Environmentally Significant Locations in the Kern County Area

Editors

Robert J. Menzie, Jr., Groundwater Technology
Herman B. Schymiczek, EMCON Associates

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Eastside Disposal Facility: A Resource Conservation and Recovery Act Class II-1 Facility

Thomas F. Gutcher, Duane R. Smith and Associates, Bakersfield, California
Robert J. Menzie, Jr., Groundwater Technology, Ventura, California

Introduction

The Eastside Disposal Facility (EDF), a California II-1 waste disposal facility, is located approximately 10 miles northeast of Bakersfield near the Round Mountain Oil Field (Fig.1). Access to the site is afforded by Round Mountain Road which is north of, and adjacent to, the Kern River. The facility property consists of approximately 245 acres which comprise the NW 1/4 and the N 1/2 of the SW 1/4 of Section 30, T.28S., R.29E., Mount Diablo Base Meridian. Twenty surface impoundments and three landfills were located on the property owned and operated by Environmental Protection Corporation (EPC) (Fig. 2). The boundaries of some of the impoundments are currently visible, however most of the impoundment dikes have been bulldozed in preparation for final closure. Accepted wastes consisted primarily of oil field wastes. Most of the treatable waste was processed by land farming in the impoundments. Other wastes were disposed in landfills. Treatment of acid sludge by mixing it with lime slurry, soda ash, and kiln dust continues at the site in two impoundments during the hot summer months when the increased temperature aids mixing.

Geologic Setting

The EDF is situated near the eastern margin of the southern end of the Great Valley Geomorphic Province. The province is a large northwesterly trending geosyncline located between the Sierra Nevada Mountains and the Coast Ranges. The general area consists of low rolling hills characteristic of dissected uplands. Part of the western portion of the site, referred to as the "landslide area", has steep slopes and a badlands appearance. The EDF is situated on the edge of a Plio-Pleistocene terrace of the Kern River (ERT, 1987a).

Lithology

The site is underlain by the marine, middle Miocene, Round Mountain silt. On some of the higher elevations on the western side of the facility, terraces of the Plio–Pleistocene Kern River Formation overlie the Round Mountain silt.

As observed in numerous soil samples collected from on–site borings, the unweathered Round Mountain silt generally consists of a dull green, massive, poorly indurated, clayey silt. It is moist and the degree of plasticity indicates significant clay content. Weathering in the Round Mountain silt, which alters the color to light greenish–grey, generally extends to depths of five feet or less at the EDF. The weathered silt is relatively cohesionless. Some portions of the Round Mountain silt on the east side of the facility appear to be reworked and have a high sand content and laminations not visible in most of the formation.

Permeabilities of the unfractured Round Mountain silt beneath the site are 10^{-6} cm/sec or less. However, the near–surface sediments are parted by locally abundant gypsum veins. The gypsum veins impart a high secondary permeability due to vuggy porosity between well–developed selenite crystals. In the upper 20 to 30 feet, these veins are generally high angle features which can greatly enhance vertical migration of fluids. But his porosity decreases to nearly insignificant levels at depth. Also, the veins tend to pinch out or are transected by horizontally–oriented veins at depth which likely prohibit further vertical migration of fluids. Iron oxide staining is common along some of the gypsum veins as well as along planar cracks in the Round Mountain silt. Hard concretions, known to polish auger drill bits to a smooth cylinder, are scattered throughout the formation.

The Round Mountain silt is a fossiliferous deposit in which fossils of both deep and shallow water fauna are found (LLM and Associates, 1980). Mollusk molds, fish scales, and sand–infilled borings were observed in numerous soil samples from the on–site soil borings. Moderately well–preserved mollusk shells are common in the canyon along the eastern boundary of the site. Although megafossils can be found in much of the Round Mountain silt, by far the highest concentration of noteworthy specimens are found in a bed referred to as the "Bonebed". The Sharktooth Hill National Natural Landmark is located 1/2 mile due east of the EDF. Fossils have been collected from the "Bonebed" at Sharktooth Hill since 1853 (LLM and Associates, 1980). The "Bonebed" is present on EPC property northwest of the EDF. Excellent specimens of shark teeth up to 5 inches in length have been collected from the area.

The Plio–Pleistocene Kern River Formation unconformably overlies the Round Mountain silt. The Kern River Formation consists of stream–deposited pebbles, cobbles, and boulders in an unconsolidated coarse sand matrix. The pebbles, cobbles, and boulders are subrounded to well–rounded. The sediments were derived from the nearby Sierra Nevada Mountains. Permeability is high in the Kern River Formation.

Structure

Several lineaments, inferred faults, and known faults exist in the vicinity (SCS Engineers, 1982). The Jewett fault (Fig. 3) is an east–west oriented fault which crosses the northern boundary of the EDF. The Jewett fault shows 230 feet of offset in the Olcese sand, which underlies the Round Mountain silt (SCS Engineers, 1982). In the vicinity of the EDF, an offset of 120 feet, upthrown to the north, has been noted (LLM and Associates, 1980). About one mile northwest of the EDF, the "Bonebed" is offset by approximately 135 feet, but the overlying Kern River Formation exhibits no offset (SCS Engineers, 1982). The difference in offset of the Olcese sand and the Round Mountain silt indicates active faulting during deposition of the Round Mountain silt. The absence of offset of the Kern River Formation indicates no movement subsequent to deposition of the Kern River Formation.

Groundwater

The first aquifer beneath the site is the second Olcese sand. Groundwater beneath the EDF occurs at depths of about 200 feet or greater. The regional groundwater flow direction is to the southwest. The water in the Olcese sand is connate water of poor to very poor quality (LLM and Associates, 1980). Water samples from several wells in the vicinity have been analyzed for general mineral content. Analytical results indicate a chemical composition similar to ocean water with the addition of a very high concentration of calcium sulfate (LLM and Associates, 1980). Water from a well just east of the EDF (well now abandoned) has been observed to produce black to grey water which emitted a strong hydrogen sulfide odor.

Naturally occurring groundwater beneath the EDF is unfit for human consumption, however some limited irrigation use is possible. Salt tolerant vegetation can be irrigated with this water, but boron tolerance is also necessary (LLM and Associates, 1980).

Historical Summary

The EDF, which the Environmental Protection Agency (EPA) identifies as facility number CAD030384267, began operation in 1971 with EPC as the operator. Site activities involved treatment in surface impoundments (land farming) and placement in landfills of a defined set of wastes. Approximately 85 percent of the wastes accepted at the EDF between 1971 and November 1985 when the site was closed were generated by the petroleum industry.

Treatment and disposal of approximately 353,850 cubic yards of waste occurred at the EDF. ERT, Inc. (1987b) reported that oil production wastes accepted between 1975 and 1985 included rotary mud (33.3%), scrubber waste (20.6%), tank bottom sediment (12.7%), oil sump sludge (10%), oil field brine (8.1%), acids and bases (0.4%), and solvents (0.1%). Liquid wastes were transported to the site by vacuum truck.

In November 1985, the EDF lost its interim status permit to accept wastes because EPC could not acquire environmental impairment insurance. New regulations, enforced by the EPA, required a $10 million policy for the facility to remain in operation. A policy was initially available at a premium of $1 million per year, but the potential provider opted not to insure the facility. Therefore, EPC ceased waste acceptance at the EDF and submitted the first of several Closure/Post–closure plans to the California Department of Health Services (DHS) in December, 1985.

Two and one–half years passed before a closure/post–closure plan was finally accepted by the DHS in March, 1987. During that time, two consulting companies (Kaman Tempo and ERT, Inc.) submitted three different plans before one was accepted with modifications.

In December 1988, Mittelhauser Corporation, subcontracted by San Joaquin Energy Consultants, Inc. (SJEC), conducted the initial site assessment. This first phase, which was completed in March 1989, consisted of drilling 2 background and 6 perimeter borings to approximately 30 feet below grade. The second phase of characterization was undertaken by SJEC between April and August 1989. It consisted of drilling 1 background, 1 landfill, and 6 impoundment borings and installing 3 groundwater monitoring wells. The third phase, which began in November 1989, consisted of drilling 1 landfill, 1 perimeter, and 13 impoundment borings. The fourth and final phase of characterization, as proposed to the DHS in December 1990 by SJEC, includes 1 impoundment boring, 17 shallow and 8 deep perimeter borings, 3 landfill borings, 6 monitoring wells and a single piezometer to be completed in the second Olcese sand. The locations of all existing and proposed borings and four existing monitoring wells are shown on Figure 4. Two monitoring wells were installed while the facility was in operation, one of which is shown on Figure 4. The other monitoring well is located in the southern portion of the EDF, beyond the limits of Figure 4.

Site Characterization

Characterization Program

A total of twenty–eight borings have been drilled to date in order to characterize the lateral and vertical extent of waste constituents present in the vadose zone. These include 3 background, 7 perimeter, 19 impoundment, and 2 landfill borings. Background borings were drilled for the purpose of determining a comparison standard. Additionally, five monitoring wells have been completed in the first and second aquifers of the Olcese sand (second and third Olcese sands, respectively).

Soil samples were collected using the Mobile Open–Spindle System (MOSS) continuous–core, split–spoon sampler while auger drilling. Analytical tests included: oil and grease (EPA Method 413.1); antimony, barium, beryllium, cadmium, total chromium, cobalt, copper, lead, molybdenum, nickel, silver, sodium, thallium, vanadium, and zinc (EPA Method 6010); arsenic (EPA Method 7061); mercury and selenium (EPA Method 7471); chloride (EPA Method 9251); sulfate (EPA Method 375.3); and volatile organics (EPA Method 8240) which includes benzene, toluene, ethylbenzene, and total xylene (BTEX) as well as 36 other constituents. In addition, moisture tests were performed on selected samples to assist in characterizing the vadose zone.

Chromium, lead, nickel, vanadium, and oil and grease were expected to indicate residuum from various waste types accepted at the EDF. Residue from refinery waste would be indicated by elevated chromium and lead concentrations, whereas produced crude oil from the Bakersfield area and oily wastes such as rotary mud, oil sump sludge, and tank bottom sediment would be indicated by elevated nickel, vanadium, and oil and grease levels. Chloride was expected to indicate increased concentrations of oil field brine wastes.

Results of Characterization

Results indicated concentrations for perimeter boring samples were variable, but below action levels and within the range of analytical results for background soil samples (Table 1). None of the metals' concentrations in soil samples from the perimeter borings exceeded their respective total threshold limit concentration (TTLC) and were generally two orders of magnitude lower than the TTLC. Concentrations of volatile organic constituents were all below or slightly above the minimum detection level (Table 2). Excepting one case, oil and grease concentrations exceeded the range of background (>105 ppm) only at shallow depths less than 7.5 feet below grade. These increased values for oil and grease (13,300, 10,500, and 5,100 ppm) probably correspond to former impoundment surfaces. Comparison of perimeter and background chloride concentrations indicate that oil field brine degraded the perimeter soil no deeper than 1.5 feet below grade. Perimeter sulfate concentrations were identical to background values. The relatively high sulfate values measured confirmed field observations of abundant gypsum filling fractures in the weathered vadose zone and occurring as veins in the Round Mountain silt.

Table 1. Regulatory limits and range of analytical results (short metals list) for soil samples from perimeter borings (ppm).

	Cr	Pb	Ni	V
Results	8.9–12.7	3.4–270*	4.5–20	7.1–18
Background	11–39.1	5.3–8.5	7.2–20.5	7.6–60.4
TTLC	2500	1000	2000	2400
STLC	560	5	20	24

* one sample at 1.5 feet below surface grade.

TTLC = Total Threshold Limit Concentration (directly comparable to laboratory results).

STLC = Soluble Threshold Limit Concentration (maximum value can be estimated by dividing the laboratory results by 10).

Table 2. Regulatory limits and range of other analytical results for soil samples from perimeter borings (ppm).

	B	T	E	X	Oil & Grease	Chloride	Sulfate
Results	ND	ND–0.011	ND	ND	ND–13,300	22–1000	1450–5520
Background	ND	ND	ND	ND	ND–208	15–810	1200–5050

ND = None Detected

Table 3. Regulatory limits and range of analytical results (modified long metals list) for soil samples from impoundment borings (ppm).

	Ar	Ba	Cd	Cr	Co	Cu	Pb	Ni	V	Zn
Results	2.25–12.4	67–3680	ND–6.56	3.47–228	ND–13.7	2.22–220	ND–768	ND–803	9.1–277	39–714
Background	3.4–8.68	9.7–249	ND–1.4	11–39.1	ND–5.78	11.4–43	5.3–8.5	7.2–20.5	7.6–60.4	41–65.4
TTLC	500	10,000	100	2500	8000	2500	1000	2000	2400	5000
STLC	5	100	1	560	80	25	5	20	24	250

ND = None Detected
TTLC = Total Threshold Limit Concentration (directly comparable to laboratory results).
STLC = Soluble Threshold Limit Concentration (maximum value can be estimated by dividing the laboratory results by 10).

Table 4. Regulatory limits and range of other analytical results for soil samples from impoundment borings (ppm).

	B	T	E	X	Oil & Grease	Chloride	Sulfate
Results	ND	ND–11.6	ND	ND–10.4	ND–118,224	142–8496	ND–2.53
Background	ND	ND	ND	ND	ND–208	15–810	1200–5050

ND = None Detected

Cumulatively, these results indicate that waste was sufficiently contained laterally within the surface impoundments by dikes constructed of the Round Mountain silt. Land farming practices were also probably effective in reducing the potential for lateral migration of waste constituents as well as in degrading the hydrocarbon wastes to lower concentrations.

Results from the second and third phases of assessment indicated that metal concentrations were significantly greater than background levels almost exclusively from the surface to 8 feet below grade within one landfill and the impoundments. All metals analyses from the impoundment borings indicated concentrations less than the TTLC for each metal (Table 3).Volatile organic compounds were only detected in one impoundment. Concentrations for antimony, beryllium, mercury, molybdenum, selenium, silver, and thallium were essentially non–detectable at their respective detection thresholds.

Table 4 shows that the range of concentrations for volatile organic constituents in soil samples collected from impoundment and landfill borings were low compared to the analytical results determined from background samples. Results for oil and grease and chloride were comparable to background levels except for a few samples.

In August 1989, a soil gas survey was performed by Epoch Well Logging, Inc. to satisfy, in part, emissions requirements of the Air Resources Board. The intent of this survey was to reduce the areas that needed additional assessment and to identify locations of surface soil degradation that would require further assessment by auger drilling. The soil gas survey, although successfully conducted, was only slightly informative.

Site Closure

Containment Cover

In September 1989, a geotechnical feasibility study for the clay barrier (cap or layer) design was undertaken by Buena Engineers, Inc., primarily to determine if the Round Mountain silt could be utilized for the final cover needed for closure (Buena Engineers, Inc., 1990). Previously, in March 1988, ERT, Inc. prepared a supplementary document to the closure/post–closure plan proposing the construction of a test plot to evaluate the effectiveness of using the Round Mountain silt for this purpose (ERT, Inc., 1988). Buena Engineers, Inc. recommended the evaluation of impoundment dikes constructed of Round Mountain silt between 1981 and 1985 rather than testing the integrity of a test plot (Buena Engineers, Inc., 1989). They argued that evaluation of the impoundment dikes would better determine the integrity of the Round Mountain silt with regard to long term performance of the final cover. Tests on the silt included in–situ moisture content, dry unit weight, triaxial permeability, Atterberg limits, particle size analysis (mechanical and hydrometer methods), maximum density–optimum moisture (modified Proctor curve), and specific gravity. Results of these analyses indicated that material from the "borrow area" (where Round Mountain silt would be supplied), northwest of the EDF in Section 23, was similar to the material used to construct the impoundment dikes between 1981 and 1985 and therefore could be used to construct the final clay cover. Triaxial liquid permeabilities of two samples were 2.04×10^{-7} cm/sec and 4.12×10^{-7} cm/sec which are within the maximum allowable permeability of 10^{-6} cm/sec set forth in the Final Cover Design Guidelines (Title 23 California Administrative Code, Section 2581).

Post–Closure Monitoring

A post–closure monitoring program is required by the regulatory agencies, generally for a period of 30 years after closure. EPC requested a variance under Title 22, California Administrative Code, Section 67188 (d)(3) to exclude vadose zone monitoring for the EDF, largely because no free liquids remain and because precipitation is very low in the area. However, monitoring of the uppermost acquifer is required and a trust fund for this purpose has been established.

As detailed in the closure and post-closure plans (ERT, Inc., 1987a), comprehensive analyses of samples collected from the on-site monitoring wells are required on the following schedule, effective after closure is complete: quarterly for the first five years, semiannually for the second five years, and annually for the last twenty years. The results of these analyses will be statistically compared to established background levels to detect possible changes in groundwater quality.

Conclusions

Although the site has not completed closure as defined by current regulations, three important conclusions can be drawn concerning the EDF site. First, the site location was well-suited for waste disposal because: 1) the Round Mountain silt has a characteristically low permeability; 2) the adsorptive capacity of clay in the Round Mountain silt inhibits fluid migration; 3) no shallow aquifers exist beneath the site; and 4) the site is located near many producing oil fields yet few residences or commercial properties. Secondly, Round Mountain silt (compacted to 10^{-7} cm/sec) will be readily available for construction of a clay cap several feet thick to prevent percolation of surface water thereby reducing the risk of leaching in the future. Finally, analyses suggest oil field waste was significantly biodegraded by naturally occurring bacterial populations as a result of land farming activities conducted at the site during its 14 years of operation.

