness varies between 4 and 24 ft. The middle lobe is thin and relatively insignificant. The lower lobe varies in thickness between 0 and 50 ft. The total reservoir thickness varies between 0 and 90 ft. Nine wells are completed in the upper lobe, six in the lower lobe, and nine through the full interval of all three.[6]

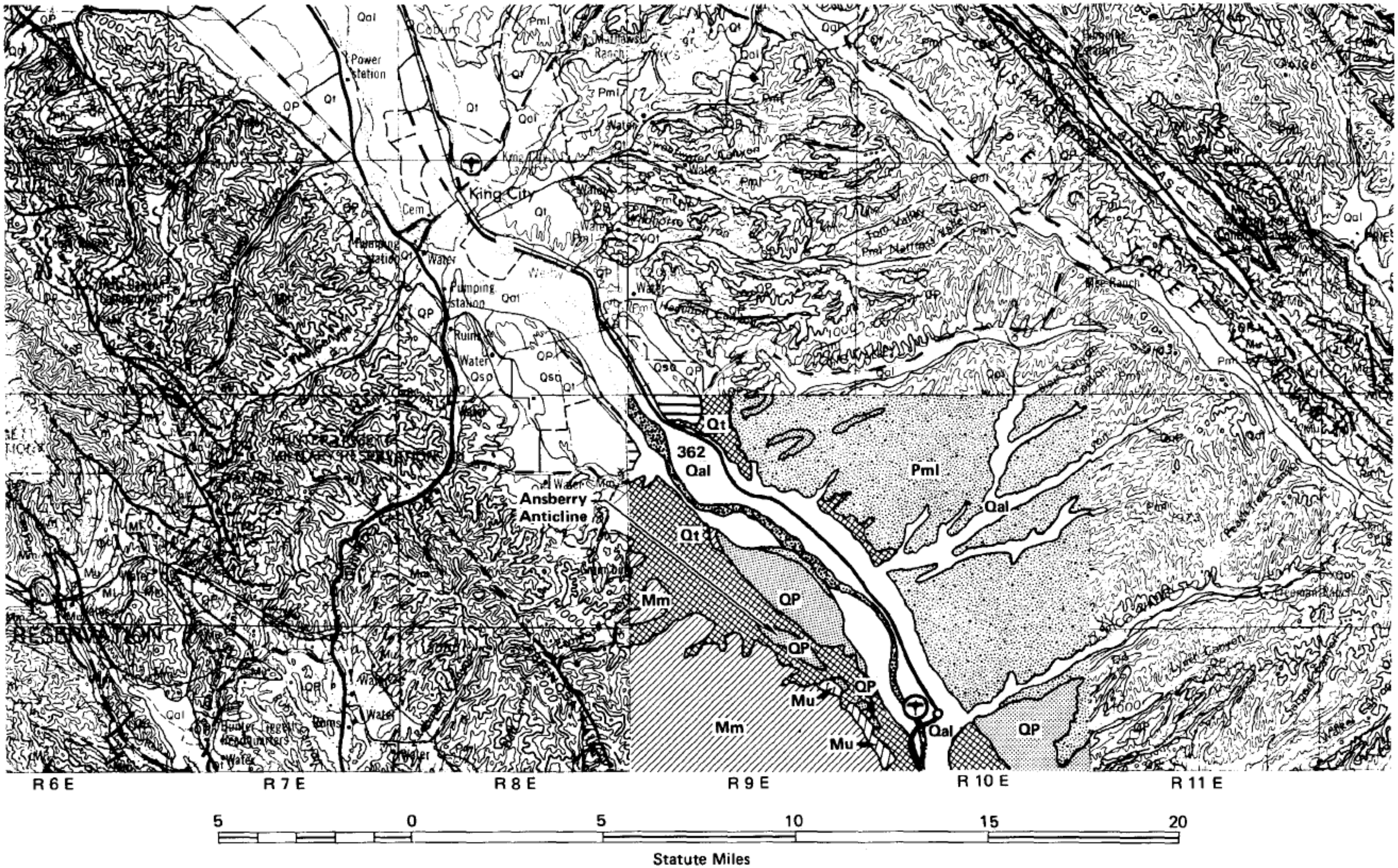
The formation water is fresh, with chlorides varying between 40 and 330 ppm, and has a pH of 8.5 because of high bicarbonate concentrations. Overall, Paris Valley production is obtained at a water cut of 90 percent. This is not sufficient for a production mechanism by water drive because the crude oil is very viscous. There is little gas in solution, and the total quantity of gas in the reservoir is too small to be of use for commercial production.[6]

Seismicity

The U.S. Geological Survey (USGS) Santa Cruz sheet in the Geological map series for California shows the active faults nearest to the project to be the Espinosa, which is about five miles from the Ansberry Anticline, and the San Andreas fault zone, about 15 miles away (see Fig. 11). There are also lesser faults on the site: a thrust fault along one side of the anticline, and two which intersect it. For a discussion of the impact of seismic activity on the site, see the "Hydrology" and "Ground Water" sections which follow.

Subsidence

The impact of earth subsidence is usually dependent on the level and type of development in the region. The most dramatic oil withdrawal-related subsidence in California is that of the Wilmington field in Long Beach. The



Quaternary	Recent	Qal	Alluvium
	Pleistocene	Qt	Quaternary nonmarine terrace deposits
		QP	Plio-Pleistocene nonmarine
Tertiary	Pliocene	Pml	Middle and/or lower Pliocene marine
	Miocene	Mu	Upper Miocene marine
		Mm	Middle Miocene Marine

Fig. 11. Geology at Paris Valley site; shown also is proximity of fault lines. (Source: U.S. Geological Survey, *Geologic Map of California, Santa Cruz Sheet*, 1958).

impact there is heightened by the urban/industrial land use and the location—near sea level and also on the coast.

The Paris Valley project site faces less severe effects from potential subsidence. Impacts would include the cracking or shearing of water and oil wells, with related potential contamination problems, and the shifting of structural foundations. Because the region is mostly agricultural with scattered farm houses and is not highly populated or developed, the impact of subsidence, if any, should be insignificant. Very large withdrawals of oil could create the potential for widespread subsidence endangering King City, but both the current project scale and the small size of the field make this very unlikely. Reinjection of waste water from the project into the oilbearing reservoir will partially repressurize the formation and also reduce the possibility of subsidence by replacing some of the removed crude in volume.

Subsidence has not been documented in the area[8] and is perhaps less likely because of the rolling hill country which characterizes the region.[9] The USGS is not aware of any problems with subsidence or of any claims for damages caused by subsidence in the Paris Valley oil field region.[8]

Soils

The project site is mostly confined to the group of soils known as the Atwater-Aliso Association (see Fig. 12). This association consists of welldrained moderately coarse soils developed in wind-modified alluvium or soft sandstone. The association is characterized by eroded 9- to 30-percent slopes on strongly sloping hilly fans and terraces, both of which often lie over other terraces and upland soils on both sides of the Salinas Valley, south of San Lucas. The surface soil is comprised of pale brown and grey sandy loams that are slighly acid on the surface, with neutral clay loams in the subsoil. The parent material is a pale-brown loose sandstone, which is neutral to alkaline.[10] The average depth of the soil varies between 18 and 60 in. but particularly in the Aliso soils, surfaces are deeply eroded. Much of the surface soil has been removed, and this exposes the underlying clay pan or hardpan. Subsoil permeation is slow to moderately slow; the surface has medium water runoff and exhibits a moderate to high erosion hazard.[9]

At the Paris Valley site, the possibility of soil erosion is reduced somewhat by the six culverts installed along the project roads, but the roads are not continuously culverted, and the surfaces are not paved. Cuts have not