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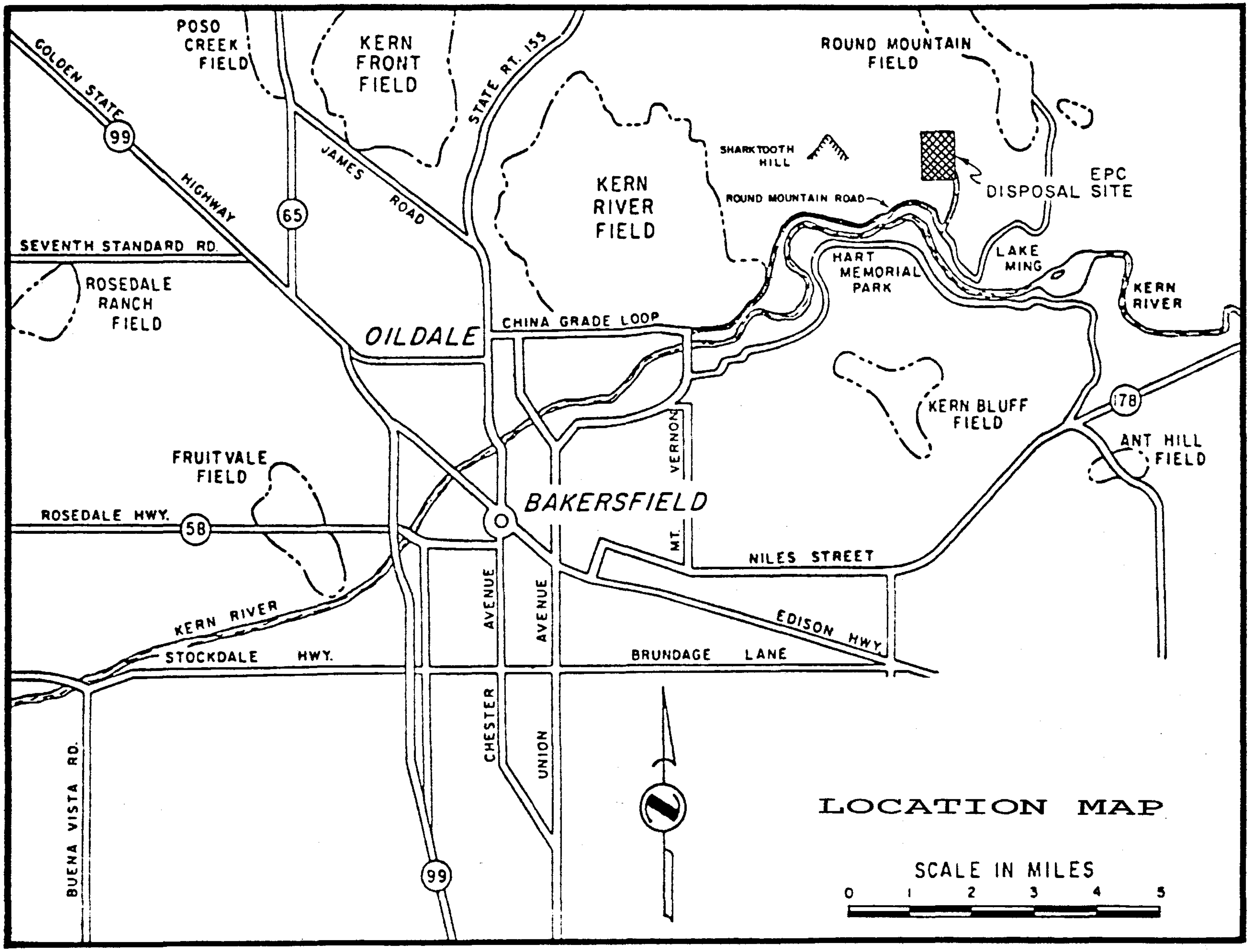

Fig. 1. Location map of Environmental Protection Corporation's Eastside Disposal Facility.

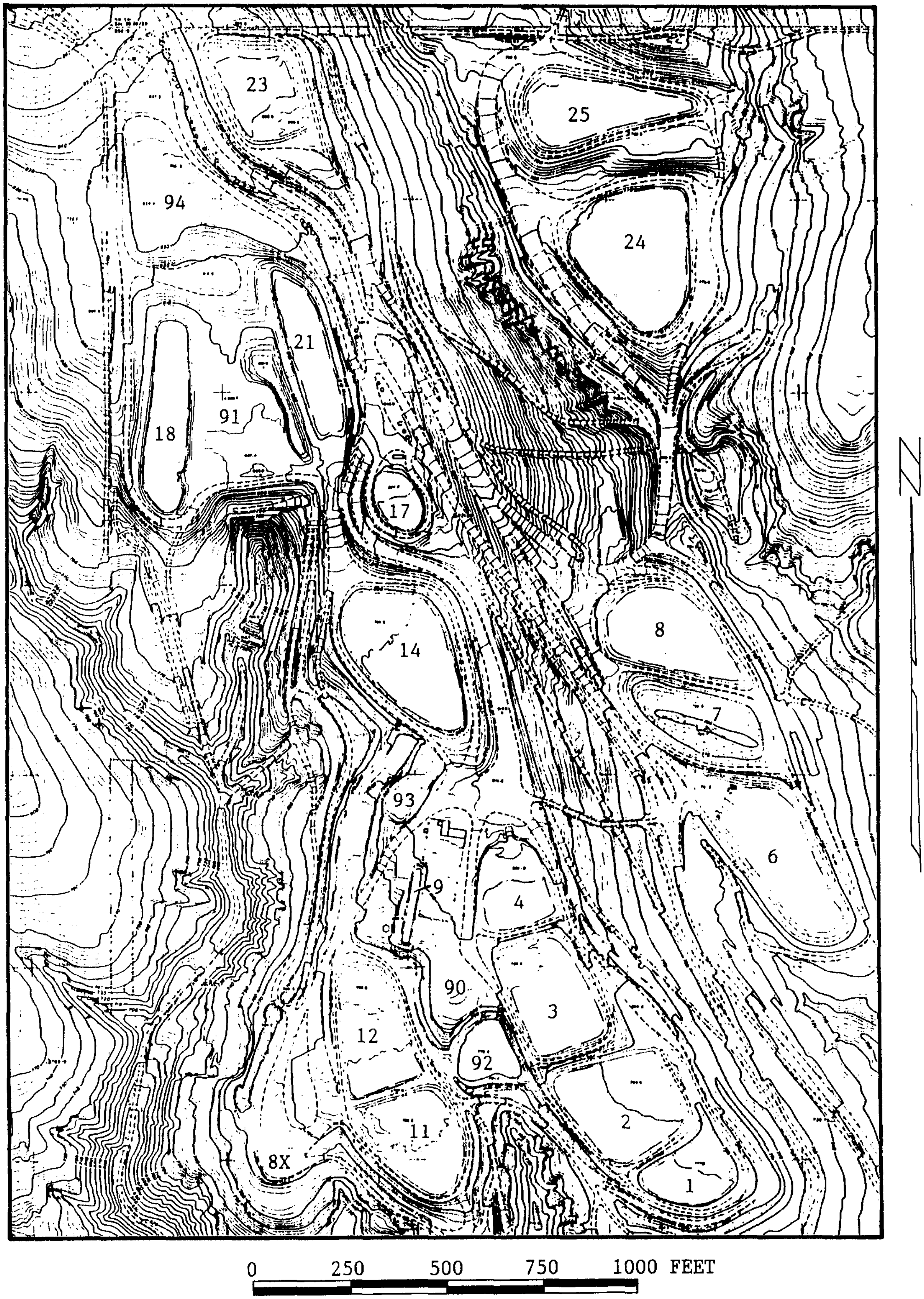

Fig. 2. Site map, Eastside Disposal Facility. Numbers refer to waste disposal units. Units 90, 91, and 94 are landfills; other units are impoundments.

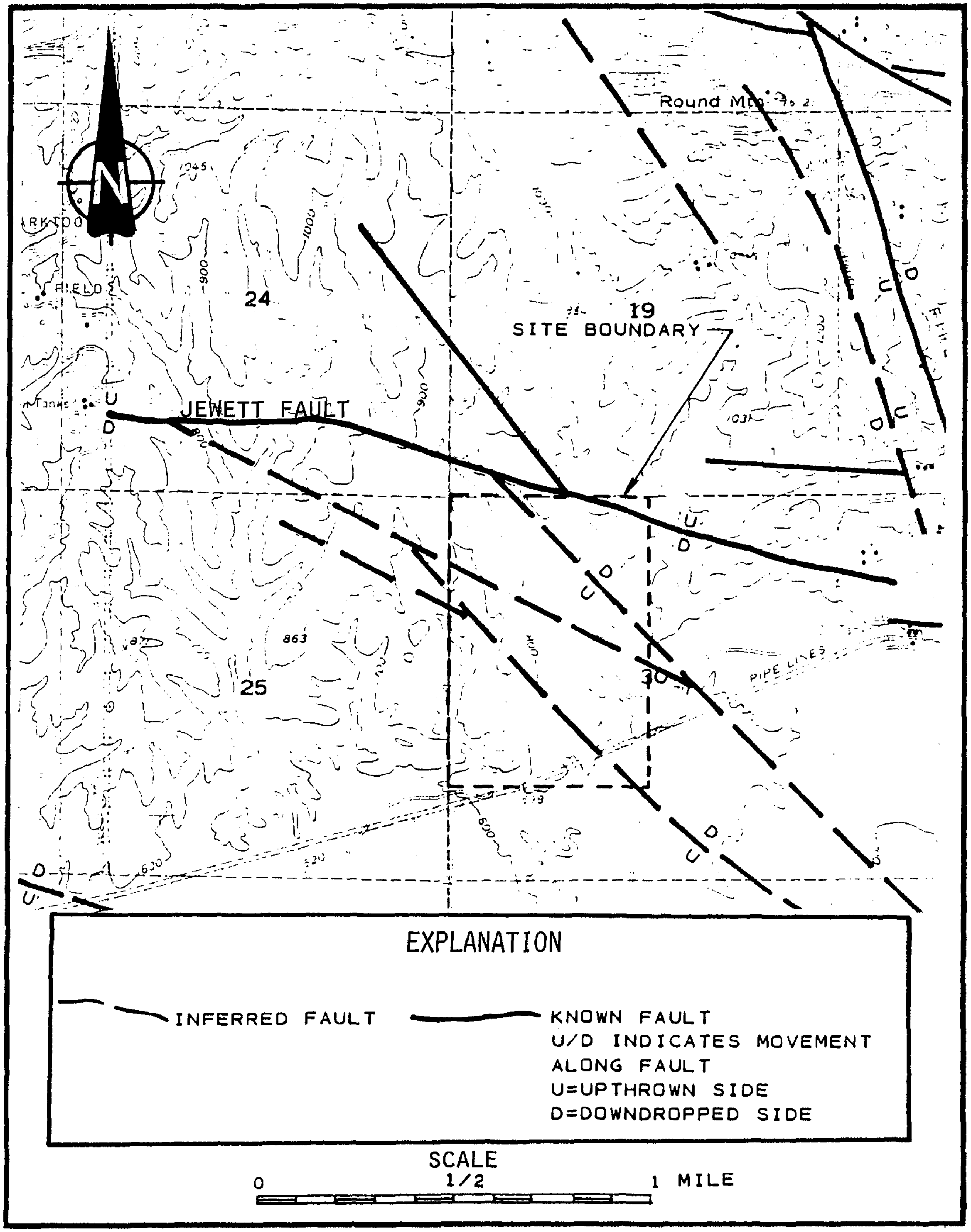

Fig. 3. Surface structure in the vicinity of the Eastside Disposal Facility (from SCS Engineers, 1982).

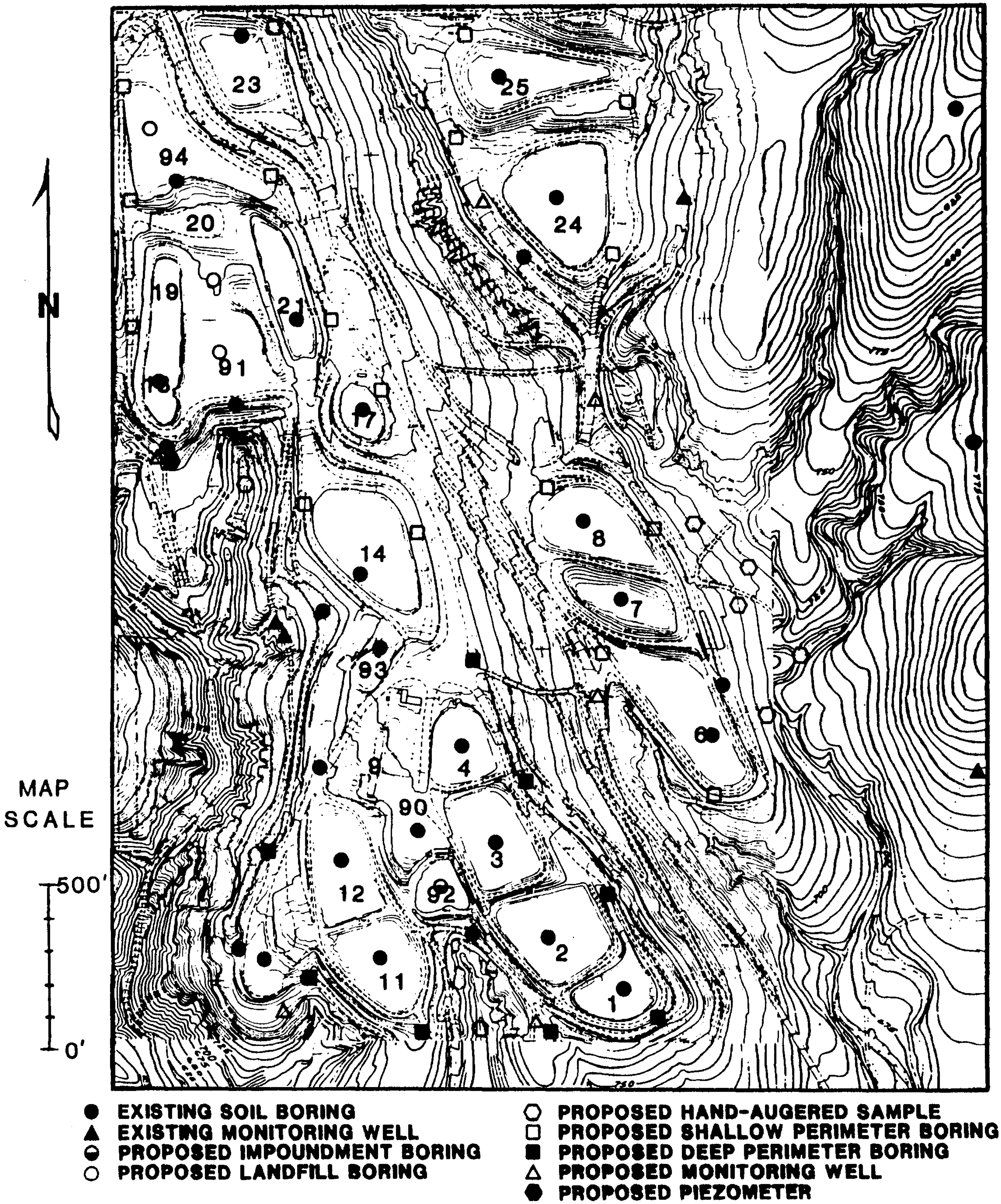

Fig. 4. Locations of existing and proposed soil borings and monitoring wells (from SJEC, Inc. documents).

Fruitvale Wastewater Injection Facility

Thomas F. Gutcher
Duane R. Smith and Associates
Bakersfield, California

The Fruitvale Wastewater Injection Facility is located at 7201 Fruitvale Extension, Bakersfield, California (Fig. 1). The 5-acre site is situated in the NW 1/4 of Section 28, T.29S., R.27E., Mount Diablo Base Meridian in the Fruitvale Oil Field. The facility disposes of non–hazardous oil field production and refinery wastewater by injection into two wells located in the northwest and southeast portions of the site. The facility began operations in December 1985.

Wastewater is delivered by vacuum truck or tanker to one of two unloading racks and emptied into holding tanks (Fig. 2). The water is then pumped through screens to remove large solids and then into large production water tanks. The water is then pumped through several progressively finer filters before it is stored in the polished water tanks. Finally, the water is pumped downhole (into the wells) by a quintiplex pump with a maximum output of 3,900 bbls/day. The sludge tank (Fig. 2) is used to store oily sludge removed from the system during scheduled back-washing. The crude oil tank (Fig. 2) collects small amounts of residual oil (5 to 7 bbls/month) delivered with the wastewater.

The wastewater is injected into the lower 600 feet of the Etchegoin Formation, including the Fairhaven sand. Figure 3 shows the contours on top of the injection interval. Figure 4 shows a cross section of the injection horizon. The Etchegoin Formation is a marine unit of Pliocene age composed of fine- to coarse- grained, grey, micaceous sands and grey, micaceous shales. The injection horizon is oil–productive in the eastern portion of the Fruitvale Oil Field, however, no production has been obtained from this horizon in the vicinity of the facility.

The injection wells were completed with great care to ensure that injection waters only enter the injection horizon. The wells are monitored annually by a water injection and temperature survey and annular pressure test. Regulatory compliance is monitored by the Division of Oil and Gas.