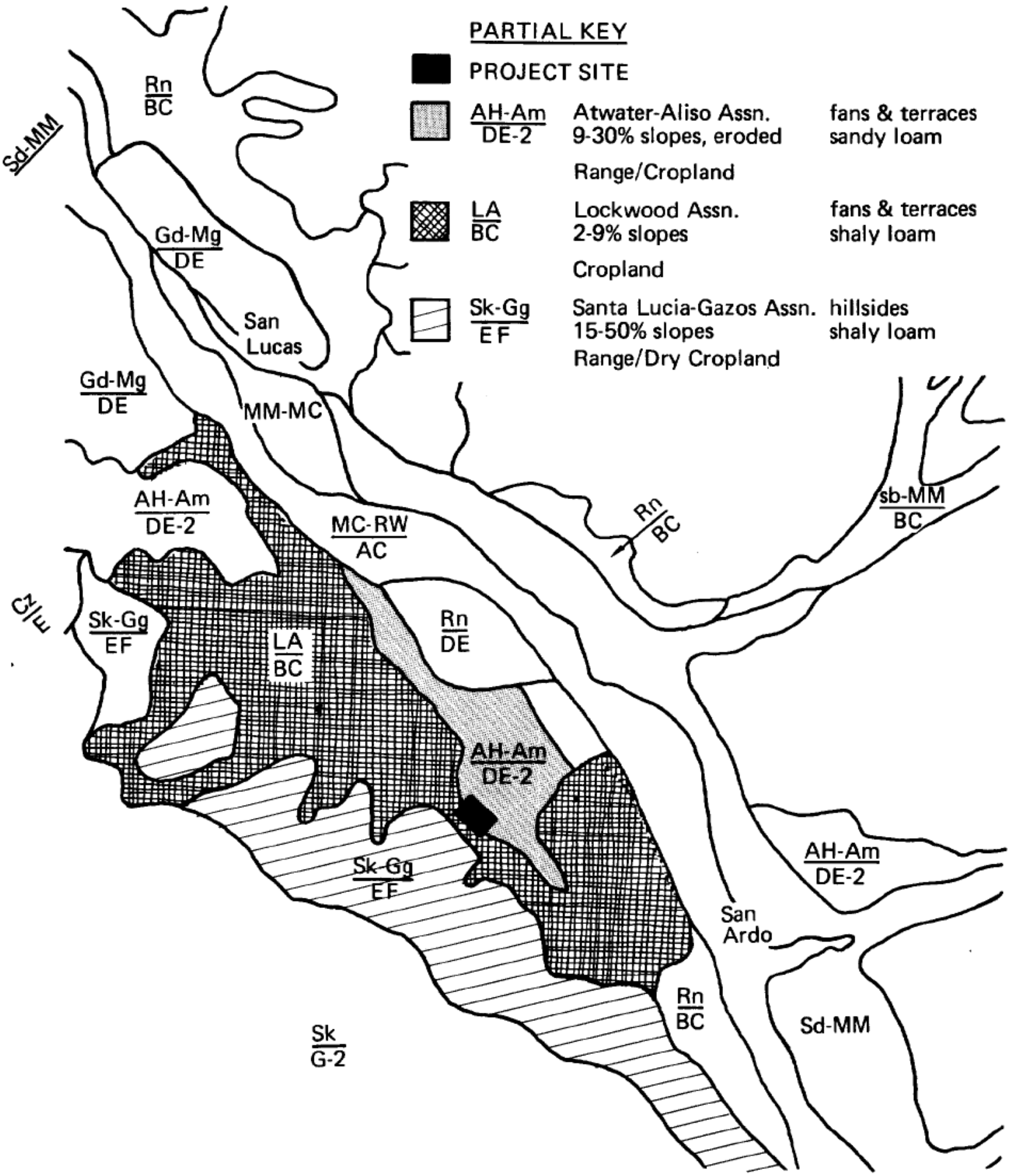


Fig. 12. Soil types in Paris Valley vicinity; the three types closest to the project are defined in the legend. (Source: U.S. Dept. of Agriculture, Soil Conservation Service, *Report and General Soil Map; Monterey Co.*, 1964).

been treated or sown with vegetation. On the contrary, weeds and other vegetation are removed from roads and surrounding pad areas and cuts to reduce fire danger.[11] Some cuts and fills at the main facility pad have been sprayed with oil to reduce the danger of a total slope failure. In spite of the generally low level of mitigation measures instituted at the site, erosion does not seem to be significant. Slopes are gentle at the site, the climate is relatively dry, the nongraded areas are left to native grassy foliage, and there are no signs of slope collapse or slumping.

HYDROLOGY

Ground Water

The Paris Valley oil reservoir is overlain by a productive aquifer formation, the Pancho Rico, which lies between 175 and 225 ft. and between 250 and 575 ft. below the surface, depending on the location on the anticline. This is a freshwater aquifer, and the formation is used by some farmers for irrigation water. Further row crop development using this resource is planned. However, most farmers use the Salinas River beds and other alluvial water sources.[12] Husky Oil has two wells on the Ansberry Lease for fresh feedwater from the Pancho Rico that are used for the project steam generator. The water is first softened and filtered, and scale inhibitor agents and oxygen scavenger are added to it.

Salt Water Intrusion and Water Supply

Continued withdrawal of fresh water from the Pancho Rico formation for both agricultural and industrial uses may lead to falling water tables there. With the expansion of intensive irrigated agriculture into the region and the possible expansion of the combustion thermal drive project, serious supply problems for all users could develop.

Salt water intrusion is enhanced by overwithdrawal of the fresh water from the formation. Already, ground water at the mouth of the Salinas River valley is contaminated and the salt/fresh water interface is moving inland. Intrusion varies seasonally and is correlated with the pumping of irrigation water for the north (lower) part of the valley.[13] Salt water intrusion is not a problem in the southern (upper) salinas Valley. Increased withdrawals from the aquifer upstream may aggravate the problem lower down.

Although it is not currently significant, the issue of water use for this project should be examined for impact should the project expand.

Waste Water Percolation

The waste water sump in the project area is lined with gunnite to prevent percolation of contaminated water, which is composed of water produced with the oil and scrubber carryoff water, into the underlying formations and possibly into the Pancho Rico aquifer. This sump currently leaks because ground squirrels chew holes in the gunnite. Husky Oil intends to drain the sump in order to patch it. Care should be taken in order to ensure that the alternate temporary sump is adequately lined.

Mud pits are required at the project site during the drilling phase. These pits are unlined and are used to store the drilling muds. In this project the muds are composed of Pancho Rico well water, gel, and rock cuttings.[14] The cuttings from the Ansberry sands may also contain some gas or oil. The probability of contamination of the Pancho Rico aquifer is extremely unlikely because of the comparatively small oil and gas contamination of the mud, the great filtering potential of the 300 ft. thick layer of gravels, sands, and clays in the overlying Paso Robles formation, and the fact that the surface soils are not extremely permeable.

Before digging the mud pits, Husky Oil applied for and received a permit from the Regional Water Quality Control Board, in this case the Central Coast Region Board No. 3, San Luis Obispo. The waste disposal permit decisions are based on an evaluation of the formations encountered in the drilling.[15] In the Paris Valley field, briny aquifers are not encountered and the formation water in the producing area is fresh. Therefore, potential groundwater contamination by brines leaching from the pit is not a problem here. Because of the low probability of aquifer contamination, permits were issued, and there was no requirement that the project mud pits be lined.[15] Following the well drilling phase of this project, the mud pits should be backfilled and restored approximately to grade.

Well Failure

A failure in active or plugged and abandoned wells could lead to contamination of the Pancho Rico aquifer by toxins and contaminants which are contained in the Ansberry formation. Along with the infiltration of oil, there is the possibility of contamination from the residue of trace metals and metal oxides present along with the oil. These materials are residues from the wet combustion process and may be dissolved in the acidic water remaining in the reservoir. As can be seen in Table 1, California crude has a lesser concentration of potentially objectionable trace elements, with the exception of nickel and vanadium, than does that of Louisiana or Texas.

There is always the possibility of oil or toxic substances resulting from fireflooding leaking from oil-bearing formations into an aquifer. Any opening between strata, such as an oil well, may allow contaminants to bypass intervening strata if the well is not properly completed. California oil and gas laws require that the wells be isolated from water-bearing strata and that evidence of this isolation be provided. Normally, the well bore is lined with casing, and the casing is cemented to prevent the interconnection of producing horizons with aquifers and also to enhance casing rigidity. To protect shallow aquifers, an outer layer of surface casing is installed near the well top. A packer is set inside the casing at the bottom just above the oilbearing strata to seal off the well sides from contamination[16] (see Fig. 4 for specifications).

Table 1. Trace elements (ppm) in U.S. crude oil.[18]

Element	Origin of crude oil: California	Louisiana	Texas
Antimony	<0.007	0.05	0.01
Arsenic	<0.007	0.05	0.12
Barium	<0.06	0.09	0.14
Manganese	<0.018	0.027	0.05
Nickel	77	4.4	3.3
Tin	<0.6	0.5	1.0
Vanadium	<48	1	1.9

In spite of these precautions, well failures do occur. Movement of the contaminants may be through the cement interstices, cracks in the cement, holes in the casing, or through holes in the tubing and casing in addition to cracks in the cement, and so on (see Figs. 13 and 14). Leaks may be caused by faulty casing connections, inadequate casing seal at the shoe, perforation at the wrong point, corrosion, poor cementing, and heavy earthquake damage. Fissures may also develop in the impermeable layers, but they are generally caused only by high injection pressures or sudden fracturing of the oilbearing formation by explosives. Pressure-induced fractures from steam injection are unlikely at the Paris Valley project because reservoir pressure is already considerably reduced, and field characteristics are well known.

Corrosive formation fluids may weaken the casing. Failure due to corrosion depends upon the completion practices, materials used in construction, rock formations, and the expertise of the operator. Enhanced oil recovery using *in situ* combustion can lead to significant casing deterioration. This is because of both the corrosiveness of the fluids remaining in the reservoir and the equilibrium temperature of the oil-bearing formation. Organic acids are formed at the burning front resulting in low pH (acid) formation waters, which can be very corrosive. However, corrosion potential is reduced in this case because the injected steam condenses from the steam phase as neutral pH water, and this dilutes the acid waters. Wells should be monitored even after abandonment because of the high corrosivity of this recovery method.[16]

Large earthquakes may also result in contamination of the aquifers. These movements would provide access through formerly impermeable formations by shearing or weakening well casings and by cracking casing cement. The USGS Santa Cruz Sheet shows the nearest faults to the project to be the Espinosa Fault, about five miles from the Ansberry Anticline, and the San Andreas fault zone, about 15 miles away (see Fig. 11). There are lesser faults on the site – a thrust fault along one side of the anticline, and two which intersect this one. Although fluid injection into underground reservoirs has produced small earthquakes in the Rocky Mountains region,[17] there have apparently been no such complications in the Paris Valley project area thus far. The most likely source of an earthquake of severe enough intensity to shear the wells is the San Andreas fault zone. This is indeed a significant danger to the wells at the Paris Valley site although much of California faces the same problem. There are really no practical mitigation measures possible beyond

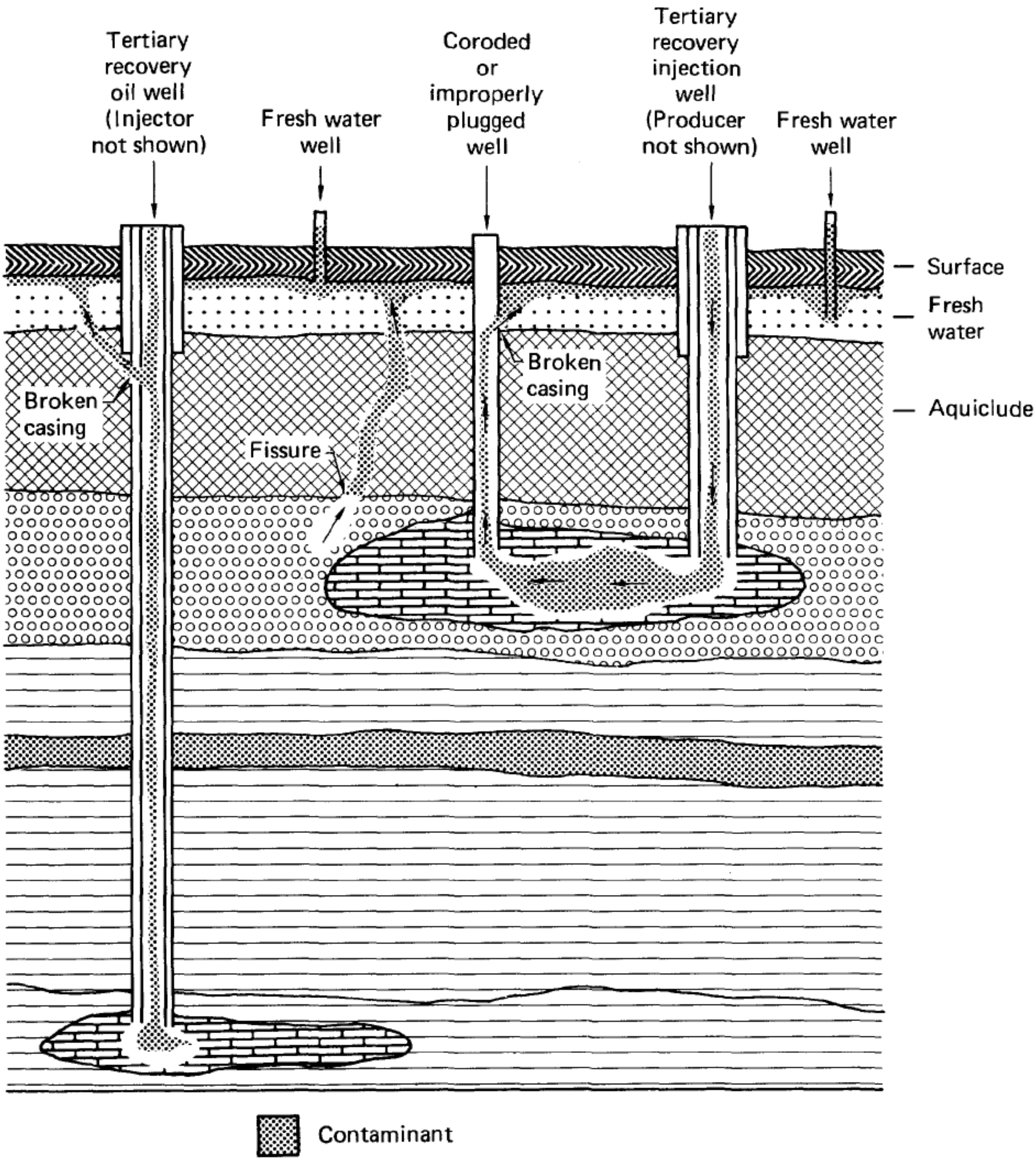


Fig. 13. Contamination of fresh water through bypass of the natural filter system.[16]