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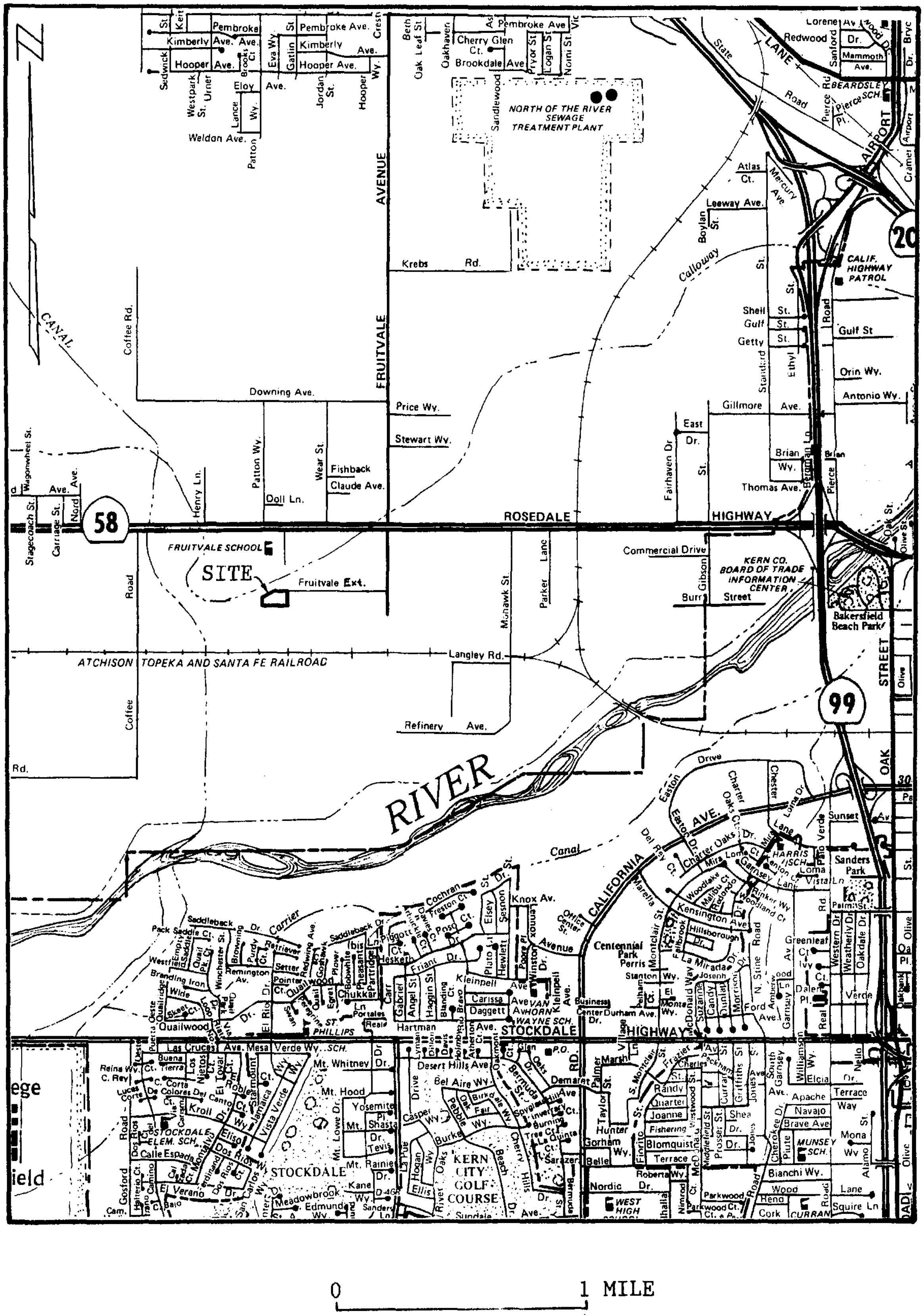

Fig. 1. Location map of Fruitvale Wastewater Injection Facility.

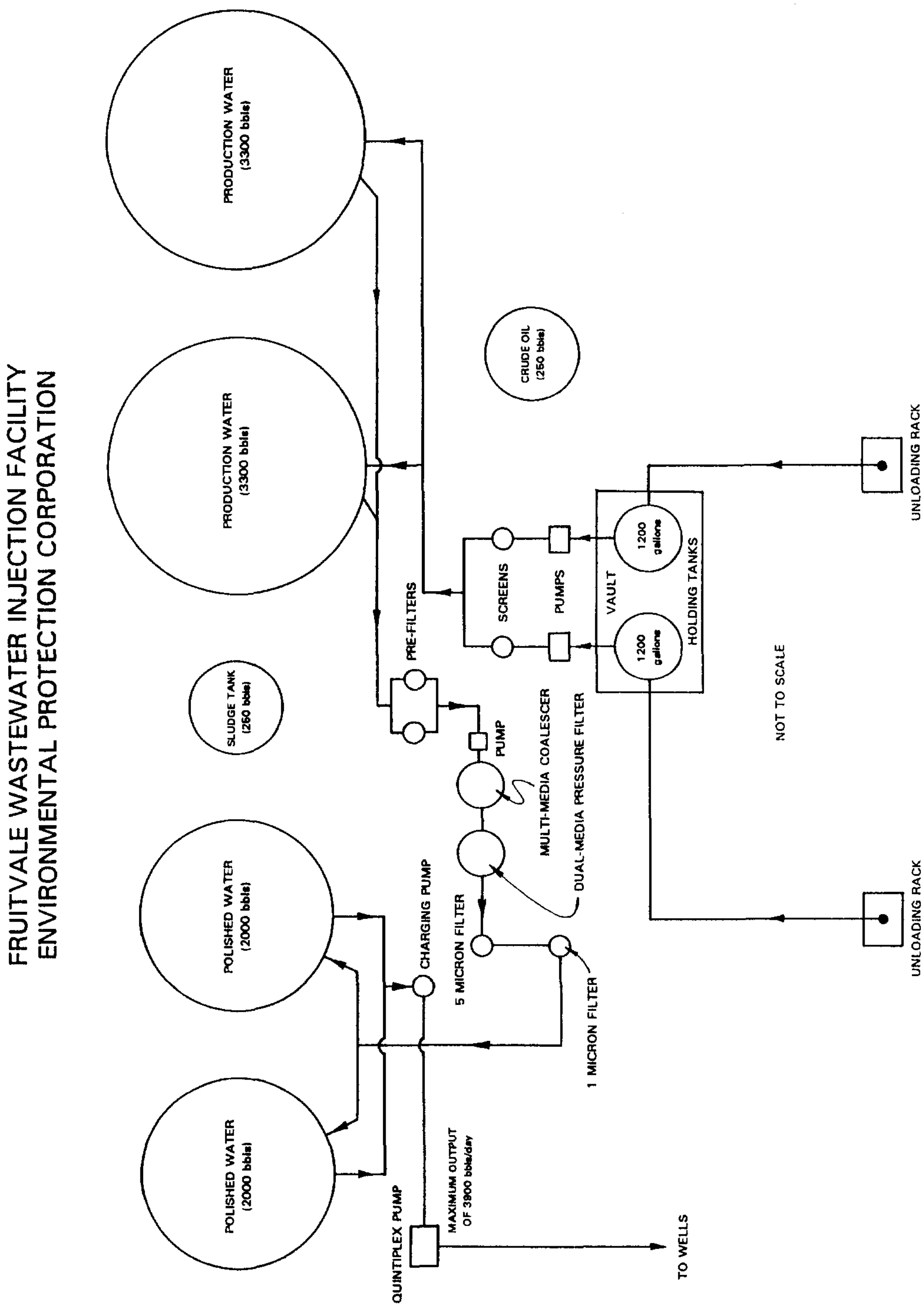

Fig. 2. Flow diagram of Fruitvale Wastewater Injection Facility.

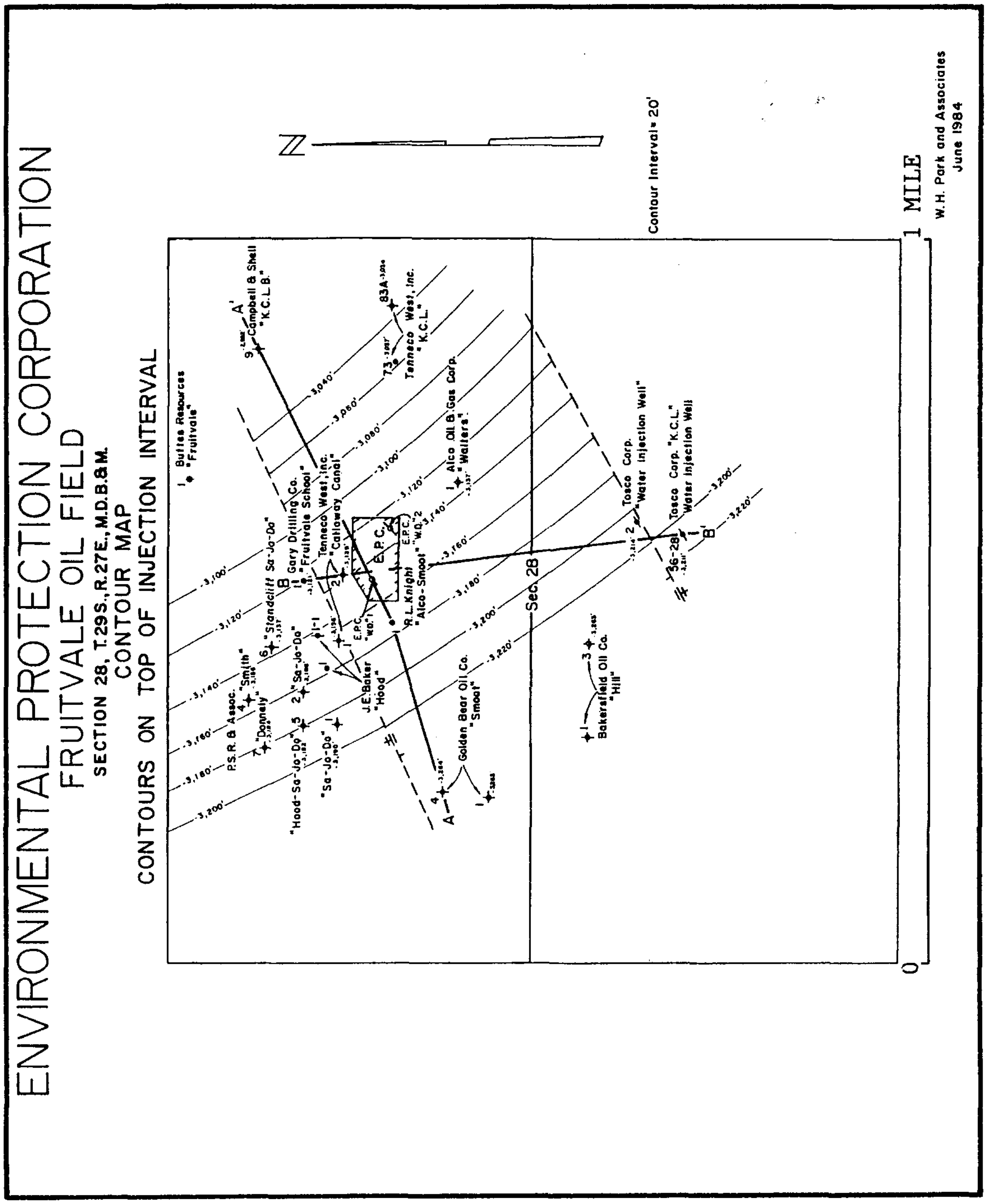

Fig. 3. Contours on top of injection interval.

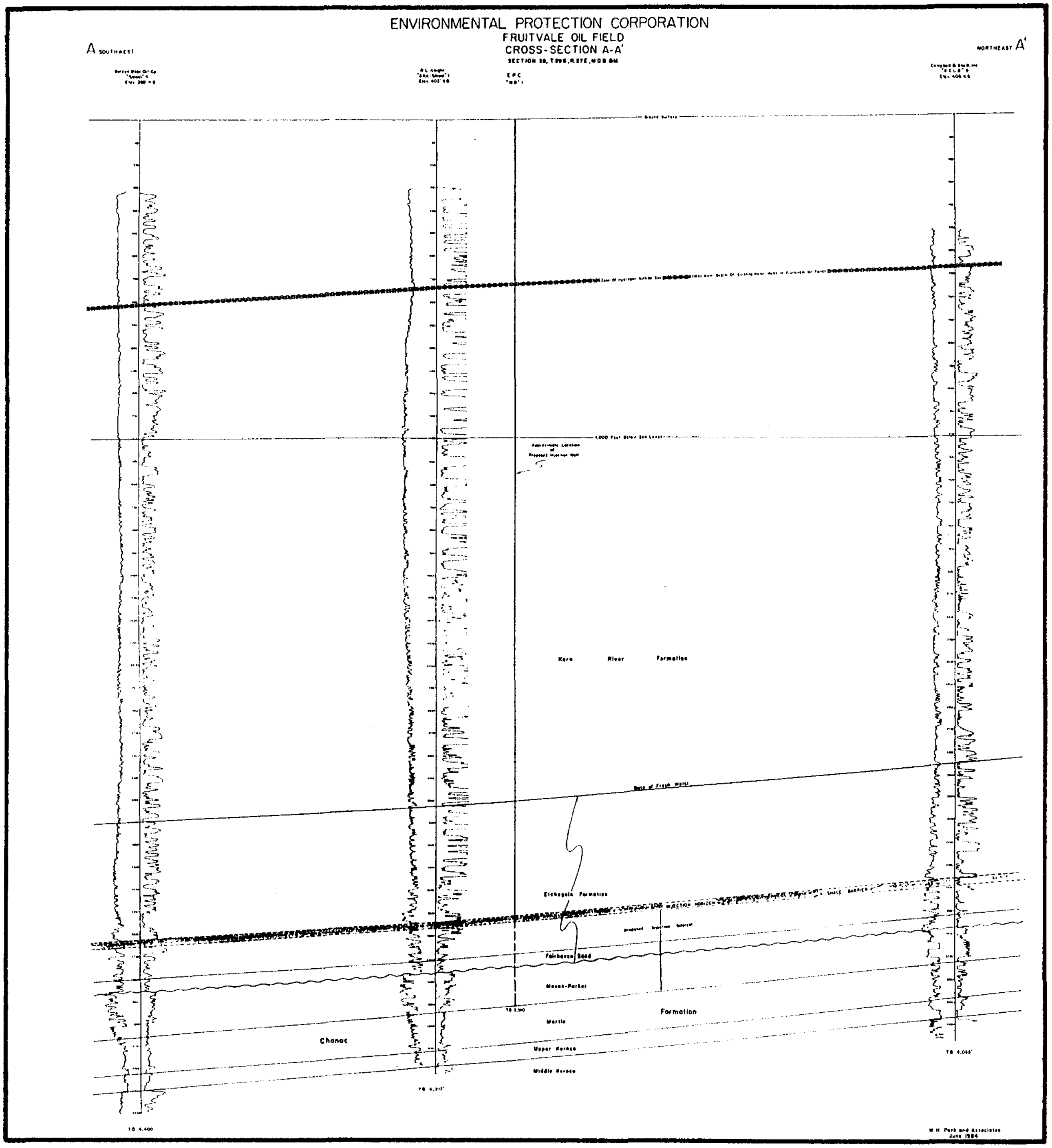

Fig. 4. Cross section A - A', Fruitvale Oil Field.

An Overview of the Tule Elk State Reserve

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Tule elk were once extremely numerous in California and ranged as far north as the north–central Sacramento Valley (Shasta County), south to the Tehachapi Mountains, east to the limit of the oak–grassland environment of the Sierra Nevada foothills, and west to the Pacific Ocean from Point Reyes to the vicinity of Santa Barbara. In California's great Central Valley the tule elk was by all accounts the predominant form of animal life, comparable to the bison of the great plains or the antelope of South Africa. Though this particular subspecies of elk normally forms herds of forty to sixty animals, they were so numerous, particularly in the fertile floodplains and lowlands of the northern San Joaquin Valley, that they were sometimes observed in groups of one or even two thousand.

Tule elk shared their grass–fill marshland and oak savannah habitat with antelope, deer, and other smaller animals. Overall food supply, especially as affected by occasional drought, was probably the factor that most directly limited the total elk population since predators (grizzly and black bears, mountain lions, and coyotes) were a threat only to very young, weak, or crippled elk. (Leading experts agree that wolves were not present in west–central California.) Indian hunters could choose many other easier forms of game though they did hunt elk occasionally. Thus for countless thousands of years elk were able to thrive and multiply in California and adapt themselves little by little to the increasingly arid conditions that followed the close of the last ice age.

Decline of the Species

The 18th century arrival of Spanish missionaries, Mission settlements, and rancheros had little direct effect on the tule elk, but somehow they brought with them a number of European grass species – highly aggressive annuals – that soon began to replace the native perennial bunch grasses. The effect of this eventually widespread plant invasion was a reduction in grazing values that undoubtedly had an adverse effect on tule elk. Then, during the 19th century, increasing numbers of both domestic and wild cattle and horses began to compete with tule elk for grazing resources.

Serious commercial exploitation of tule elk began during the early 1900s when elk were taken as part of the hide and tallow trade. One observer estimated that by 1845 about 3,000 elk and deer hides were being exported from California each year. Starting in 1827, however, the fur trade began to bring hundreds of professional hunters into California each year. The "fur–brigades," as they were known, generally consisted of large numbers of men, and very often these groups would choose to winter in the central valley where the weather was relatively mild, and where there were excellent grazing opportunities and a wealth of game. Elk were shot by the hundreds, and driven from the open prairie into the tules by the constant pressure of the hunters.