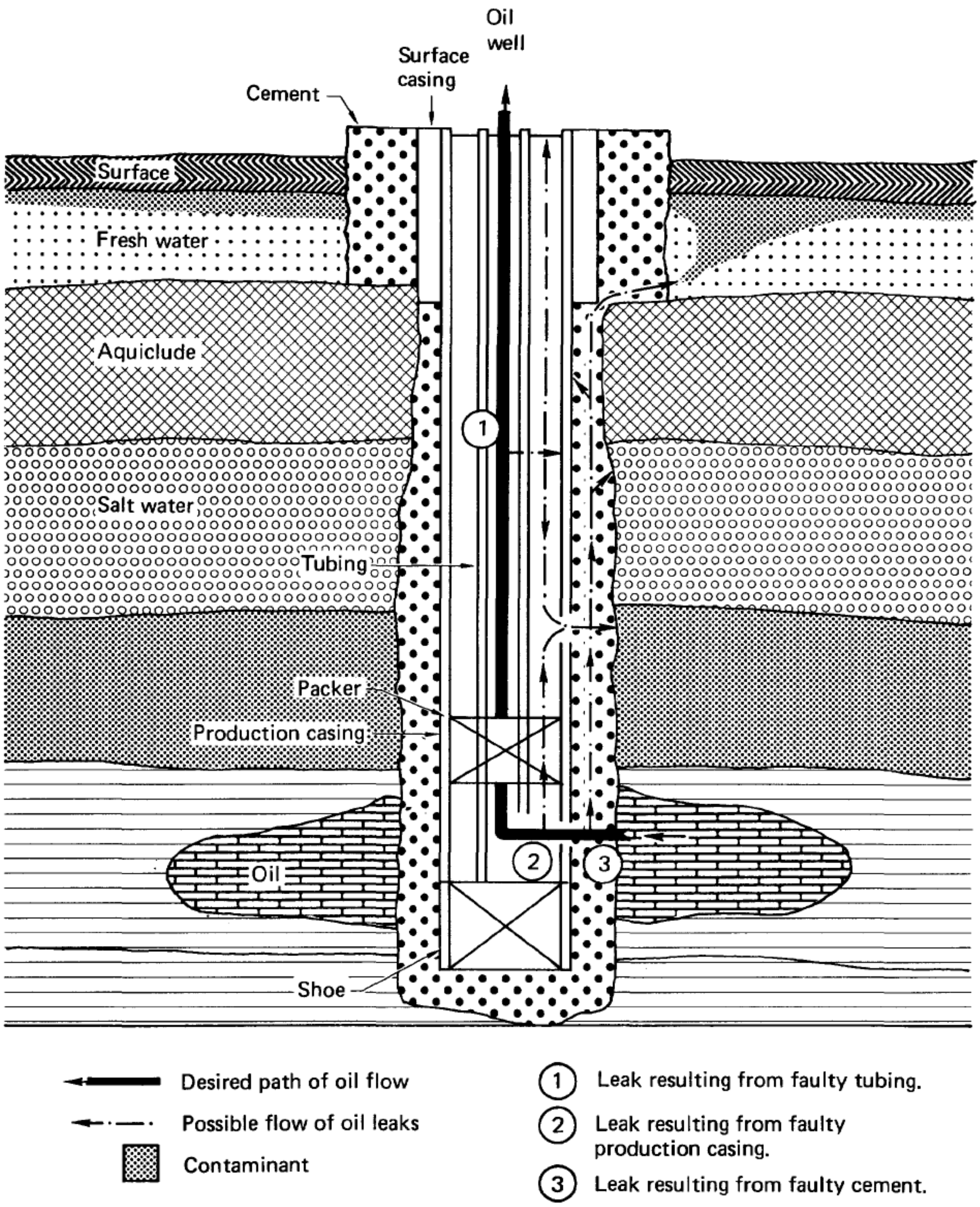


Fig. 14. Potential paths of fresh water contamination resulting from well failure.[16]

proper well completion, other than simply not constructing wells and buildings on the site.

Leakage is most common in abandoned wells, especially those which were abandoned before more modern techniques of capping and plugging were developed. This is particularly true if these wells are not monitored or maintained. On the basis of the above discussion, the probability of significant aquifer contamination at the Paris Valley site due to interconnection of an aquifer with its producing horizon is considered to be negligible.

Surface Water Quality

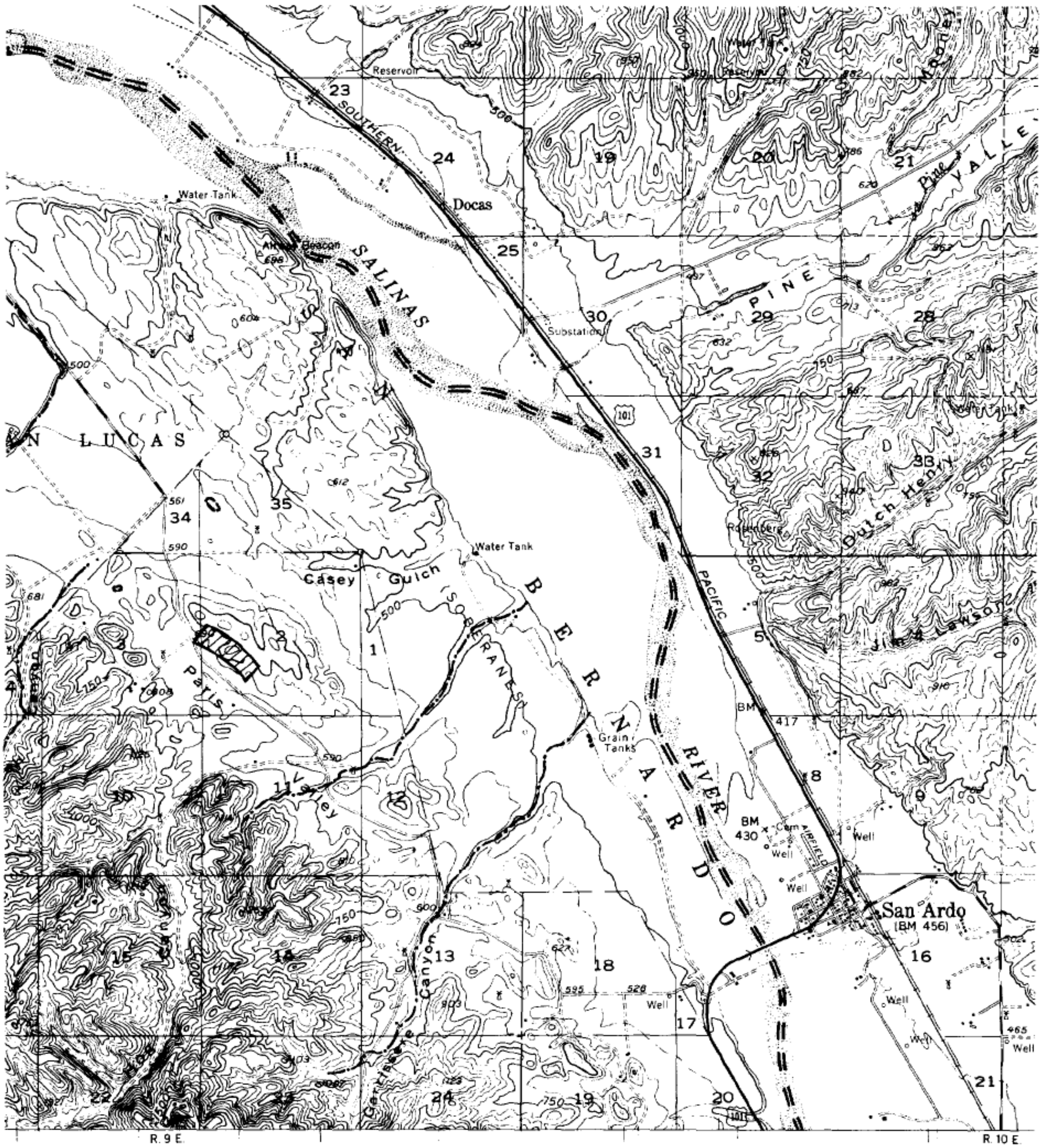
There are several sources of possible contamination of surface water. The different issues are described in the following sections.

Oil Leaks

The chances of failure of the pipes which transport produced crude away from the wells are small. If a leak develops, it could contaminate a number of the intermittent streams that lie downhill from the site. However, their intermittent nature would make spill clean-up simple most of the year. Although the dry climate reduces the rate of pipeline corrosion, the Atwater-Aliso Association soils have a very high corrosivity rating for untreated steel pipe, and they also have moderate to high shrink-swell characteristics.[10] Consequently, these pipelines should be regularly monitored. The pipeline expansion joints being used at the site should reduce the possibility of failure due to internal or seismic stresses.

The characteristics of the oil itself reduce contamination hazards. The produced oil must be heated to be fluid at all. Any spills from heated pipelines would soon congeal. The effect would be similar to dumping tar at the failure point, and consequently as large an area would not be affected as would a spill of a less asphaltic crude. Since the nearest intermittent streams are approximately 4,500, 9,000, and 10,250 ft. away, respectively, the chance of their contamination by an oil spill is very small (see Fig. 15).

There are very few containment berms on the Paris Valley site. The production and injection well pads are wide places in the road and are not surrounded by berms. This reduces the chance of containment of any spills or leaks, although the viscosity of the crude obviates this deficiency to a great degree. However, on a site inspection it was noted that leakage from an improperly installed drain pipe below the generator's scrubber has eroded a small ditch that runs across the pad and road sites to a depression. Here,



Scale 1:62500

1 1/2 0 1 2 3 4

Miles

▨ Project Site

Contour interval 50 feet
datum is mean sea level

Fig. 15. Surface hydrology in Paris Valley region; all creeks are intermittent. (Source: U.S. Geological Survey, *Topographical Map, San Ardo, Calif.*, 1956).

the oily water collects. A berm around the pad would prevent this type of incident.

Produced Waste Water

There is no impact anticipated on surface hydrology by the waste water. Much of the produced water is reinjected into nearby formations and the rest is cleaned for use on the site, as cooling water in equipment, for example. None of the produced water is released into surface waters.

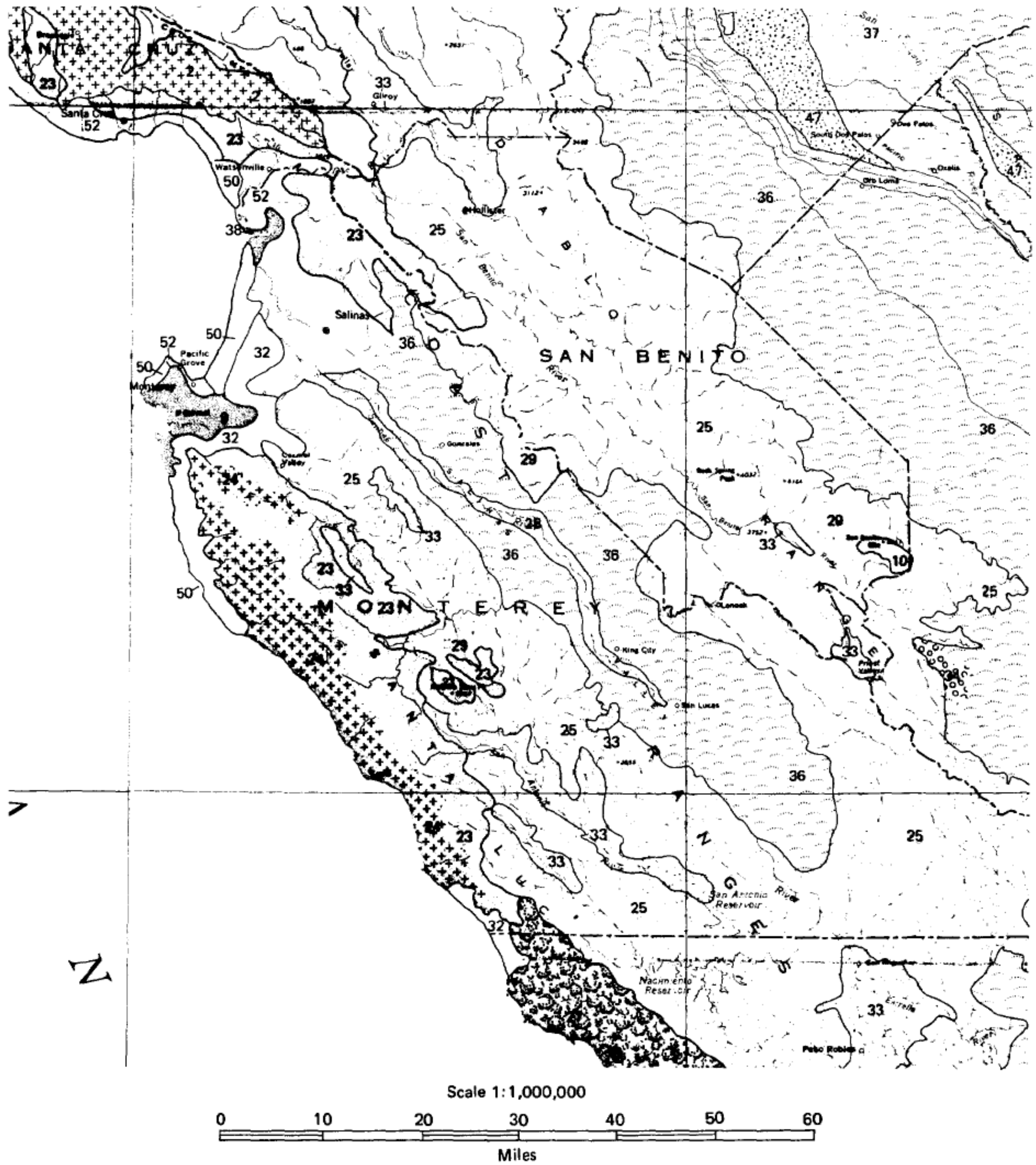
Erosion

Erosion and slope failure could also contaminate surface waters of the intermittent streams near the site. The potential for erosion is fairly high on these slopes and in the soils of the area, particularly because of the grading done during construction of access roads and pads. However, as discussed above, erosion does not appear to be a significant problem at the site.

Because the streams are intermittent, turbidity and fresh water habitat-destruction by silt contamination, if any occurs, is not anticipated to be significant. These intermittent streams flow only during periods of high rainfall and are incapable of supporting significant freshwater aquatic life. Contaminants or eroded material may deposit in the dry stream bed, but they will be flushed out during heavy rains that will also dilute the material. This flow will be joined by other intermittent stream flow which eventually discharges into the sands of the Salinas River bed. Erosion-induced surface water contamination of the streams is also expected to be minimal due to the streams' distance from the site, the general topography, and their intermittent nature.

VEGETATION AND WILDLIFE

Elevations in the region range from 500 to 900 ft. Project elevations range from 650 to 800 ft. The mean annual temperature is 60°F, and the mean annual precipitation is 11 to 15 in. The local vegetation consists of annual grasses, forbs, and occasionally brush. It is a dense to somewhat open community of medium tall bunchgrass and forbs. Height and seasonal aspects of the prairie can vary greatly. Dominant species are needlegrass (*Stipa cernua*) and speargrass (*Stipa pulchra*)[18] (see Fig. 16). There are no known species of rare or endangered plants in the project region.[19]



9 Coastal cypress and pine forest (*Cupressus-Pinus*)
10 San Benito forest (*Calocedrus decurrens*)
23 Mixed hardwood forest (*Arbutus-Quercus*)
25 Blue oak-digger pine forest (*Pinus-Quercus*)
29 Chaparral (*Adenostoma-Arctostaphylos-Ceanothus*)
32 Coastal sagebrush (*Artemsia—Eriogonum-Salvia*)
33 Valley oak savanna (*Quercus-Stipa*)
36 California prairie (*Stipa spp.*)
38 Coastal Saltmarsh (*Salicornia-Spartina*)
47 San Joaquin Saltbrush (*Atriplex polycarpa*)
50 Northern seashore communities (*Elymus-Baccharis*)
52 Coastal praire scrub mosaic (*Baccharis-Danthonia-Festuca*)

Fig. 16. Vegetation types in Paris Valley vicinity. (Map, Natural Vegetation of California, by A. W. Küchler, Dept. of Geography, Univ. of Kansas, Lawrence, Kansas, 1977).

The Ansberry Anticline has little natural vegetation, as it is surrounded by agricultural activities and was recently planted in barley. Consequently, development of the project has not removed natural vegetation or rare and endangered species of plants, although the initial agricultural development may have. Therefore, the project has had no significant impact on the natural vegetation. It is possible that there will be some colonization by weedy species at the site, now that the land between the graded roads and pads is no longer being farmed.

Wildlife in the region is characteristic of the Coast Range prairie environment, and it includes deer, quail, doves, raptors, coyotes, cottontail and jackrabbits, foxes (including the San Joaquin Kit Fox), gophers, moles, pocketmice, kangaroo rats, and an occasional mountain lion in the surrounding hills.[20] The San Joaquin Kit Fox (*Vulpes macrotis mutica*) is a rare species protected by law and largely restricted to areas of native vegetation which support kangaroo rats (Fig. 17). The Kit Fox is present in the Paris Valley region and is often killed along the highway by passing cars.[20] Its decline is due to the conversion to agricultural land of native vegetation supporting kangaroo rats, the fox's main food source, which reduces its habitat area.[19] Again, because the Paris Valley field was previously a barley field, the impact of the subsequent oil field development is insignificant, except to perhaps provide more potential native vegetation in the spaces between the graded roads and pads.