Tule elk were nevertheless still numerous until 1848, when the California gold rush began to bring thousands of new immigrants to California. Then, overnight, the human demand for food began to double and redouble. Cattle that had been worth two dollars – for their hides – were suddenly worth $35.00 for their food value. Elk and other forms of wild game were free for the taking, and some 49ers found it more profitable (and more pleasant) to hunt than to work in the mines. Within two years the entire tule elk population in the Sacramento Valley had been wiped out. In the San Joaquin Valley where hunting pressure was less severe the elk managed to survive somewhat longer, but even there they very quickly disappeared from the open range. In 1863, market hunters claimed to have killed the last elk cow and calf left in the tules of the San Joaquin Delta, thus restricting the remaining elk range to the willow and tule–filled marsh country between Buena Vista and Tulare Lakes. Even this refuge began to disappear in later years as the area was slowly diked, drained, and cleared for agricultural use.

Preservation of the Species

In 1852 the California State Legislature passed a law that prohibited elk hunting throughout half of each year in certain counties. In 1854 the law was made statewide. No provision was made, however, for regulation or enforcement. In 1873, the Legislature banned all elk hunting in California. By then, however, there was serious doubt as to whether any tule elk still remained alive.

A couple of years later (in 1874 or 75) a single pair of elk was observed in the tule marshes near Buena Vista Lake. A.C. Tibbets, a deputy warden for the Fish and Game Commission, was convinced that these two animals were the last of their kind, and he was either correct or extremely close to the mark, for over the next few years as the marshes were drained and the land put to agricultural use, the number of elk exposed to view remained very small. In 1895 after twenty years of protection, a thorough and precise count revealed that there were then just twenty–eight tule elk in the world.

Great credit should be given to Henry Miller, of the Miller and Lux cattle empire, for the crucial role he played in preserving the tule elk species in the years after 1874. For one thing he issued strict orders to his own employees to protect the elk, most of which were then ranging Miller and Lux land. He also offered a $500 reward for information about anyone disturbing them.

The number of tule elk increased rapidly after 1895 and by 1914 it was estimated that they were doing $5,000 to $10,000 worth of damage to Miller and Lux agricultural crops each year. Miller nevertheless continued to protect the elk though he did ask that the herd be limited to 400 animals. He also attempted (with the help of the U.S. Biological Survey, the California Academy of Sciences, and others) to transplant elk to various public parks and zoos. Most of these transplant operations failed in one way or another, although two of them eventually led to the creation of wild, free–ranging herds, one in the Cache Creek area of Colusa County, and one in the Owens Valley on the east side of the Sierra Nevada. Both of these herds are in existence today with about 80 animals in the Cache Creek area and about 400 in the Owens Valley.

The Tupman Reserve

As early as 1912 proposals were made to provide a fence–enclosed preserve for the tule elk then roaming the Buttonwillow area of Kern County near Buena Vista Lake. This seemed to be the best way to prevent even more serious conflict between tule elk and local agricultural interests. Nothing of the sort was accomplished, however, until 1930 when the Miller and Lux ranch owners provided 600 acres for a temporary holding area to be used until a state–sponsored refuge could be established. Tule elk are notoriously hard to round up or drive, however, so only about 63 elk were ever placed in the Miller and Lux enclosure, while about 100 others continued to roam the countryside.

In 1931 the state legislature passed a bill calling for the establishment of an elk sanctuary, and in March 1932, responding to this directive, the State Park Commission purchased a 953–acre site near the little town of Tupman, California. By the end of August that year the new site, which soon came to be known as the Tupman Reserve, was completely fenced and elk from the temporary (Miller and Lux) enclosure were moved to the new site. The state agency then known as the Division of Fish and Game was assigned to operate the sanctuary and they began by rounding up most of the free–roaming elk in the vicinity so that in all about 140 elk were finally enclosed.

At the time of its acquisition the elk sanctuary was a fairly good example of the last natural habitat of wild, free–roaming tule elk. Water was abundant in Buena Vista Slough along the southern edge of the property and supported a rich growth of willows, cottonwoods, and associated riparian vegetation. Nevertheless, it was soon found that the limited acreage was not sufficient to support 140 tule elk. Forage on the more arid portion of the range was soon depleted and eventually a decision was made to reduce herd size. This situation was further aggravated in 1952 when construction of Isabella Dam on the Kern River virtually eliminated all seasonal flooding in the Buena Vista and Tulare Lake area of the San Joaquin Valley. Within the Reserve itself, all the willows and cottonwoods soon died, and the once–lush riparian habitat along Buena Vista Slough completely disappeared.

In 1954 management of the elk herd – by then reduced to just 41 animals – was turned over to the State Park System and soon afterward a supplementary feeding program was devised in order to keep the elk in good health. Artificial ponds were also created to provide opportunities for the elk to cool off during the heat of the summer and otherwise indulge in their favorite sport of "wallowing."

But today the Reserve is no longer a good example of tule elk natural habitat and for this reason the Department of Parks and Recreation is looking for ways to provide a more spacious and appealing natural environment for the elk. New management and development programs are under consideration for the present reserve, but it now appears that the best long–run solution may well be to locate a new and considerably larger reserve in which to protect and interpret California's unique subspecies of elk.

Natural History

Three kinds of elk are native to Western North America. All are now thought to be members of the same species, *Cervus elaphus*, the red deer of Europe and North America. Each variety, or subspecies, however, does have a distinct range and a set of clearly recognizable characteristics. Rocky Mountain elk, *Cervus elaphus nelsoni*, are somewhat larger than tule elk and are found in the Rocky Mountains and Great Basin area. Some of these elk have been introduced into Monterey, San Luis Obispo, and Shasta Counties. Roosevelt or Olympic elk, *Cervus elaphus roosevelti*, are thought to be the largest variety of elk, and are found in northwestern California, and western Oregon and Washington. A free roaming herd of Roosevelt elk can be seen at Prairie Creek Redwoods State Park. Tule elk, *Cervus elaphus nannodes*, are lighter in color, smaller (550 lbs. for males, 410 lbs. for females), and have shorter coats, larger teeth (apparently an adaptation to their relatively fibrous diet) and a number of other special characteristics, many of which help suit them to their relatively warm, dry natural habitat.

Under natural conditions tule elk tend to form herds of forty to sixty animals within which there is a loose, flexible, but very thoroughly defined social order. Separate systems of dominance or hierarchy are established between cows and between bulls and for the herd as a whole. These relationships are developed and maintained by activities such as eye contact (the direct stare, for instance), or fights that may involve rearing and boxing with the forelegs, or – among the males – head–to–head combat with antlers. Full–fledged fights are relatively rare, however, because most conflicts are resolved by more subtle forms of testing.

Hierarchy systems within the herd favor those individuals that are best adapted to the environment and are therefore of significant long–term adaptive and evolutionary value. Social and cooperative herd behavior is also of great survival value, particularly as protection against predators. Thus the inherited ability of tule elk to work together in the herd situation is as important a characteristic as more obvious physical factors such as height, weight, color, etc.

Communication within the herd is complex and involves all of the senses. Though it may seem surprising, smell seems to be the most highly developed and important of the factors. Nevertheless, sounds (both voluntary and involuntary) and visual signs are used extensively in maintaining and coordination normal activities. While grazing, for instance, each tule elk is able to maintain an agreeable distance from its neighbor and to receive and pass along information about the nature and direction of possible threats – all by means of signs and signals that may seem negligible to a human observer. Chewing and various digestive tract noises – even the faint creak and clicking sound normally made by the animals' hooves – play a role in the quiet symphony of sounds and sights that keeps the herd moving together as a unit. And anything – even a gentle wind – that disrupts or confuses the normal pattern is likely to make the entire herd nervous and edgy.

The Annual Cycle

MOLTING: Each spring tule elk shed their old coats and acquire short, sleek and rather reddish new ones. By October or November this new coat is fully grown and has faded to the light buff color that is a special characteristic of tule elk.

ANTLERS: Only male tule elk carry antlers. These are cast each year during the spring and then regrown. Size increases with age up to about the sixth or seventh year. During regrowth the antlers are covered with velvet and are both sensitive and easily damaged. Velvet is normally shed in late July or early August just prior to the rutting season.

RUTTING: Many behavioral and physiological changes precede the actual breeding season which occurs in middle to late summer (August to early October). In July, while still in velvet, adult bulls join the cow herds. Sooner or later one bull – the master bull – drives all the other bulls out of the herd and then does whatever he can to keep rival bulls away from his harem. This situation continues until the constant demands of herding, defending, fighting and breeding reduce the vitality of the master bull enough that he can be driven off and replaced. This whole mating process is attended by bugling, antler–thrashing and a variety of other highly stylized forms of behavior that are both fascinating and characteristic of elk around the world.

CALVING: Calves are born in the spring (April and May) after a 250–day gestation period. They weigh about 20 to 25 pounds at birth. Normally, the expectant cow leaves the herd at the time of birth and remains more or less solitary until the calf is strong enough to run with the herd. The calf is quite weak and helpless at first but rapidly gains strength so that it can run swiftly and with some endurance two or three weeks after birth. Nursing continues until about September though the calf begins to browse for itself a few days after birth. The spotted coat is shed in late July or August when the calves are about four months old.

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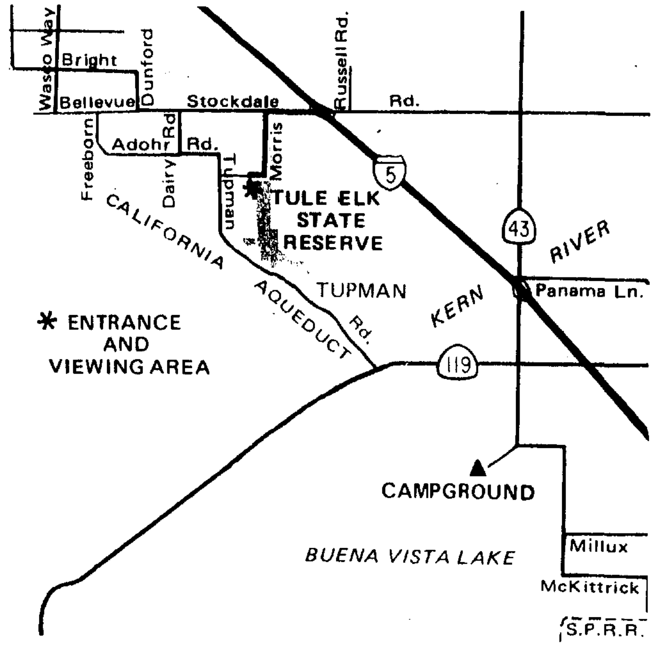

CLOSURE OF A HAZARDOUS WASTE SITE: THE WESTSIDE DISPOSAL FACILITY

S. Knott, F. Krieger, and P. Uribe
Uribe & Associates
Oakland, California

ABSTRACT

This paper describes the closure of the Westside Disposal Facility, owned by Santa Fe Energy Resources, Inc. The Westside site was chiefly used to dispose of locally generated oil field wastes. However, the facility also accepted some non-oil field wastes that are hazardous under the Resource Conservation and Recovery Act (RCRA). Therefore, the site became subject to Federal regulations promulgated by the Environmental Protection Agency (EPA) as well as State regulations administered by the California Department of Health Services (DHS) and the Regional Water Quality Control Boards (RWQCB).

State and Federal regulations require the characterization of site geology and hydrogeology as part of closure. Because the Westside site is located in an oil field, geophysical data from well logs and water quality data from produced fluids were available to assist in site characterization. Three deep boreholes were drilled to the uppermost saturated zone. Because the uppermost groundwater occurs in a low-yield unit, innovative completion techniques were employed to maximize well productivity.

INTRODUCTION

SITE DESCRIPTION

The Westside Disposal Facility is an 80-acre site located in the Midway Valley, part of the Midway-Sunset Oil Field (Fig. 1). The facility operated between 1973 and 1985 and is now undergoing closure. Over 95% of the wastes accepted were from oil producers. The wastes consisted of drilling mud, oil field brine, oil sump and tank bottom sludges, scrubber wastes, acids/bases, solvents, and a relatively small amount of other wastes that included plating wastes.

Most of the wastes accepted at the site were classified as nonhazardous, although several of the wastes contained heavy metals such as chromium, lead, nickel, and vanadium. The plating wastes contain constituents listed as hazardous under the Resource Conservation and Recovery Act (RCRA).

Waste treatment included waste spreading and incorporation into the soil. Since the majority of the wastes consisted mostly of water, evaporation was effective in reducing waste volumes because of the dry climate. A pH of approximately 7 was maintained in the impoundments to promote biodegradation of the oil residues. Acid wastes were sometimes neutralized with lime. When operations ceased, the site consisted of 23 unlined surface impoundments covering approximately 72 acres of the 80-acre quarter-section (Fig. 2). The impoundments at the site have been dry since December 1986.

GEOLOGIC SETTING

The Midway Valley is a syncline flanked on the northeast by the Buena Vista Hills and Elk Hills and on the southwest by the Temblor Range. The site is underlain by approximately 600 feet of alluvial deposits consisting of lenticular and discontinuous bodies of poorly sorted silt, fine sand, and clay, with occasional gravel deposits. At the base of the alluvium is a thick, clay-rich zone.

The alluvium is unconformably underlain by the upper part of the Plio-Pleistocene Tulare Formation. This formation consists of alluvial fan and alluvial plain deposits interbedded with laterally continuous beds of clay, silt, and fine sand. The upper part of the Tulare is an oil-producing formation.

DESCRIPTION OF CONTAMINATION

Sampling data indicate that the waste residuals at the site comprise heavy metals and low levels of organic compounds, including crude oil residues, volatile organics, and halogenated organics. The highest concentration of each constituent occurs within the upper 15 feet of the sediment column, and for most constituents, maximum concentrations were found in the upper three feet. Below 35 feet, most inorganic constituent concentrations are lower than maximum levels measured in off-site background borings. Elevated chloride concentrations, trace organic constituents, and moisture data suggest that liquids from the site may have infiltrated to a depth of approximately 150 feet in some areas. Table 1 summarizes the residual waste constituents at the site.

Sampling data indicate that the heavy metals represent the most significant contamination at the site in terms of persistence and health risk. Although elevated, the heavy metals for the most part have not been detected at concentrations that are high relative to their Total Threshold Level Concentrations (TTLCs).

SUMMARY OF SITE ASSESSMENT

Site characterization is required as part of closure. Several characterization programs have been conducted at the Westside Disposal Facility. A preliminary site characterization consisted of 20 soil borings to depths of 10 feet, with analyses for lead, chromium, zinc, and "oil and grease." Later, 82 boreholes were drilled to varying depths (maximum of 145 feet). Core samples were analyzed for heavy metals, organic compounds, chloride, sulfate, "oil and grease," and moisture.

In addition to these soil borings, four monitoring wells were installed in 1985. Although all were drilled to at least 700 feet, none of the wells produced water on pumping. Water samples were recovered from two of the wells using a sample bailer. Of the two remaining wells, one did not encounter water at all; the other encountered some moisture, but did not yield water samples.

The regulatory agencies (DHS, EPA, and RWQCB) were not satisfied that the site geology and hydrogeology had been adequately characterized by the soil borings and monitoring wells. At one time, an agency geologist suggested that at least 15 deep boreholes might be required for adequate site characterization. Based upon the site location (remote area in an oil field), great depth to groundwater (over 650 feet), relatively low levels of contamination, and the concentration of waste residuals in near-surface sediments, it did not appear that the environmental risk represented by the site warranted extensive and costly deep drilling and sampling at the site.

Table 1. Residual wastes at the Westside Disposal Facility

Heavy Metals	Organic Compounds
Cadmium	Benzene
Chromium	Carbon tetrachloride
Copper	Chlorobenzene
Lead	Chloroform
Nickel	1,1-Dichloroethane
Vanadium	1,1-Dichloroethene
Zinc	Trans-1,2-dichloroethene
	Dichloromethane
	1,2-Dichloroethane
	1,2-Dichloropropane
	Ethylbenzene
	Isopropyl benzene
	Tetrachloroethene
	Toluene
	1,1,1-Trichloroethane
	Trichloroethene
	Trichlorofluoromethane
	Xylenes

As a cost-effective alternative to additional drilling, an extensive characterization of the site was prepared using existing geologic and hydrogeolgic data. The data included driller's and electric logs from the numerous oil wells on and in the near vicinity of the site, as well as geologic maps and hydrogeological reports. After their review of the site characterization report, the agencies agreed that only three additional boreholes would be required to complete the site characterization.

The previous monitoring wells had been installed using standard construction techniques. However, because the uppermost groundwater occurred in a very low-yielding interval, the wells failed to provide water samples on pumping. Therefore, an innovative well construction procedure was proposed and accepted by the agencies. Rather than standard water well completion techniques, which entail using a tremie pipe to install the gravel pack and grout seal, "clean" completion techniques were used to complete the three new boreholes. The "clean" completion techniques consisted of the following steps:

1. Installation and cementing of protective casing to the top of the desired sampling interval;
2. Removal of mud filtrate damage and drilling mud by under-reaming the completion interval with a retractable arm under-reamer;
3. Installation of the screen and gravel pack using water circulation placement techniques.

The three boreholes were to be drilled to the uppermost groundwater, the uppermost zone of oil saturation, or 1,000 feet, whichever came first. The boreholes were continuously cored and geophysically logged with wire-line tools. Core samples were analyzed throughout the depth of the boreholes. Two of the boreholes encountered groundwater at depths below 650 feet and were completed at depths of 687 and 708 feet; the third did not encounter groundwater, but reached oil at about 900 feet. The two boreholes that encountered groundwater were completed as piezometers and water samples were collected. There was no evidence of groundwater contamination by residuals at the site.

Based upon the results of the geologic and hydrogeologic characterization, as well as the supplementary drilling program, the agencies agreed that the site had been adequately characterized and that the groundwater beneath the site was not at risk from site residuals. This was a significant finding, since groundwater is a major focus of agency concern at hazardous, and indeed all, waste disposal sites. The following description of site geology and hydrogeology is based upon data obtained from the three deep boreholes and shallow soil borings, as well as upon previously available geophysical information from oil wells in and on the site.

SITE GEOLOGY

Figure 3 is a schematic diagram of the geology beneath the site. The site is immediately underlain by over 500 feet of unsaturated alluvial sediments. At the base of the alluvium is a clay-rich zone 50 to 100 feet thick.

Underlying the alluvium below 600 feet is the upper part of the Tulare Formation. The upper part of the Tulare Formation is gently folded, with a northwest-southeast trending syncline under the western half of the site and a parallel anticline under the eastern half of the site (Fig. 4). The Tulare sands (labelled the "T-sands" in Fig. 3) contain the uppermost saturated zones beneath the site.

SITE HYDROLOGY

The alluvium was found to be unsaturated throughout, and at least 25 percent of the sediments are moisture deficient, i.e., they contain less water than they would retain if they were originally saturated and allowed to drain by gravity. The existence of moisture-deficient soils and the thick vadose zone indicate that there is no groundwater recharge occurring beneath the site. The lack of groundwater recharge is not surprising, since the Midway Valley receives six to seven inches a year of precipitation and has an average pan evaporation rate of about 95 inches a year (CDWR, 1986).

The uppermost aquifer beneath the Westside site occurs within the upper part of the Tulare Formation in a sandy unit labelled the "T-3" sand. Under the western half of the site, in the structurally low part of the syncline shown in Figure 4, the uppermost saturated zone occurs below 650 feet and is water-bearing. On the eastern half of the site, which is underlain by an anticline, the T-3 sand is unsaturated; the uppermost saturated zone occurs at approximately 900 feet and contains oil.

The T-3 saturated zone was determined to be semi-confined, since the piezometric surface measured in on-site piezometers is above the top of the sand. Water level measurements and information from geophysical logs from nearby oil wells indicate that there is a slight groundwater gradient to the northeast. However, the local groundwater gradient and flow direction may be influenced by oil field activities such as steam and water flooding, which are going on north of the site.

QUALITY OF GROUNDWATER

Total Dissolved Solids (TDS) in the uppermost groundwater beneath the site was measured at between 4,000 and 5,000 parts per million in the two on-site piezometers. The water also contains elevated concentrations of chloride, sulfate, and boron.

REGULATORY BASIS FOR CLOSURE

California hazardous waste site closures are regulated by the EPA under RCRA, the DHS under the Health and Safety Code, and the RWQCB, which administers the Water Code. Generally, site closures follow one of two alternatives: closure-in-place with the wastes capped and monitored; or clean closure by removal and decontamination. In the past, "removal and decontamination" often used background concentrations as the clean-up criteria. Regulations issued by EPA in 1987 re-interpreted the "remove and decontaminate" standard to allow for risk-based cleanup criteria.

EPA has interpreted RCRA's "remove and decontaminate" standard for clean closure of hazardous waste sites based upon the risk posed by the waste residuals to human health and the environment. Thus, site-specific cleanup standards must be developed to protect against adverse risks to human health and the environment. Title 22 and Title 23 of the California Code of Regulations set forth the State regulations governing site closures and are administered by DHS and the Regional Water Quality Control Boards, respectively. These regulations also require "removal and decontamination" for clean closure.

CLOSURE PROCEDURES FOR THE WESTSIDE DISPOSAL FACILITY

Because of the site-specific characteristics of the Westside Disposal Facility, a risk-based closure was believed to be most appropriate for the site, rather than a conventional RCRA closure, which would involve installing a multi-layer cover over the site and monitoring the vadose zone and the groundwater. The geologic and hydrogeologic setting of the Westside site make it naturally protective of groundwater resources and render conventional groundwater monitoring impractical. In addition, the residual waste constituents are present in relatively low concentrations, and there is no surface or groundwater at risk from the site. The uppermost saturated formation produces oil and is used for the reinjection of oil field wastewater.

Given these site characteristics, conventional RCRA requirements are unnecessarily costly and may not provide increased protection to public health or the environment. In addition, because this facility is located in an active oil field, one goal of the site closure is to maximize surface access to the site so that the mineral resources can be extracted.

Therefore, a risk-based approach is being followed to perform an environmentally sound closure that takes into account the unique siting characteristics of this facility. Site-specific cleanup standards have been developed following State and Federal risk assessment guidelines. Variances from the State (DHS) and Federal requirements for groundwater monitoring have also been submitted for the site.

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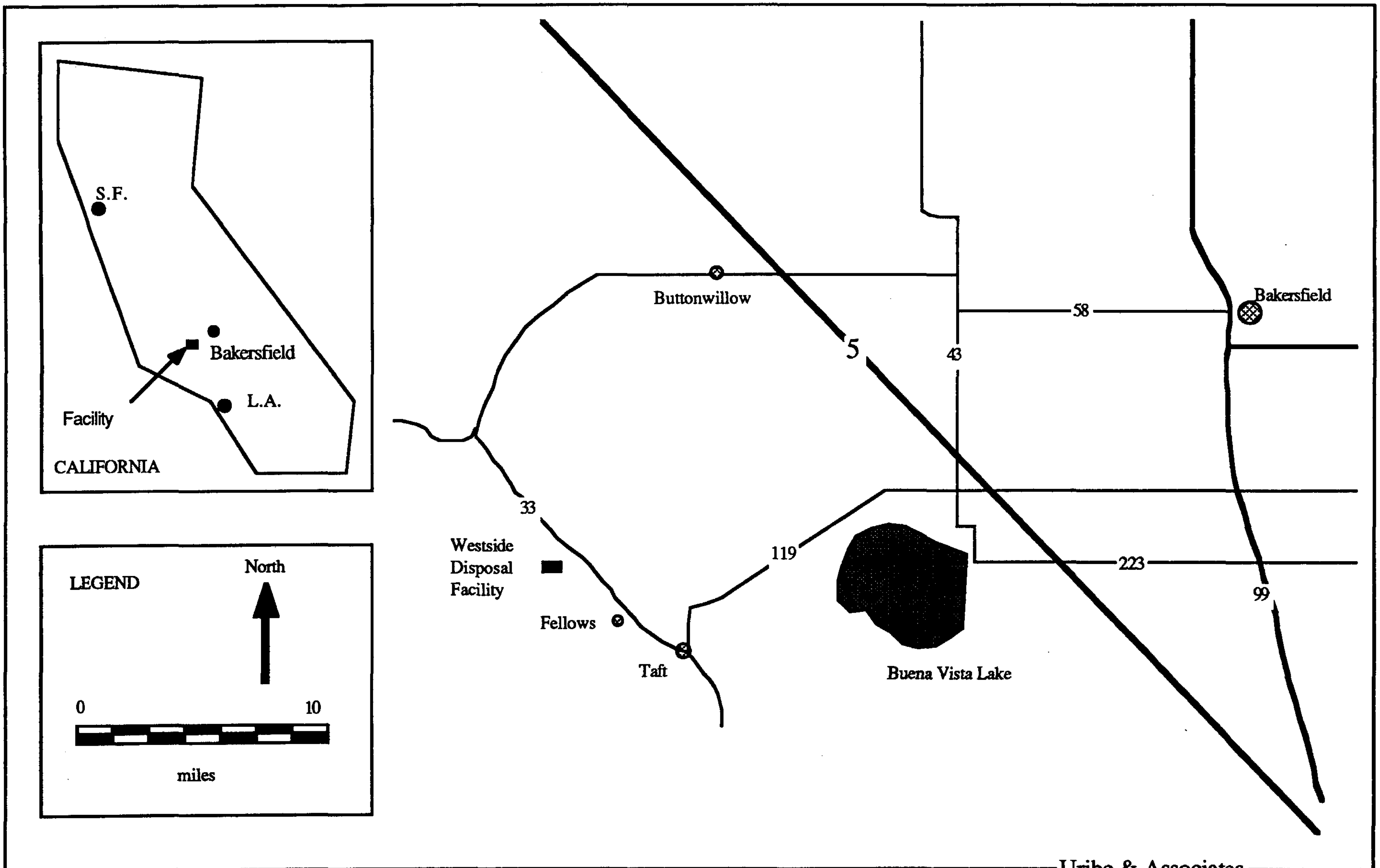

Figure 1 Location of Westside Disposal Facility

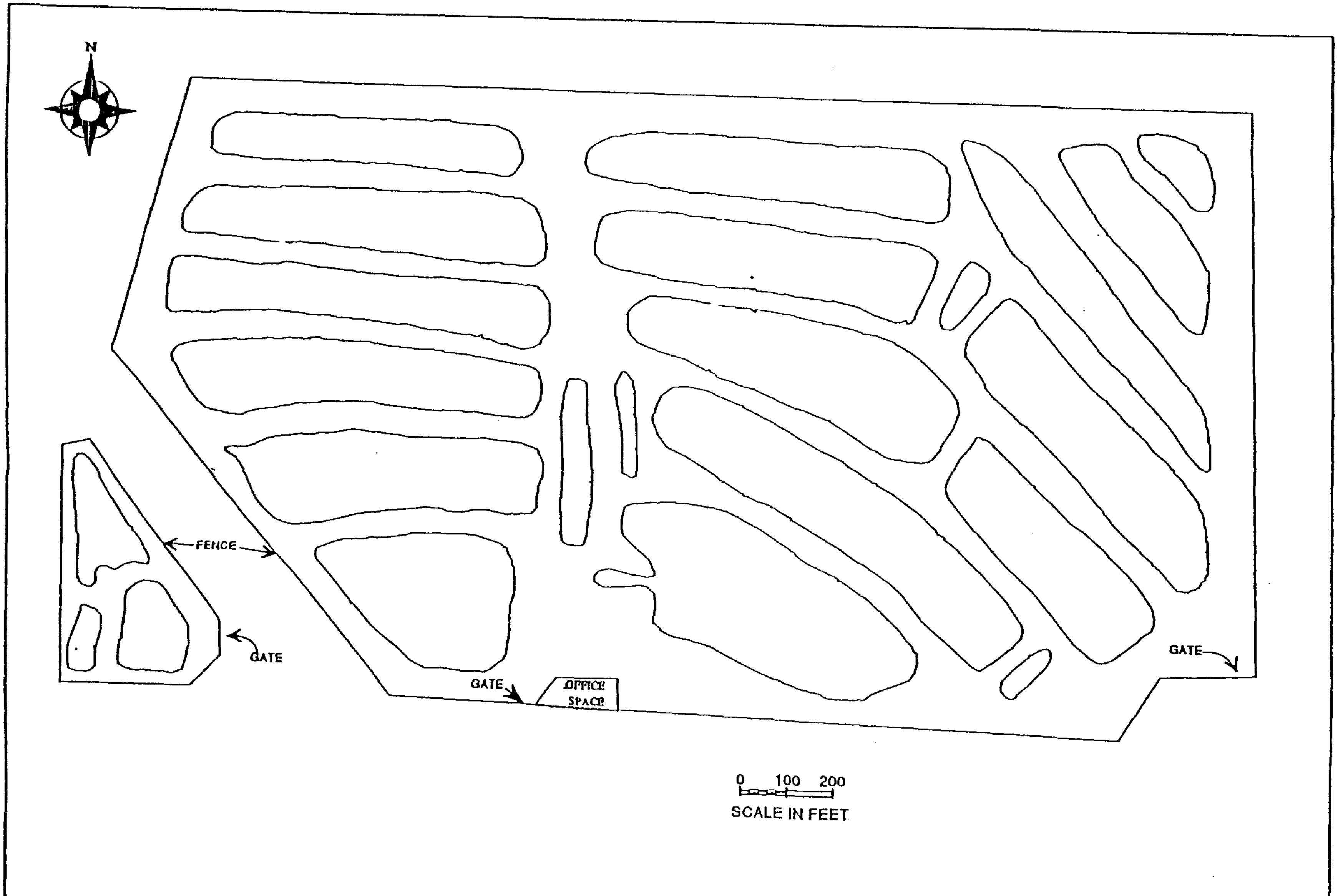

Figure 2 Westside Disposal Facility with Surface Impoundments

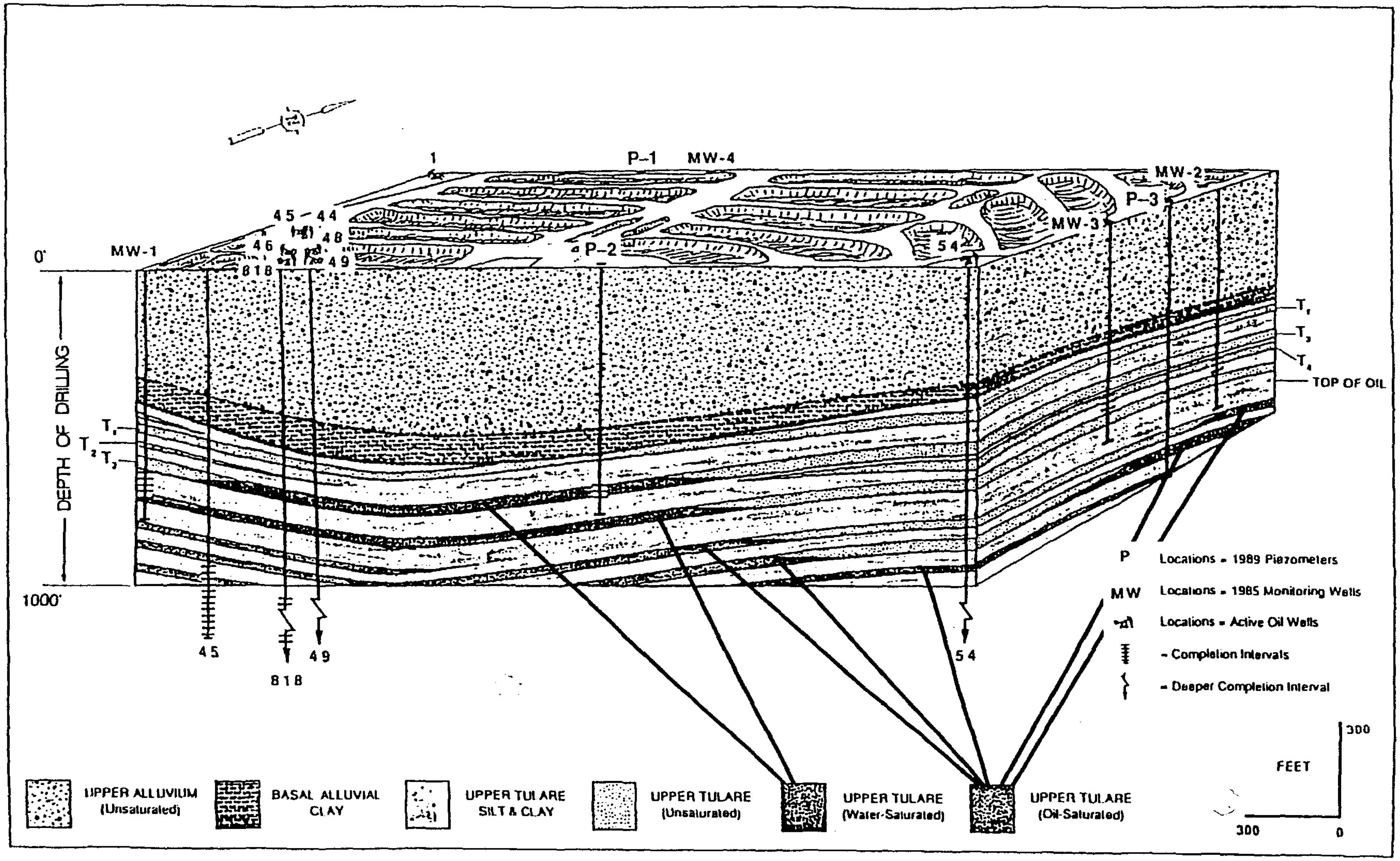

Figure 3 Block Diagram of the Westside Disposal Facility with Impoundments, Well Locations, and Subsurface Geology

(Color versions of this diagram will be available during the site visit)