The project region, as is the whole of Monterey County, is feeding grounds for the California Condor (*Gymnogyps californicus*)[21], an endangered species protected by state and federal laws. Decline of the California Condor is due primarily to shooting, interference with nesting habitat, and poisoning from the consumption of poisoned rodents, as well as from pesticides.[22] The quantity of food available to the Condor does not appear to be a problem. They feed on carcasses of cattle, sheep, deer, small mammals, and road kills. Nesting does not take place in or near the project region (see Fig. 18). The primary impact of the project would be a marginal loss of habitat for the condors' prey in the conversion of a dry barley field to an oil field. However, there have been no condor sightings in the region for at least the past 17 years.[20]

Because oil sumps are a hazardous and attractive nuisance to birds and other fauna, they are usually surrounded by a netting on a frame. At the project sump, the panels of netting are in poor condition, having loose panels

Fig. 17. Range of San Joaquin Kit Fox, 1975.[21]

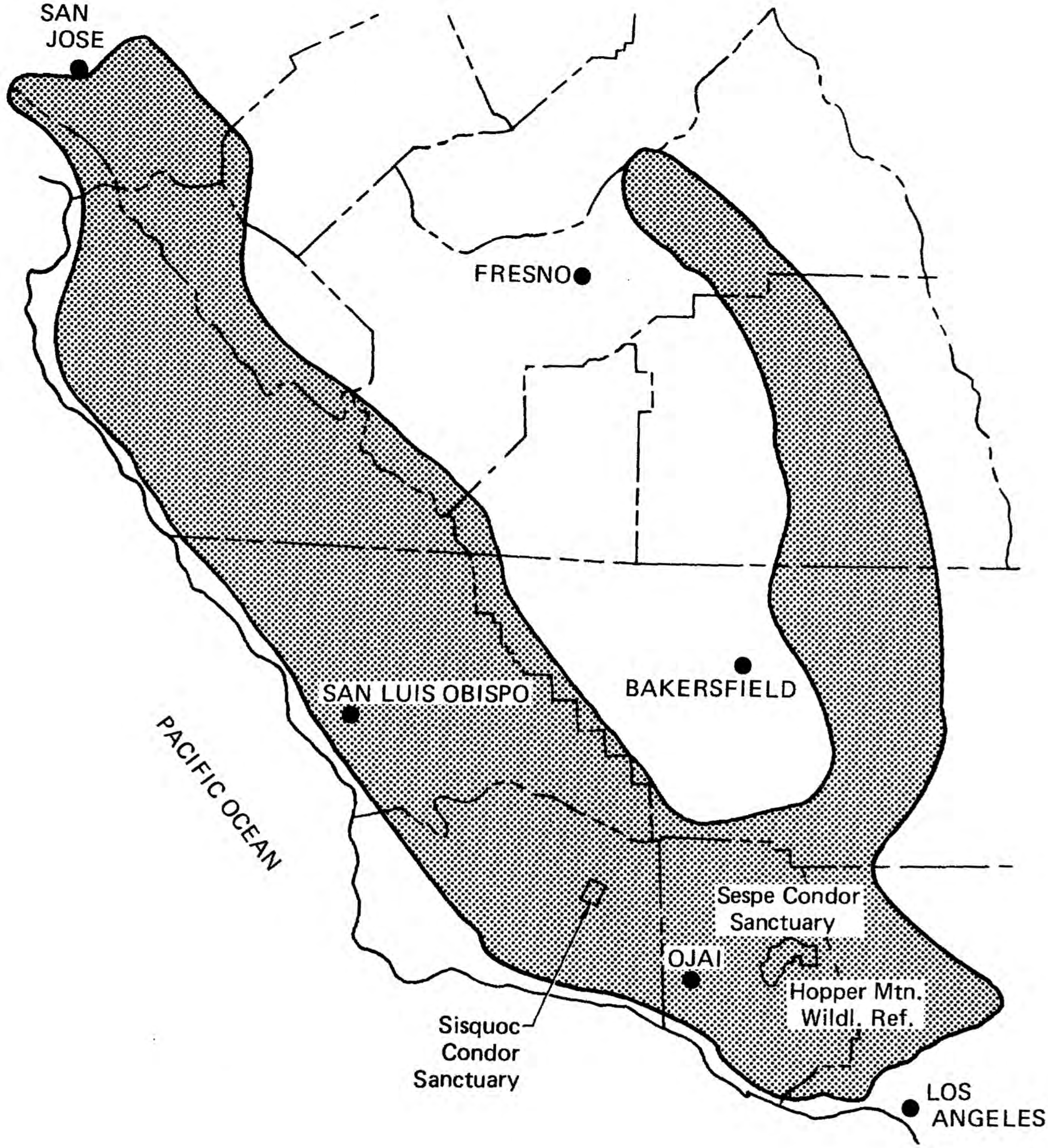


Fig. 18. Range of California Condor, 1975.[2]

for worker access that are not tied closed, and rents in the material. At the time of the site visit, two frantic birds were attempting to escape the enclosure. Once birds enter through gaps in the netting, it is more difficult for them to get out than to get in. The broken netting is more likely to lead to exhaustion of the birds and to increased exposure to the oily pool than if the site were un-netted. Care must be taken to maintain the integrity of the netting system, so that it may serve the purpose for which it was constructed.

The total impact of the project on local wildlife in general is minimal and is confined primarily to loss of habitat. This effect of the project itself is minimized by the fact that the site had been converted from natural vegetation to field crops prior to oil field development. The oil field is characterized by a mix of open roads and bare earth pads and weedy growth on intervening patches. The impact on the wildlife of noise and human presence at the oil field is similarly not significant because change due to agricultural development has already occurred, and those species remaining are tolerant of this somewhat more active environment. Wildlife in the surrounding area are probably temporarily disturbed, but conditions may return to normal should site restoration be implemented.

AIR QUALITY

There are two primary sources of air pollution: the equipment (for generating steam, the air compressor, and associated equipment), and the combustion gases from the *in situ* combustion process.

Equipment Emissions

The air compressor is run on electricity and consequently has no on-site or even local regional air quality impact. Electricity powers the air compressor, the fluegas scrubber fan, and the pumps. There is no impact on air quality at the project site. However, the use of electricity will have an impact on air quality elsewhere. The effect will vary with the fuel/hydroelectric production method and will probably be insignificant in view of the total demand for electricity. The steam generator and associated equipment burn oil and gas, respectively.

Oil-burning units produce three pollutants of major interest: sulphur dioxide, nitric oxide, and particulate material. In addition, a small amount of unburned hydrocarbons is emitted from the units, plus a trace of carbon monoxide.

SO_x

The sulphur content of fuels is limited by the Monterey County Air Pollution Control District (APCD) regulations to 0.5 wt% of sulphur for liquid fuel or to the equivalent rate that would be obtained by fluegas scrubbing. The Paris Valley lease crude averages 1.5 percent sulphur content by weight, and this oil will be used for the 22 MMBTU/hr generator. Now 342 lb/bbl × 1.5 percent = 5.13 lb/bbl (S) = 10.26 lb/bbl (SO_2).[23] To meet Monterey County APCD standards, this must be reduced to 0.5 percent equivalent. A scrubber is installed for this purpose. The calculation is 342 lb/bbl × 0.5% (S) = 1.710 lb/bbl (S) = 3.420 lb/bbl (SO_2).