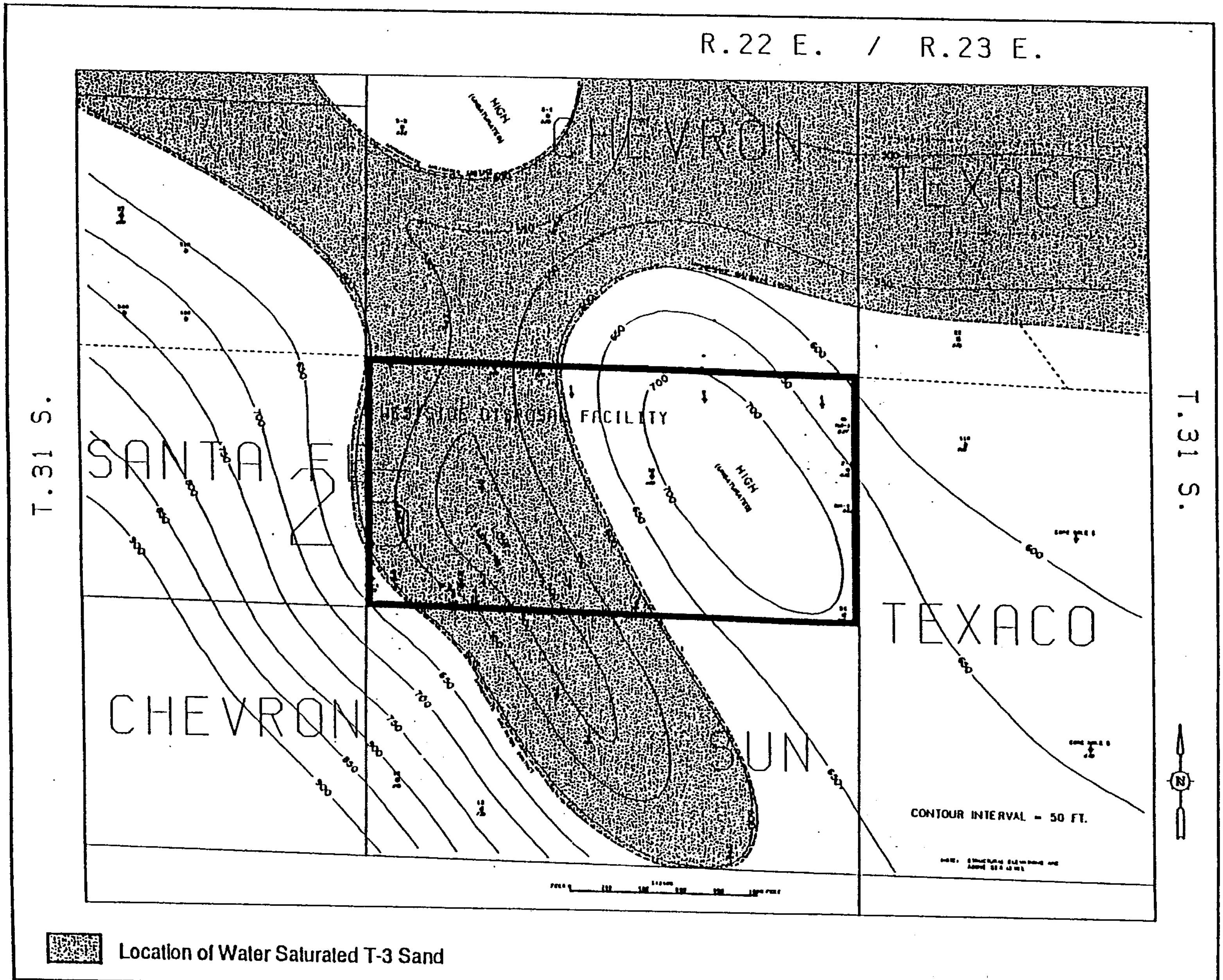

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Figure 4 Structure Contours on Top of the T-3 Sand in the Upper Tulare Formation Showing Water Saturation

An Overview of Lining Systems for Landfills and Surface Impoundments

Sangeeta Prasad Donald E. Hullings, and Richard T. Von Pein
EMCON Associates

INTRODUCTION

Before the 1970's, lining systems were rarely included in landfills and surface impoundments. Such sites generally relied on in situ soils to provide barriers against contaminants leaking from the site and migrating into the ground water. The ground–water level was sometimes close to the base of the landfill or surface impoundment or the in situ soils consisted of materials with relatively high permeabilities, or both. Therefore ground water underlying the site was frequently contaminate.

In 1972, the California State Water Resources Control Board adopted Subchapter 15 (now Chapter 15), "Discharges of Waste to Land," as an addition to Chapter 3 (now Division 3), "Water Resources Control Board," in Title 23, "waters." Chapter 15 was developed as a guideline for governing waste disposal to land and to establish a statewide disposal site and waste classification system. The classification of disposal sites was based on the geologic and hydrogeologic features of the disposal area and its capability to protect surface– and ground–water quality. For disposal sites that could accept hazardous wastes, geologic conditions at the site were required to be naturally capable of preventing vertical migration of liquids and gases emanating from the waste; artificial barriers could only be used to control lateral waste movement. The site could be underlain by usable ground water only in exceptional circumstances.

Requirements for disposal sites accepting municipal waste were different from those accepting hazardous waste. Municipal waste sites could be underlain by usable ground water. Geologic conditions at these sites were required to be either 1) naturally capable of preventing lateral and vertical hydraulic continuity between liquids and gases emanating from the waste to usable surface or ground water or 2) the disposal area had to be lined to prevent migration. Acceptable artificial barriers for municipal waste sites were low permeability clays, plastic geomembranes, or rubber geomembranes.

About the same time as regulations for landfill and surface impoundments were being revised, synthetic liners (geomembranes) gained popularity, primarily for use in canal linings and potable water reservoirs. The most common geomembranes used were chlorosulfonated polyethylene (CSPE, also known by the trade name Hypalon™) and polyvinyl chloride (PVC). The use of these products soon extended to landfills and surface impoundments, which eventually led to the development of new geomembrane types.

Because it resists many chemicals and has relatively good physical properties, high density polyethylene (HDPE) has become the geomembrane of choice to line landfills and surface impoundments. Very low density polyethylene (VLDPE), along with HDPE, is increasingly being used in landfill covers. Although VLDPE has slightly lower tensile strength and chemical resistance than HDPE, it is more flexible, thus allowing for the large deformations which may occur as waste settles.

In 1984, Chapter 15 was modified to its current form. Under Chapter 15, hazardous waste sites require composite lining systems, consisting of low permeability clays overlain by geomembranes, unless an exemption from the prescribed standard is granted. For municipal waste sites, either the natural geology must consist of low permeability soils or a minimum 1–foot–thick layer of low permeability soil with a maximum permeability of 1 x 10^{-6} centimeters per second (cm/sec) must be constructed. A composite lining system is not required for these sites; however, most major landfill companies have adopted composite liners as their minimum requirement. The Environmental Protection Agency (EPA) is expected to soon require composite lining systems for municipal waste sites under their modified 40 Code of Federal Regulations (CFR) Part 257, Subtitle D regulations.

This paper discusses some of the major issues pertaining to the flow of liquids through liners and the construction of clay, geomembrane, and composite lining systems. The low permeability layer and geomembrane are addressed individually, followed by a discussion of composite lining systems. Where applicable, regulatory requirements are included.

CLAY LINERS

Current regulatory requirements governing clay liners are based on permeability, classification, compaction, and construction criteria. However, since the main purpose of a clay liner is to provide a barrier against contaminant migration, the key property is permeability. The following paragraphs discuss factors affecting soil permeability and its relationship to classification, compaction, and construction. A brief discussion of construction quality assurance is also included.

PERMEABILITY

The flow of liquids through a clay liner is described by Darcy's Equation:

$$Q = kIA$$

where

Q = flow rate
k = hydraulic conductivity
I = hydraulic gradient = pressure head/path length
A = cross sectional area perpendicular to flow direction

The most important influence on the flow rate is hydraulic conductivity (also referred to as the coefficient of permeability or permeability). For different soil types the permeability can vary by several orders of magnitude. The hydraulic gradient is defined as the pressure exerted by the liquid on the clay liner divided by the length of the flow path through the clay liner. It is the driving mechanism for liquid flow. In a landfill with an appropriately functioning leachate collection system, the maximum hydraulic gradient will be between 1 and 2 feet. Finally, the quantity of flow is directly related to the surface area of the clay liner; as the landfill size increases, the total flow increases proportionally.

For hazardous waste sites, Chapter 15 requires a maximum natural subsurface or clay liner permeability of 1 x 10^{-7} cm/sec based on appropriate field tests. For the same soil compaction conditions, field permeabilities can be an order of magnitude greater than laboratory permeabilities. These permeability requirements pertain to the liquid (including waste and leachate) that is being contained.

Although low permeability clays can decrease the fluid flow rate, breakthrough of fluid through a clay liner will eventually occur. A typical leakage rate through a municipal landfill clay liner (permeability of 1×10^{-6} cm/sec), with 1 foot of liquid above the 1 foot thick liner, is approximately 2,000 gallons/acre/day (gpad). To minimize leakage, the hydraulic head must be decreased by an effective leachate collection and removal system (LCRS) constructed above the clay liner. However, even with an effective LCRS, the leakage through a municipal landfill clay liner approaches 1,000 gpad.

Factors Affecting Permeability

CLASSIFICATION

The permeability can vary by orders of magnitude depending on the type of soil. For a soil liner, clay is most often used, but mixtures of low permeability clay and coarser soils may meet the permeability requirements. Bentonite is frequently added to reduce the native soil permeability.

Chapter 15 requires that at least 30 percent of the soil material (by weight) passes the Number 200 U.S. Standard sieve and that the material be classified "SC" (clayey sand), "CL" (clay, sandy or silty clay), or "CH" (clay, sandy clay) according to the Unified Soil Classification System (USCS). There is some discrepancy here, since under the USCS, a soil must contain at least 50 percent passing a No. 200 sieve to be classified as a "CL" or "CH" material. In any case, the materials should be fine grained with a significant clay content and no organic matter. Determining the Atterberg limits, which somewhat reflect the soil mineralogy, is required by the USCS to classify soils and thereby decide if a certain soil may be suitable for use in a clay liner. Note that although these factors may relate to permeability, soil samples must be tested in the laboratory to determine their actual permeabilities.

COMPACTION

Permeability depends not only on soil properties, but also on the degree of compaction. Each soil type has unique compaction conditions relating to moisture content, dry density, and compaction effort. The American Standards for Testing Materials (ASTM) test designations D698, "Standard Compaction Test" or D1557, "Modified Compaction Test" are widely used standards for compaction tests.

Figure 1 shows the relationship between dry density, moisture content, and permeability for a typical soil. The maximum dry density and optimum moisture content are also indicated. As shown in Figure 1, the amount of moisture in the soil during compaction significantly affects the permeability. Generally, at the same compactive effort and with increasing moisture content, the soil fabric forms a more compact structure that results in decreasing permeability. For many traditional geotechnical applications, compacting to maximum dry density and near optimum moisture conditions is preferred so that the highest strength and most stable soil layer can be achieved. For liner applications, however, the clay may need to be compacted at a moisture content a few percent above optimum to obtain a lower permeability. Chapter 15 requires that a clay liner be compacted to at least 90 percent of its maximum dry density but does not give a moisture content.

Construction

In the field, the correct compaction operation must be used to obtain the desired permeability results. The equipment used must reduce the size of clay clods that cause discontinuities in the clay liner and adversely affect the permeability. Since the liner is usually placed in lifts of 6 inches or more, the compaction equipment must penetrate to at least this depth so that there is no discontinuity between lifts that could create preferential flow paths. A kneading compactor, such as a tamping foot roller, is therefore the equipment usually specified for liner construction.

The clay liner is constructed to specified grades and thickness. Usually a 2 percent minimum grade is required for adequate drainage of the overlying LCRS. The thickness of the clay liner is generally governed by regulatory requirements. In California, hazardous waste sites require a 3–feet minimum thickness while municipal waste sites only require a 1–foot minimum thickness.

Construction Quality Assurance (CQA)

Chapter 15 requires that the construction of lining systems be supervised and certified by a registered civil engineer of certified engineering geologist. The registered civil engineer's or certified engineering geologist's representative in the field is the construction monitor. The construction monitor observes the construction of the clay liner for items such as loose and compacted lift thickness, adequate bonding between lifts, and the occurrence of dessication cracks on the finished clay liner surface. The monitor also arranges or performs specified construction testing, which, at a minimum, includes permeability, in–place density, moisture content, and particle size.

SYNTHETIC LINER

Geomembranes are relatively impermeable flexible sheets made from plastic or rubber. In some situations geomembranes can substitute for a clay liner or, as discussed later, can be used in conjunction with a clay liner to produce a more effective lining system. Geomembranes are delivered to a site in large rolls or folded panels and then placed and seamed together. Although a wide variety of geomembranes is available, the most commonly used geomembrane in landfills and surface impoundments is HDPE. We will therefore limit our discussion to this material. The following paragraphs discuss the mechanism of flow through a synthetic liner, properties of HDPE geomembrane, and synthetic liner construction and CQA.

Flow Through A Synthetic Liner

Liquids travel through the synthetic liner on a molecular level due to differences in hydraulic and vapor pressure on either side of the geomembrane. Although the exact mechanism is unknown, the measured flow rates are much lower than through a clay liner. "Permeability" as applied to soil, does not apply to geomembranes. For comparison, however, an "equivalent hydraulic conductivity" for synthetic liners is about 1×10^{-12} to 1×10^{-14} cm/sec, much lower than a clay liner. Assuming 1–foot of liquid above the geomembrane, significantly less than 1 gpad of leakage will occur through an intact HDPE geomembrane.

Most leakage through a geomembrane occurs through geomembrane defects. Flow through defects is calculated using the orifice equation in which the flow rate depends on the area of the defect and the pressure head. Defects may be caused by poor seaming, construction damage, punctures, tears, environmental stress cracking (ESC), and tensile failures. A "good" liner is estimated to have one standard size defect (area of 1 square centimeter) per acre. The flow through a standard defect, assuming the geomembrane is between two pervious media and a 1–foot head is applied, is 3,000 gpad. Comparing this to the diffusion leakage rate of less than 1 gpad emphasizes the importance of minimizing defects.

HDPE

The only Chapter 15 material property requirement for synthetic liners is that the minimum thickness be 40 mils. The thickness can be related to the geomembrane's "equivalent hydraulic conductivity," however, as discussed previously, most flow occurs through geomembrane defects. The flow rate through defects is indirectly related to the geomembrane thickness since defects are more likely in thinner geomembranes. That is, as the geomembrane thickness increases, the physical properties (tensile strength, puncture resistance, tear resistance) increase and the number of defects decreases. Although 40–mil HDPE is available, 60–mil or 80–mil HDPE geomembranes are more commonly used because of their better physical properties. They are also easier to install and seam. Also available are 100– mil and 120–mil HDPE, however, at the higher thicknesses the geomembrane becomes relatively inflexible and is more difficult to install.

In addition to the geomembrane's thickness, the designer usually specifies tensile properties, including tensile strength, elongation, and tear and puncture resistance. Although the geomembrane should not be designed as a structural member to resist stresses, some stress on the geomembrane cannot be avoided and a certain amount of tensile strength is required. Since the geomembrane is often placed in conditions which are not ideal, tear and puncture are important.

Another group of generally specified material properties relate to the ability of geomembranes to endure environmental conditions such as ultraviolet (UV) radiation and fluctuations in temperature. Carbon black is almost always added to HDPE to protect it from degrading when exposed to UV radiation. If too much carbon black is added, however, other material properties may be reduced. HDPE also expands and contracts with temperature fluctuations (a rule of thumb is a 1 foot change in length per 100 feet of material per 100 degree temperature change). These cyclic expansions and contractions create wrinkles in the geomembrane panels, often at the toe of a slope, and can lead to seam failure.

Construction

HDPE geomembranes are manufactured at a plant in approximately 11– to 33– feet–wide rolls weighing about 3,000 pounds. The rolls are transported to the site where they are deployed, cut into panels, and then seamed together. Because HDPE installation requires specific skills, geomembranes are generally installed by specialized contractors. The HDPE manufacturer often has its own installation crews.

There are several important aspects to constructing an HDPE liner: 1) the panels must be sized to minimize the number of seams and irregularly shaped pieces; 2) since wind can easily lift HDPE and tear or damage it adjoining panels are seamed immediately after placement and sandbags are placed on top of any free edges; and 3) allowance must be made for the thermal expansion and contraction behavior of HDPE. HDPE installed and anchored in place in warm temperatures will contract when the temperature decreases and may stress the seams, possibly causing seam failure. Conversely, if the panels are deployed under cool conditions, and not seamed until the temperature increases, wrinkles will form in the panels due to the expanding material. It is important to consider temperature when designing and installing HDPE geomembrane.

Since most geomembrane defects occur at the seams, seaming is the most important construction activity. The most common seaming processes are hot wedge (also known as fusion) and extrusion welding. Hot wedge welding is performed for long, straight seam lengths. The weld is formed by inserting a small hot wedge in the overlap of two adjacent panels. The hot wedge is moved along the seam length, and as it moves it melts some of the polymer from the underlying and overlying sheet. A pair of rollers pass behind the wedge and presses the geomembrane sheets together. Once the principal method of seaming HDPE, extrusion welding is now used mainly for detailed work or in areas where access is limited. In the extrusion method, hot HDPE resin is extruded over the overlap between adjacent panels. As the hot resin is extruded it mixes with the resin in the geomembrane sheet. The entire mass cools to form the completed seam. Before extrusion welding can begin, the edge of the geomembrane panels are ground to remove any oxidants and waxes that may have migrated to the geomembrane surface and could adversely affect the seam.

Construction Quality Assurance (CQA)

As with the clay liner, Chapter 15 requires synthetic liner construction to be supervised and certified by a registered civil engineer or certified engineering geologist. Even without the regulatory requirements, a good CQA program is crucial since it reduces the number of liner defects, thus minimizing the leakage rate.

A good CQA program consists of several items. First, the specified material properties are verified by an independent laboratory. Second, since seaming is the most important aspect of synthetic liner construction both nondestructive and destructive testing is completed. Nondestructive testing, consisting of vacuum testing for extrusion welded seams and pressure testing of wedge welded seams, is performed on 100 percent of the seams. Destructive testing consisting of removing samples and testing for tensile properties, is conducted at seam intervals of about 500 feet.

COMPOSITE LINERS

The composite liner, consisting of a low permeability soil overlain by a geomembrane, is a significant improvement over either a clay or geomembrane liner. The following sections describe the flow mechanism through a composite liner and compare typical geomembrane, clay, and composite liner leakage rates.

Flow

As discussed in the synthetic liner section, almost all leakage through a geomembrane occurs through defects. In a composite liner, the fluid first migrates through a defect in the geomembrane and then spreads laterally, if there is space between the geomembrane and clay. Once between the geomembrane and clay, fluid flows into and through the clay liner. The distance the fluid can flow laterally depends on the contact between the two materials. Perfect contact is nearly impossible because of two major construction constraints. First, wrinkles develop in the geomembrane due either to temperature fluctuations (which cause geomembrane expansion and contraction) or to placement procedures. Second, constructing a perfectly smooth clay surface is difficult. Fortunately, the overburden materials usually placed above the geomembrane aid in providing a reasonable contact.

Leakage Rate Comparison

The amount of leakage through the composite depends on the number of geomembrane defects, the clay liner permeability, the geomembrane and clay contact, and the hydraulic head. As discussed previously leakage rates for a municipal landfill clay liner can be as high as 2,000 gpad and for a geomembrane alone with one standard size defect nearly 3,000 gpad. These values are obtained assuming 1 foot of liquid above the liner. In comparison, a well constructed composite liner would have a leakage rate on the order of 0.1 gpad. Even under less than ideal conditions a composite liner would have a leakage rate of less than 1 gpad. This does not imply, however, that the quality of composite liner construction is not important. Without proper CQA, the number of defects per acre would significantly increase and an increased leakage rate could be expected.

SUMMARY

This paper has provided general information regarding the history and current practices for lining landfills and surface impoundments with clay, geomembrane, and composite liners. It is not intended to be all inclusive, nor to provide comprehensive information on lining systems. Most of the information presented has emphasized flow through liners, construction criteria, and CQA aspects. Where applicable, regulatory requirements were included. The different liners were also compared. The results of the comparison show that under similar conditions, composite liners allow less leakage than either clay or geomembrane alone.

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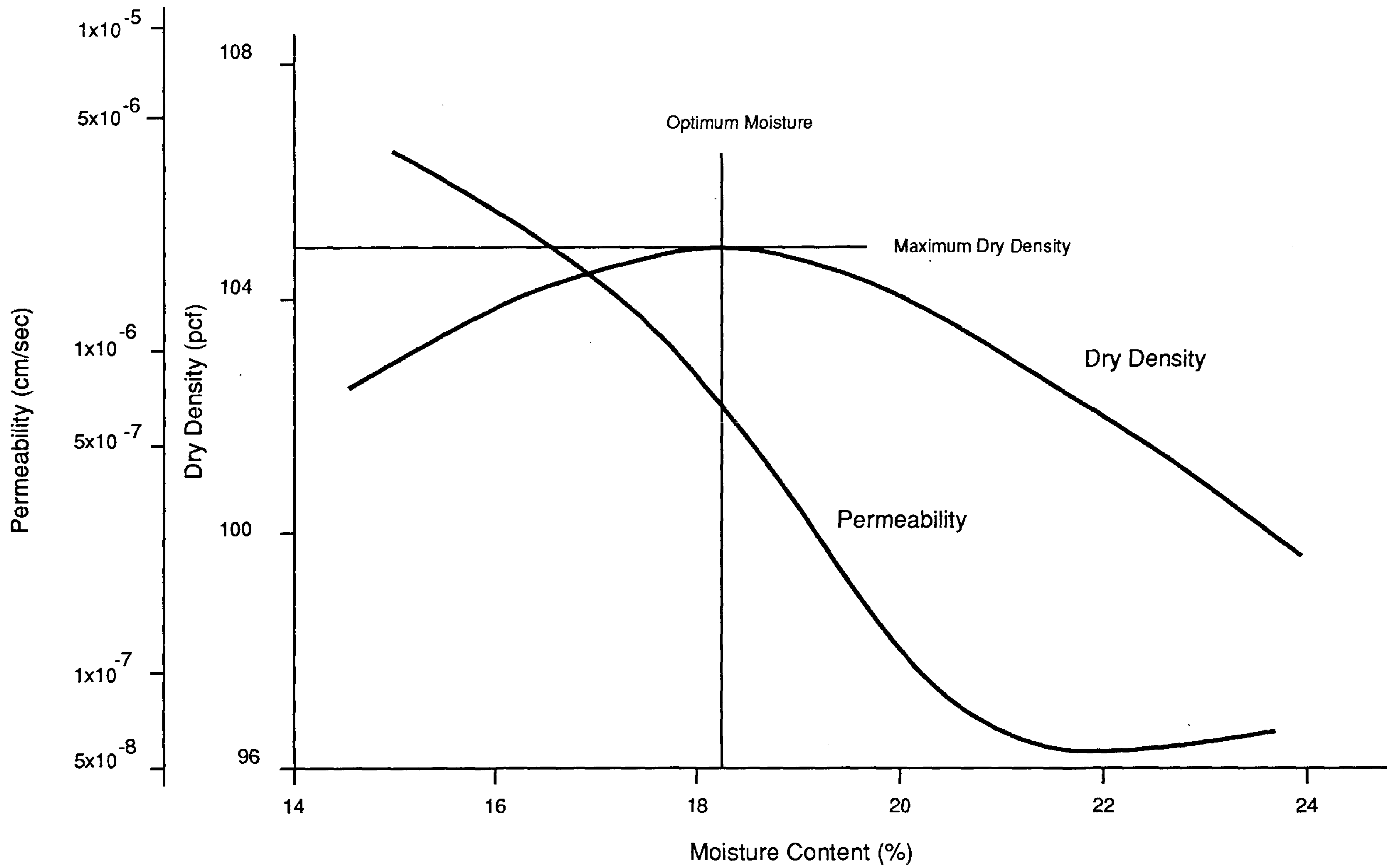

Figure 1. Relationship Between Permeability, Dry Density and Moisture Content

Geology and Environmental Monitoring of the Lokern Facility

Marianna Buoni
Laidlaw Environmental Services
Buttonwillow, California

Julie Hayes and Dave Harnish
Environ
Emeryville, California

HISTORICAL SUMMARY OF FACILITY ACTIVITIES

The facility was originally developed by Petroleum Waste, Inc., a subsidiary of McKittrick Mud Company (McKittrick Mud), on land owned by McKittrick Mud. In February 1986, McKittrick Mud became a wholly-owned subsidiary of International Technology Corporation (IT). On June 21 1989, the facility, land and assets were purchased by GSX Services of California, Incorporated, a wholly-owned subsidiary of GSX Services of California. On April 17, 1990 the cooperation changed its name to Laidlaw Environmental Services (Lokern) Inc.

Location and Description

The facility covers 320 acres, encompassing the east half of Section 16, T29S, R22E, MDB&M. The property is owned by Laidlaw Environmental Services, (Lokern), Inc. The facility is on the north side of Lokern Road (2500 West Lokern Road), approximately 4 miles west of its intersection with State Route 58. The nearest population center is Buttonwillow, approximately 7 miles east of the site. Land uses in the vicinity of the site have included irrigated and unirrigated grazing, irrigated cropland and petroleum exploration.

A substantial amount of hydrogeologic investigative work has been completed at the facility. The investigations have included borings, geologic mapping, and lab and field tests. The mean annual precipitation at the site is 5 inches and the average annual evaporation is 108 inches. The probable maximum precipitation in a 24-hour period is 5.36 inches. The nearest surface water, the California Aqueduct, is 1/2 mile northeast of the site, at its closest point.

History

The facility operates as a treatment and disposal facility for hazardous and nonhazardous wastes. The facility has been used for land disposal of liquid and solid hazardous wastes since 1983. Volume reduction by solar evaporation has been the primary process for liquid waste treatment. Land disposal has been conducted in two ways: 1) depositing liquids, sludges and solids in surface impoundments; and 2) depositing solids in a landfill.

A wide variety of designated and hazardous wastes generated in petroleum exploration, production, refining, and marketing operations are currently disposed of at the facility. Wastes with organic lead concentrations that exceed 100 mg/kg, extremely hazardous waste, and waste with a pH less than 2.1 or greater than 11.0 are prohibited from being discharged into surface impoundments at the facility.

Waste Management Unit (WMU)

Existing WMU's liner systems consist of the following elements (described from bottom to top):

Surface impoundments 1 through 13, and 15 have 24 inches of native soil compacted to a permeability of 1×10^{-6} cm/sec, a 20 mil polyvinyl chloride – oil resistant (PVC-OR) synthetic liner, and 12 inches of protective soil cover.

Surface impoundments 14, 16 and 17 have 24 inches of native soil compacted to a permeability of 1×10^{-6} cm/sec, a 20 mil PVC-OR synthetic liner, 18 inches of uncompacted soil, a 20 mil PVC-OR synthetic liner, and 18 inches of protective soil cover.

Surface impoundments 18 and 21 have 24 inches of native soil compacted to a permeability of 1×10^{-6} cm/sec, a 30 mil PVC-OR synthetic liner, 18 inches of uncompacted soil, a 30 mil PVC-OR synthetic liner, and 12 inches of protective soil cover.

Surface impoundment 19 has 24 inches of native soil compacted to a permeability of 1×10^{-6} cm/sec, a leachate collection and removal system (LCRS), a 30 mil PVC-OR synthetic liner, 24 inches of compacted soil (no specified permeability), a 30 mil PVC-OR synthetic liner, 24 inches of compacted soil (no specified permeability), a 30 mil PVC-OR synthetic liner, and 24 inches of compacted soil (no specified permeability).

Surface impoundments 20, 24, 25 and T-1 have a 24-inch clay liner compacted to a permeability of 1×10^{-7} cm/sec, a leachate collection and removal system, a 40 mil PVC-OR synthetic liner, a 24-inch clay liner compacted to a permeability of 1×10^{-7} cm/sec, a 40 mil PVC-OR synthetic liner, a 24-inch clay liner compacted to a permeability of 1×10^{-7} cm/sec, a 30 mil PVC-OR synthetic liner, and a 24-inch, compacted, protective soil cover (no specified permeability).

Surface impoundments 22, 23 and 27 have 24 inches of native soil compacted to a permeability of 1×10^{-7} cm/sec, a 40 mil PVC-OR synthetic liner, 24 inches of compacted soil to a permeability of 1×10^{-7} cm/sec, a 40 mil PVC-OR synthetic liner, and 24 inches of compacted, protective soil (no specified permeability).

Unit 28, a landfill, has a 36-inch clay liner compacted to a permeability of 1×10^{-7} cm/sec, a 40 mil PVC-OR synthetic liner, a secondary (LCRS, a 40 mil PVC-OR synthetic liner, a 36-inch clay liner compacted to a permeability of 1×10^{-7} cm/sec, a 40 mil PVC-OR synthetic liner, a primary LCRS, geotextile and a 24-inch, protective soil cover (no specified permeability).

Surface impoundment 31 has a 24-inch clay liner compacted to a permeability of 1×10^{-7} cm/sec, a 40 mil PVC-OR synthetic liner, a 36-inch clay liner compacted to a permeability of 1×10^{-7} cm/sec, a 40 mil PVC-OR synthetic liner, a LCRS, a 40 mil PVC-OR synthetic liner, a 36-inch clay liner compacted to a permeability of 1×10^{-7} cm/sec, a 40 mil PVC-OR synthetic liner, and a 24-inch, protective soil cover (no specified permeability).

WMU 26 and R1-4 are the only WMUs to date which have been closed. All other WMUs are either active (Surface impoundments 18, 21, 22, 23, 27, 31 and Landfill 28), inactive, pending clean closure and the future construction of landfills (Surface impoundments 1 through 17, 19, 20, 24, 25, and T-1).

Future Operations

Modification of the Laidlaw Environmental (Lokern) Facility will include the following main elements:

Conversion of hazardous WMUs at the facility from liquid hazardous waste disposal to solid hazardous waste disposal by retrofitting 20 existing WMUs into new landfills and operating additional new landfills in previously undeveloped areas of the facility.

Operation of a new stabilization treatment unit (STU) liquid and solid wastes to stabilize, to render wastes less toxic, and/or to render the toxic constituents less mobile prior to land disposal. The STU will include a drum handling storage area (DHSA) for storage of hazardous waste containers prior to the processing of their contents in the containers in the STU. The STU will allow for the receipt, temporary storage, and processing of wastes that cannot be disposed of directly in a landfill due to restrictions in 40 CFR 268 and Title 22, California Code of Regulations, Section 66900. The STU will include a truck wash station, waste receipt tanks, waste processing equipment, containers for treated wastes at the treated waste handling area, and treated waste container handling equipment.

Additional facility improvements include closure of twenty existing WMUs, upgrade of support facilities including roads, truck receiving construction of a new laboratory facility and construction of new landfills.

Operation of nonhazardous Class II surface impoundments will continue.

Regional Geology and Hydrology

The Laidlaw Environmental Services (Lokern), Inc. facility lies on the Antelope Plain on the southwestern flank of the San Joaquin Valley at an elevation of approximately 400 feet above sea level (Fig. 2). In the vicinity of the facility, this gently sloping plain has been mapped as Quaternary alluvium underlain by the Plio–Pleistocene Tulare Formation (Wood and Davis, 1959).

The Quaternary sedimentary sequence was derived from reworked alluvial fan, flood–basin, and deltaic deposits which originated from older formations encountered in the Coast Ranges to the west (Page, 1986). Underlying the Quaternary alluvium is the Tulare Formation. The Tulare Formation is of similar origin as the Quaternary alluvium but includes an additional thick series of lacustrine sediments which were deposited by historic portions of Tulare Lake. Within the lacustrine sequence of the Tulare Formation, several clay layers have been identified, including the Corcoran Clay (Croft, 1972). On a regional hydrological basis, the massive Corcoran Clay is considered a confining layer for a lower aquifer. Based on structural and paleontological characteristics, it appears that the silts and sandy silts found in the upper 30 to 120 feet at the facility are a portion of the Quaternary sequence and that the underlying sandier sediments represent the transition from the Quaternary alluvium to the Tulare Formation.

Regional mapping by Rector (1983) shows that the Tulare Formation is approximately 2,000 feet thick in the vicinity of the Lokern facility, and gently dips to the northeast (Fig. 2). Data from the facility indicates that a massive clay is approximately 600 feet deep near the site. This clay may be equivalent to the Corcoran Clay, however, maps from the Kern County Water Agency, 1988 Water Supply Report (1989) show the Corcoran Clay pinching out before it reaches the facility.

Regionally, the major direction of groundwater flow is from the western margin of the valley to the east towards the axis of the valley basin. The quality of groundwater in this margin area of the Central Valley is poor with high total dissolved solids making it unsuitable for irrigation.

Local Geology and Hydrogeology

Local nomenclature has been developed for the near–surface hydrologic and stratigraphic units below the site. Three distinct stratigraphic units, each characterized by the presence of a water–bearing zone, are identified within the upper 600 feet of the sedimentary sequence below the site. These hydrologic and stratigraphic zones are shown on the site block diagram in Figure 2, in the generalized stratigraphic column illustrated in Figure 3, and on the cross section in Figure 4. All beds dip gently to the northeast.

The two highest water–bearing zones are perched with respect to the water table and present only in the northern one–third of the facility. These two zones are greater than 120 feet deep and are referred to as the Upper and Intermediate Perched Zones. The true water table underlies most of the facility at depths between 240 feet and 275 feet, and is referred to as the Lower Water Table Zone.

UPPER ZONE

The Upper Zone is the shallowest stratigraphic zone and consists of a Silt Unit and an Upper Sand Unit. The Upper Zone extends from the ground surface to a depth of approximately 70 to 200 feet (Figs. 2 and 4). The Upper Sand Unit is saturated only in the northern area of the site; as the base of the unit dips below approximately 230 feet Mean Sea Level (MSL) it intercepts a perched water zone which sits on top of the Upper Clay Layer (Fig. 4). This zone of saturation is known as the Upper Perched Zone. Within this area, perched ground water is encountered between approximate depths of 115 and 143 feet below ground. The Upper Perched Zone is under unconfined conditions and portions of it overlie unsaturated sediments of the Intermediate Zone. The overall direction of groundwater flow is toward the east at a velocity of approximately 10 feet per year.

INTERMEDIATE ZONE

The Intermediate Zone is the next down in the stratigraphic sequence and is composed of the Upper Clay Layer, the Intermediate Unit, and the Lower Clay Layer. The Intermediate Zone varies in thickness from 35 to 65 feet (Fig. 4). The Upper Clay Layer, which ranges in thickness from 2 to 15 feet, acts as an aquitard separating the Upper Perched Zone from the Intermediate Perched Zone (discussed below). The underlying Intermediate Unit is approximately 30 to 40 feet thick and consists mainly of sandy silt with occasional thin interbeds of clay and fine sand. Below the Intermediate Unit lies the Lower Clay Layer which ranges in thickness from 4 to 12 feet and also acts as an aquitard across the site, separating the Intermediate Perched Zone from the Lower Water Table Zone (discussed below).

Like the Upper Sand Unit, the Intermediate Unit is dry in the southern two–thirds of the site. However, as the base of the unit dips below approximately 185 feet MSL, it intercepts a perched water zone (Fig. 4). This zone of saturation is known as the Intermediate Perched Zone. In the northern area of the site, the top of the Intermediate Unit dips below the potentiometric surface, and groundwater in the Intermediate Perched Zone becomes confined (Fig. 4). The direction of groundwater flow in the Intermediate Perched Zone is predominantly to the south and east at a velocity of approximately 20 feet per year.