NO_x

Nitrogen Oxide (NO) is produced by oxidation of combustion air, nitrogen, and nitrogen compounds in the fuel. There are no local standards for nitrogen oxide, but there are standards for nitrogen dioxide (NO_2) which is produced by photochemical oxidation of NO in the atmosphere. The rate of conversion of NO to NO_2 depends primarily on the concentration of NO and other pollutants, mainly oxidants and ozone, as well as on the intensity and duration of sunlight. The ratio of NO_2 to NO_x, ($NO+NO_2$), typically ranges from 0.2 to 0.5 in many areas,[24] but data is lacking for the Paris Valley vicinity. The U.S. Environmental Protection Agency suggests an NO_x (taken as NO_2) emission rate of 2.52 lb/bbl.[23] NO_x emissions from the project are not expected to exceed standards.[15]

Particulates

Particulate emissions are derived mainly from trace amounts of metallic and siliceous impurities present in the fuel oil. Particulate emissions are estimated to be near 0.7 lb/bbl, based on data developed by the National Enforcement Investigations Center.[23]

Carbon monoxide

Only trace amounts of CO emissions are expected from the steam generator because of the large amounts of excess air used for combustion in oil field steam generators.[15] Carbon monoxide emissions are estimated to be 0.02 lb/bbl.[23]

Hydrocarbon emissions

Only trace amounts of hydrocarbons are expected from the steam generators. Larger amounts may be released as vaporous hydrocarbons in fugitive emissions of steam from the producing wells.[15] Hydrocarbon emissions approximately 0.1 lb/bbl.[23] Because only trace amounts of hydrocarbons, carbon monoxide, and nitrogen oxides are anticipated,[16] no measures have been instituted to control these emissions.

In Situ Combustion Gases

Husky has not utilized mitigation measures with regard to several phases of the operation. These areas are delineated in the following discussion.

Air quality is generally difficult to model for *in situ* projects because the emissions are released at ground level and have little upward momentum. This results in the highest concentrations of pollutants occurring in the area of the oil field itself.[17] Any detrimental health effects would be essentially confined to site workers.

The high temperatures of the fireflood process lead to a number of gaseous products which may be present in the production well emissions or remain in the reservoir after the process is complete. This issue needs more research in order to determine the nature and effect of these products. Sulphur compounds may be released as a consequence of crude combustion, but researchers on the environmental impact of *in situ* combustion have assumed that because of the very acid water produced, most of the sulphur compounds remain in the flood water and in the water produced during wet combustion processes. Emissions of sulphur compounds from the wells may occur in the late phases of the combustion process.[16] The formation of nitrogen oxides is not favored at the $700^{o}F$ to $1,200^{o}F$ typical burning temperature of a fireflood operation. Most of the emissions would probably be nitrogen. Light hydrocarbons, comprising 1 percent of the produced gas, appear chiefly as propane, methane, and to a lesser extent, ethane.[16] Emissions of SO_x, NO_x, and hydrocarbons are small and may fluctuate throughout the burn with differing operating conditions (see Tables 2 and 3). The small volumes and irregular rates of the emissions make it difficult to model their dispersion. Husky Oil applied for and received appropriate air quality permits necessary to initiate this project.

Some other fireflood operators in the United States have found that vapor recovery systems to handle the effluent gas and condense light hydrocarbon fractions for sale are economically justified. Husky is making no attempt to recover these gases and monitors them only once a week.

Dust

There are no relief measures being taken against dust for the greater part of the site. Most of the roads are unpaved and undampened, though at the central equipment facility, an oil/dirt mixture has been used on slopes and on part of the road to reduce the dust produced.

Table 2. Typical composition of produced gas stream from *in situ* combustion.*[18]

Product	Trace mol wt%
Carbon monoxide	2.5 - 3.0
Carbon dioxide	12 - 14
Oxygen	1.0
Nitrogen and oxides**	78 - 83
Hydrocarbons	0 - 1.0
(Methane 0.4-0.5)	
(Ethane 0.1	
(Propane 0.4-0.5)	
(pH of produced water: 1.6 - 8.6)	

*Figures are based on a survey of 31 projects. These gas streams were measured at near-optimum operating conditions early in the life of the flood. As the flood progresses, the composition of emissions may change to include oxides of sulfur.

**Formation of NO_x compounds is not favored at the typical burning temperatures in a fireflood of 700 to 1,200°F. Most of the emissions would probably be nitrogen.

Table 3. Average emissions of gaseous compounds from *in-situ* combustion (regional differences in the operating and reservior characteristics of the in situ combustion affect the emissions produced).*[18]

Compound	Emissions, Scf/bbl of oil produced
Carbon dioxide	435
Carbon monoxide	160
Nitrogen and NO_x**	4,220
Oxygen	185
Hydrocarbons	150

*Assumes all sulfur compounds remain in solution with produced water. However, emissions of SO_x may occur in the late phases of a fireflood. Figures are based on a survey of the gas streams of 31 firefloods (average value).

**Formation of NO_x compounds is not favored at the typical burning temperatures in a fireflood of 700 to 1,200°F. Most of the emissions would probably be nitrogen.

Mitigating measures instituted by Husky Oil include the following actions. A soda ash fluegas scrubber is installed on the 22 MMBTU/hr steam generator. This apparatus uses 1.5 wt% sulphur lease crude in order to reduce emissions to 0.5 percent or less sulphur equivalent, as required by the Monterey Air Pollution Control District. Natural gas, produced at the Paris Valley field is used to heat the three fuel oil storage tanks and the combustion air preheater. This action reduces the site's effect on regional air quality.

NOISE

The region around the Paris Valley field is predominantly rural and consequently has very low noise levels. Typical day-night sound levels (L_{dn}) are expected to be below those of a small town, whose levels average between 46 and 53 L_{dn}.[25] No readings of ambient noise levels within the Paris Valley oil field have been taken. The closest sensitive receptor is a residence approximately 1320 ft away from the project site, and the next closest is a half mile away. The noise impact of the three phases of project development can only be estimated.

Construction

The project involves construction of access roads and grading in preparation of pads for drilling and equipment sites. Sound levels vary during the construction phase with the type of construction equipment used, and the combined sound levels depend on the mix of equipment, but they should average between 85 and 95 dB_A at 50 ft. Typical equipment noise levels are known to be: a scraper, 88-95 dB_A at 50 ft; a grader, 77-87; a truck, 69-91; a paver, 82-89.[25] Three workers on the construction crew used two pieces of equipment for between 14 and 28 days to prepare the project site for drilling and operations.

The probable maximum of 95 dB_A at 50 ft would be preceived as 65 dB_A at the residence 1320 ft away. The impact of much of the construction is considerably reduced by a hill which acts as a barrier between the main equipment site and the nearest residences. However, other portions of the site are fully exposed, and the dB_A levels stated above still apply for these areas.

Drilling

There are some additional noise impacts of short duration, prior to and during the drilling phase. Trucks transport rig components, pipe, and other materials to the site. These noises are of short duration and are transitory. Drilling itself should average around 90 dB_A at 50 ft. The U.S. Occupational Safety and Health Administration (OSHA) standards require an average of less than 90 dB_A in an eight-hour period, for an individual. Short term peaks of 100 to 105 dB_A are present during some drilling operations.

At an average of 90 dB_A at 50 ft, impact on the nearest residence is estimated to be 60 dB_A. During peaks in drilling, the noise of 105 dB_A at 50 ft would reach the residence at 75 dB_A. Husky performs drilling at the Paris Valley site only during daylight hours.[14] This measure is necessary because of the proximity of residences where sleep would otherwise be disturbed.

Operations

Operations noises are generally quieter than those noises associated with construction. Generators and compressors for steam production may produce around 69-75 dB_A at 50 ft, and the pumps around 79 dB_A at 50 ft.[25] Secondary transitory noise sources are workers checking the site in a light truck (72 dB_A at 50 ft), and by a three-man crew performing occasional maintenance with equipment. Pickups of produced crude are made every few days by an oil tanker truck. These operating noises will continue for the life of the project.

The noise of much of the operations (such as the manifold, generator compressor, etc.) is considerably reduced by the top of the anticline which blocks off the noise from the site to the nearby farmhouses. The compressor and the manifold also are enclosed on the top and three sides by metal work, which also reduces noise except directly in front of them (facing away from the farmhouse). These are also blocked off by the hill. However, there are wells and steam injection sites which are exposed fully to receptors. At an average dB_A of 75, impact on the residence 1320 ft from the exposed portions of the project would be approximately 40 dB_A.

UTILITY SYSTEMS

Water

Fresh water for steam is drawn from two shallow wells completed in the Pancho Rico formation. These wells produce the required 15,000 to 20,000 BWPD (barrels of water per day) for the project. Because all water for the project is removed from the Ansberry Lease aquifer, there is no impact on local water systems.

Sewer

All water produced is cleaned and then either reinjected into a nearby oil-bearing formation, or used in wet forward combustion, for cooling hot producing wells, or as scrubber water and is then reinjected as above.[6] There will be no impact on local sewage systems.

Power

Some electrical power is utilized at the project site. Because the Pacific Gas and Electric Co. (P.G. & E.) could not guarantee a completion date or construction cost, Husky constructed the 60/12-kV substation and the power lines to connect with P.G. & E. lines about three miles away. Husky obtained approval for this connection from the Monterey County Planning Commission. The 60 kV power is reduced to 2,300 V to power the compressor.[6]

Electricity is also used for well pumps and for the fluegas scrubber fan onsite. Offsite, electricity is used to run pumps on the water wells and in the reinjection of production water elsewhere in the Paris Valley field. This electrical use is a small addition to Husky Oil's operational uses and to those of Monterey County and will have no significant impact on the local suppliers.

Liquid fuels are also utilized at the project site. Produced crude is used to fuel the steam generator. Natural gas, also produced by Husky, is used to power the combustion air preheater and to heat the wash tank and the three sales tanks, which store both fuel oil and trucked oil.[6] Because no liquid fuels are purchased to operate the project, there is no impact on local utilities and suppliers.

LAND USE

The fertility of Paris Valley soils is moderate to low, and present land use is confined mainly to range and dry cropland. The Ansberry anticline was previously planted to dry crop barley. The immediate region around Paris Valley is primarily agricultural and includes scattered farmhouses. About 10 miles to the south lies the San Ardo Oil Field which is quite developed and presents an industrialized landscape in the primarily agricultural and grazing region of the upper Salinas Valley. Ten miles north is King City, pop. ~5000, a residential community of ranchers and a shipping point for valley produce.[26]

SOCIOECONOMIC CONDITIONS

Demography

Husky obtains its work crew by contracting out for a crew during the construction phase of the project. Grading and construction of roads and pads for the well sites and surface facilities requires approximately three workers. The drilling rig and crew are also on contract. This crew requires three workers and a foreman.[14] There are also other visitors to the site who check the drilling mud and deliver supplies to the crew. The completion time varies with each well. Well maintenance is being handled through contracts for pulling machinery and for an average of three workers.

The total Monterey County civilian workforce was 83,545 people in 1970.[27] The small crews for construction, the drilling rig, and maintenance crews hired by Husky Oil for completion of the project form only a small percentage of the total employed either by Husky or in the county. The impact of this additional employment is therefore insignificant. The workers operating facilities at the site are all employed by Husky Oil. No new workers have been hired for operating the experimental project in Paris Valley.[14]

Community Services

Because no new Husky employees will be brought in either to develop or to operate the project, and development was done on relatively short-term construction and drilling contracts, there is no anticipated impact on community services. These services would include security, social services (such as schools and hospitals), and cultural services (such as libraries and museums).

Aesthetic and Historic Resources

There are no identifiable cultural or historical resources on the site. However, as a precaution, an archeologist will perform a site survey before any further ground disturbance occurs at the project site.[28]

IRREVERSIBLE COMMITMENTS OF RESOURCES

The irreversible commitments of resources are the injected water, the crude oil burned, and the labor and the materials for developing and operating the project facilities. Much of the water will remain in the oil reservoir, and the oil, labor, and materials are minimal. Except for the completed wells, all the equipment used in the project is portable and reusable. Other than small construction crews temporarily employed at the site, drilling crews, and maintenance personnel, the project will require only one or two workers for continued operation.

ALTERNATIVES TO THE PROPOSED ACTION

The proposed experiment is one of 21 involving various techniques for enhanced oil recovery.

No Action

This project is one of several nationwide that are testing the *in situ* combustion process, and termination of the Paris Valley project would not preclude testing at the other sites. However, for the process to be adopted by industry, the method's suitability must be demonstrated under a variety of conditions. The narrower the range of conditions encountered, the less reliable any positive results would be.

A "no action" policy would result in some possible reduction in the rate of environmental degradation, especially of air quality. The gases, particulates, and noise generated by developing and operating the project and the subsequent combustion of the product would not be generated. Retention of the land for agricultural use would also add a very small percentage to California's total agricultural output.

Alternate Processes

The various enhanced oil recovery (EOR) techniques evaluated under this program are those with high potential for industry use. Locations and techniques were selected to be compatible and are not interchangeable. In the absence of site-specific impacts peculiar to a particular method, substitution of another technique for the one proposed would serve no purpose.

Alternate Sites

The location of this project was chosen because of reservoir characteristics which are suitable for experimenting with the *in situ* combustion method. The low gravity of the crude is such that it might have been left untouched without the use of an enhanced oil recovery method, particularly once primary production has slowed or ceased.

In situ combustion is best suited to a relatively uniform, isolated sandstone reservoir with an oil of gravity 40° or less, producing formation depths between 100 and 3,000 ft, a formation porosity of 20 percent or greater, a thickness of 10 ft or greater, a permeability of 100 mD or greater, and the product of oil saturation multiplied times porosity greater than 0.1.[4] The Paris Valley reservoir matches these conditions well. The reservoir has an oil of 10.5° gravity, and the producing formation is between 700 and 1,000 ft in depth, with a thickness varying between 0 and 90 ft, a 32.2-percent porosity, and a permeability of 3,748 mD. Any proposed alternative site must meet similar requirements and be operated by parties interested in this type of experimental project.

Alternative Uses of the Project Site

The project site could be retained for dry-farm barley production or converted to higher intensity agricultural production through irrigation. Row cropping has been proposed in areas around the site. As nearby urban areas expand and the value of this agricultural land rises, particularly for the production of more intensive agricultural foodstuffs such as row crops, it may be economical to lease the surface for cropping around the well sites. In any case, uses of the land surface are not permanently impaired by oil field development.

Other Uses of Funds

The total cost for the enhanced oil recovery program is $151.4 million, of which the government's share is $53.5 million, or 35 percent. Because oil and gas are unquestionably limited resources, it may seem more reasonable to divert this sum to work on other energy sources with more long-term promise. It seems desirable to bridge the time gap, now inevitable, between the decline in oil and gas and the rise in alternative sources as long as development of the latter would not suffer as a result.

In fact, the government outlay of $53.5 million would probably not detract significantly from other energy work. In Fiscal Year 1977, a total of $2.2 billion in federal funds was spent on energy research and development. By comparison, the EOR program cost may be visualized as 4 percent of one year's outlay for nuclear research, or about half a year's outlay for research in solar power. The diversion of the EOR program costs to research in other energy sources would increase total government funding by 2 percent for only one year, based on fiscal 1977 amounts.

RELATION OF SHORT-TERM TO LONG-TERM USES OF THE ENVIRONMENT

The short-term use of the environment for the combination thermal drive project does not preclude other long-term uses. The plugged and abandoned wells should not interfere with the use of the site for barley production or other agricultural development, for example.

On a larger scale, the EOR program itself balances the short-term and long-term uses of the environment. The role of oil as an energy source in the U.S. will decline substantially between now and the year 2000. The rate of decline will be influenced by market conditions, government policy, and the status of alternative sources, etc. It is clear, however, that a major role cannot be long sustained by identified reserves. As oil recovery nears its economical limit, domestic oil fields will be converted to other uses. The successful commercial application of one or more of the enhanced oil recovery methods tested would not preclude, but only postpone, this conversion. However, EOR may have one long-term benefit. Because a decline in oil availability is expected before a rise in alternative sources, economic or political conditions might push one or more new sources into the marketplace before its environmental impacts are entirely known and accounted for. Long-term degradation of the environment could well occur, because the capital expended, and thus the incentive to continue despite the environmental consequences, would be enormous. The more time EOR buys to resolve technical and environmental problems of alternative sources, the less probable this scenario becomes.

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