LOWER ZONE

The Lower Unit extends from the base of the Lower Clay Layer of the Intermediate Zone to the top of a very fine-grained unit, possible the regional Corcoran Clay, which occurs at a depth of approximately 600 feet below ground. The average thickness of the Lower Zone across the site is approximately 400 feet (Fig. 4). The Lower Unit is composed of interbedded sands, silts, and clays which vary in thickness from 2 to 50 feet. Some of the thicker sand beds (30 to 40 feet) can be correlated between wells, but most beds are relatively thin and pinch out between monitoring wells.

The Lower Water Table Zone occurs in the Lower Unit. Groundwater is present in the Lower Zone below the entire site and is encountered between approximate depths of 240 and 275 feet below ground (Fig. 4). Groundwater occurs under a combination of unconfined, semi–confined, and confined conditions, depending on location. Confined conditions become prevalent in the far northeastern portion of the site, where the Intermediate Zone Lower Clay Layer, acting as a confining unit, dips below the potentiometric surface of the zone (Fig. 4) Groundwater flow in the Lower Water Table Zone is toward the northeast at an average velocity of 50 feet per year.

Subsurface Environmental Monitoring

The unsaturated zone and the three upper groundwater zones beneath the Lokern facility are extensively monitored as required in the facility permits, and according to other federal and state regulations and guidance.

UNSATURATED ZONE MONITORING

Unsaturated zone monitoring is the second level of the leak detection system for leakage from WMUs, after the LCRS. The moisture content of the unsaturated or "vadose" zone soils beneath the WMUs at the Lokern facility is monitored using a system of access tubes built into the soils beneath the landfills. A neutron probe detector is periodically lowered into the access tubes and is designed to detect any increase in moisture content. The purpose of this early warning monitoring system is to highlight a potential release before it reaches the groundwater beneath the site.

Vadose zone monitoring is currently being conducted at the recently constructed WMU 33 (Fig. 1) and additional plans for vadose zone monitoring systems have been submitted to state and federal agencies. Moisture content will be monitored monthly and, after sufficient background data has been collected, will be reduced to quarterly. The data will be compared to background moisture content measurements and reported to state and federal agencies.

If an increase in moisture content beneath a WMU is detected at any time during the monitoring program, the Lokern facility must take the following steps: 1) local, state, and federal agencies will be notified within 7 days of determination of an increase in moisture content; 2) a retest of the vadose zone beneath the WMU will occur within 30 days; and 3) if the results of the retest still indicate an increase in moisture content beneath the WMU, a plan for additional assessment of the problem will be submitted to the state and federal agencies within 30 days. This plan will involve drilling a borehole near the area where the moisture increase was detected and collecting soil samples for chemical tests. These soil samples would be analyzed for hazardous constituents that would be indicative of leachate from the WMU.

GROUNDWATER MONITORING

The twenty-two monitoring wells and twenty-six piezometers are mostly screened across the uppermost portion of the three upper water-bearing zones (Fig. 5). The design facilitates detection of any potential impact to groundwater early, before it has a chance to migrate downward. The spacings between wells was developed after extensive finite-element model simulations of various landfill leakage scenarios. A "worse-than-worst" case landfill leak scenario was modeled using known and estimated soil and aquifer characteristics so the resulting groundwater plume could be evaluated for its elongation and width when it reached the point of compliance. The modeled plume width was the basis of the well spacings.

Nine of the monitoring wells are background wells located upgradient of facility operations. Seventeen of the monitoring wells are located downgradient of WMUs. The Upper Perched Zone contains 10 piezometers, 4 background wells, and 9 point-of-compliance wells; the Intermediate Perched Zone contains 6 piezometers, 2 background wells, and 1 point-of-compliance well; and the Lower Water Table Zone contains 6 piezometers, 3 background wells, and 7 point-of-compliance wells.

Groundwater flow and groundwater quality in each of the three zones are monitored every three months. Water elevations are measured to provide information on groundwater flow direction and flow rate. Groundwater samples are also collected quarterly from the monitoring wells and tested for 35 organic and 40 inorganic chemicals some of which are known characteristic components of the landfilled wastes. The results of these regular analyses are checked carefully against background values to determine if groundwater quality at the Lokern facility has been affected by waste disposal activities. Results of the groundwater monitoring are reported to local, state and federal government agencies. To date there has been no evidence of impact on groundwater by the Lokern facility.

Monitoring Well Construction

During 1990, 10 monitoring wells and 2 piezometers were installed at the Lokern facility. Wells were constructed in two stages, to assure that the well was constructed to account for actual hydrogeologic conditions. The procedures are discussed below.

First, pilot borings were drilled using mud rotary techniques. The pilot boring was continuously cored and logged by a geologist and geophysically logged upon completion. Each completed core was reviewed and correlated with geophysical logs and other core descriptions. After the hydrogeologic correlations were complete, the well was designed appropriately. Each well had a custom-designed filter-pack and slotted screen based on grain size analysis from the sediments in the screened interval. This assured maximizing well efficiency and minimizing turbidity of samples. All pilot borings were grouted to the surface following completion.

Monitoring wells and piezometers were then installed using air rotary casing hammer (ARCH) methods. Compared to other methods, this drilling method is excellent for finding first water, and does not develop much of a mud cake on the borehole wall. The ARCH system involves rotary drilling with air through a temporary steel drive casing. The drill bit and casing are advanced together to provide a stable, clean borehole.

At the design depth of the well the drill rods were removed, but the drive casing was left in the hole to maintain the open boring. Steam-cleaned PVC casing was then installed with stainless steel centralizers placed at regular intervals. Monitoring wells completed in the Upper Perched Zone were constructed of 2-inch diameter PVC casing. Monitoring wells and piezometers completed in the Intermediate Perched and Lower Water Table Zones were constructed of 5-inch diameter PVC casing. The sand pack was tremied into the annulus from the bottom of the borehole to two feet above the top of the screen. A five-feet thick, pelletal bentonite seal was placed immediately above the sand pack, placed slowly with water regularly introduced to ensure proper hydration. A 20-foot-thick, bentonite slurry seal was then emplaced above the bentonite pellets with a tremie pipe. The remaining annulus was grouted with a cement-bentonite slurry. While the sand pack, bentonite, and cement-bentonite slurry were added to the annulus, the drive casing was slowly removed from the borehole.

Finally, the ten new wells and two piezometers were developed so they would produce clear water by a combination of surging, pumping, and bailing. Well development was considered to be complete once the turbidity and the water quality parameters stabilized and a prescribed minimum volume of water was removed.

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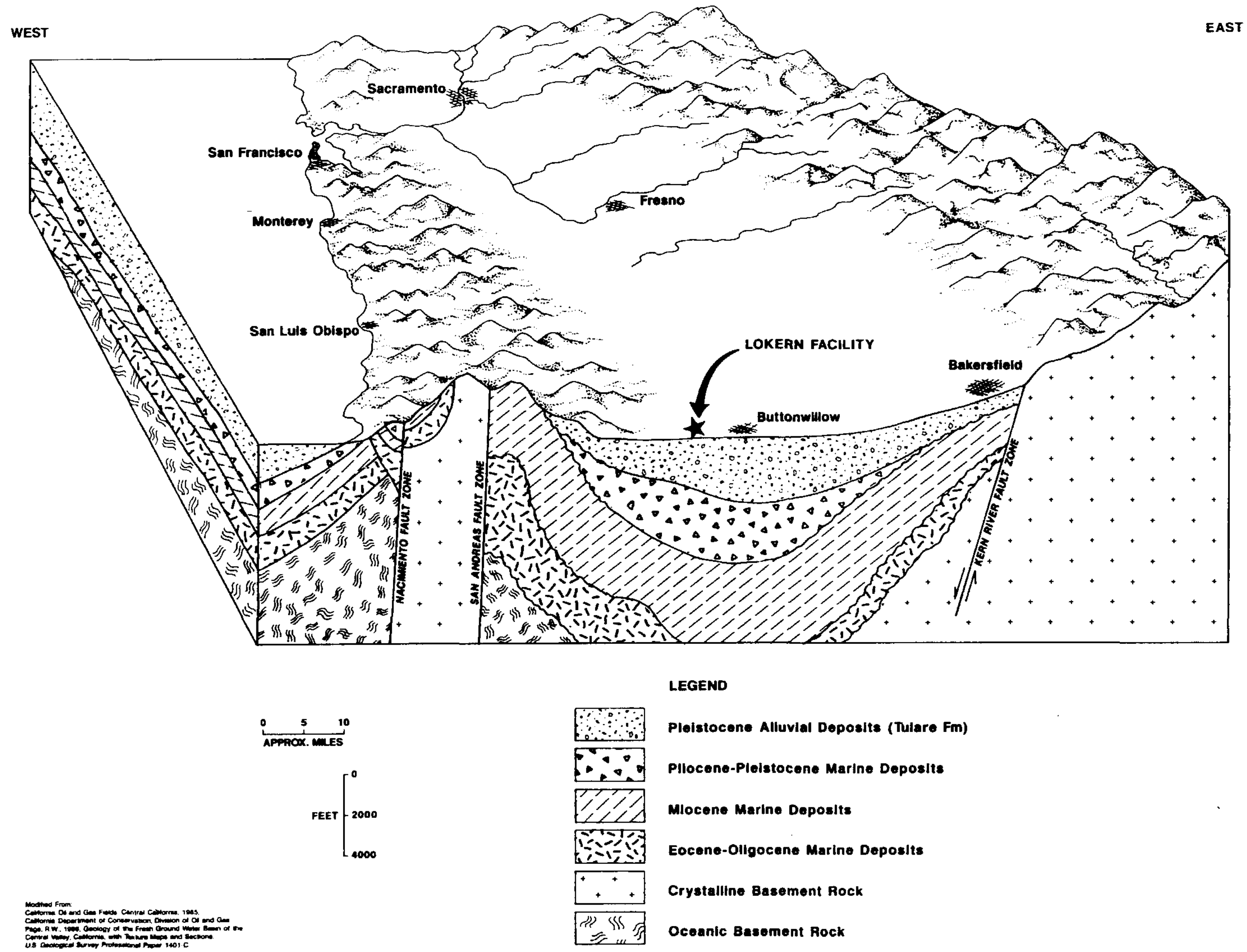

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Counsel in Health and Environmental Science

Schematic Geologic Section of the Southern Central Valley
Laidlaw Environmental Services (Lokern), Inc.
Buttonwillow, California

DRAWN BY	CONTRACT NUMBER	DATE	APPROVED	REVISED	FIGURE
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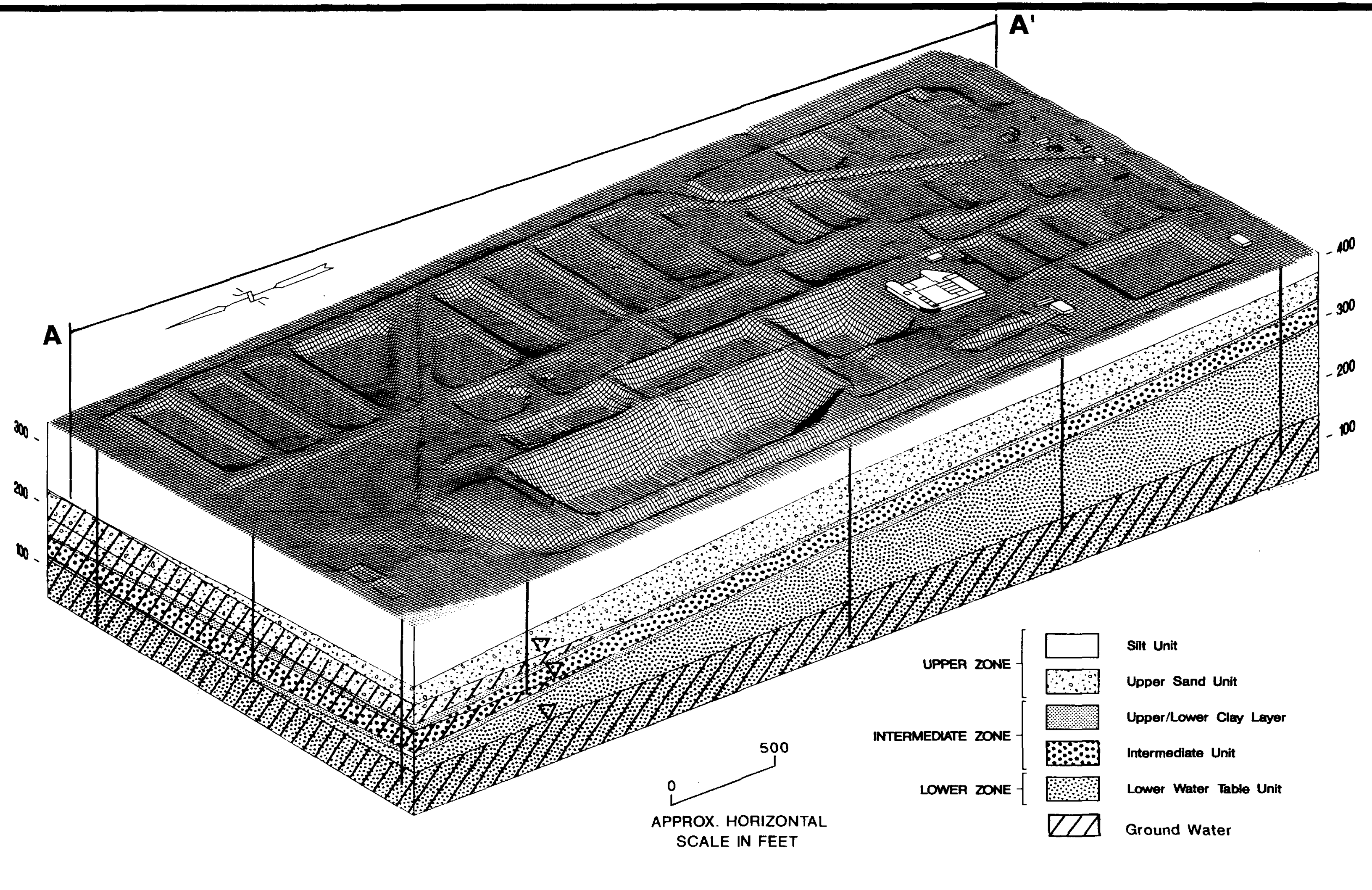

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Counsel in Health and Environmental Science

Schematic Subsurface Diagram of Lokern Facility
Laidlaw Environmental Services (Lokern), Inc.
Buttonwillow, California

DRAWN BY	CONTRACT NUMBER	DATE	APPROVED	REVISED	FIGURE
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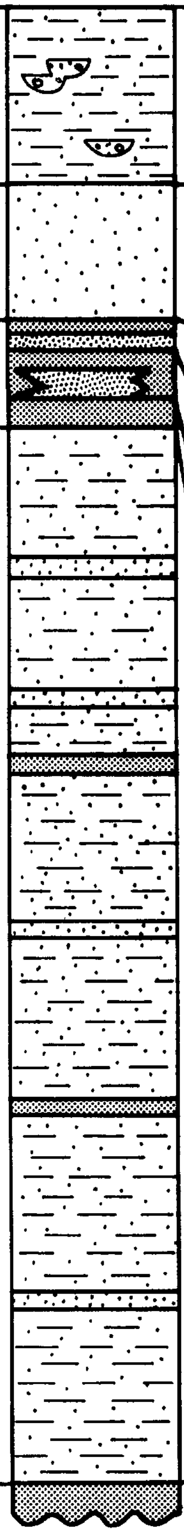

APPROXIMATE THICKNESS	LITHOLOGIC UNITS	HYDROLOGIC ZONES *
30-125 FEET	SILT UNIT Silt to Silty Sand: Soft to firm; dry to damp; light yellowish brown to light olive brown; trace calcite/gypsum. Artificial fill upper several feet (intermixed clay, silt and silty sand). Occasional sand and sandy gravel lenses less than 3 feet thick.	UPPER PERCHED ZONE
45-75 FEET	UPPER SAND UNIT Sand: Very fine- to coarse-grained; subangular to subrounded; moderate to well sorted; loose to very dense; dry to damp; light yellowish brown to light olive brown; trace iron staining; slight coarsening upward.	
35-55 FEET	UPPER CLAY LAYER Clay: Fat; stiff to very stiff; damp to moist; pale olive (5Y 6/3) to dark greenish gray (5G 4/1); micaceous; fish bone fossils; 1-6 feet thick.	INTERMEDIATE PERCHED ZONE (Potentiometric data represent lower sand body within the Intermediate Unit)
400-500 FEET	INTERMEDIATE UNIT Two correlateable sand lenses - one near the top and a second, thicker, bed in the lower half - sandwiched in a matrix of clay, silty clay, silt and sandy silt.	
	LOWER CLAY LAYER Similar to Upper Clay Layer, 2-13 feet thick. Intermixed and interbedded olive brown to grayish brown clay, silt, and sand.	
	LOWER UNIT Intermixed and interbedded olive brown to grayish brown clay, silt, and sand	LOWER WATER TABLE ZONE
	CORCORAN CLAY	

NOTES:
* Hydrologic Zones correlate directly to the Stratigraphic Zones with similar names.

Modified after IT Corporation, Part B Permit Application, Figure 4.2-5, January 1988.

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Generalized Stratigraphic Column
Laidlaw Environmental Services (Lokern), Inc.
Buttonwillow, California

DRAWN BY	CONTRACT NUMBER	DATE	APPROVED	REVISED	FIGURE
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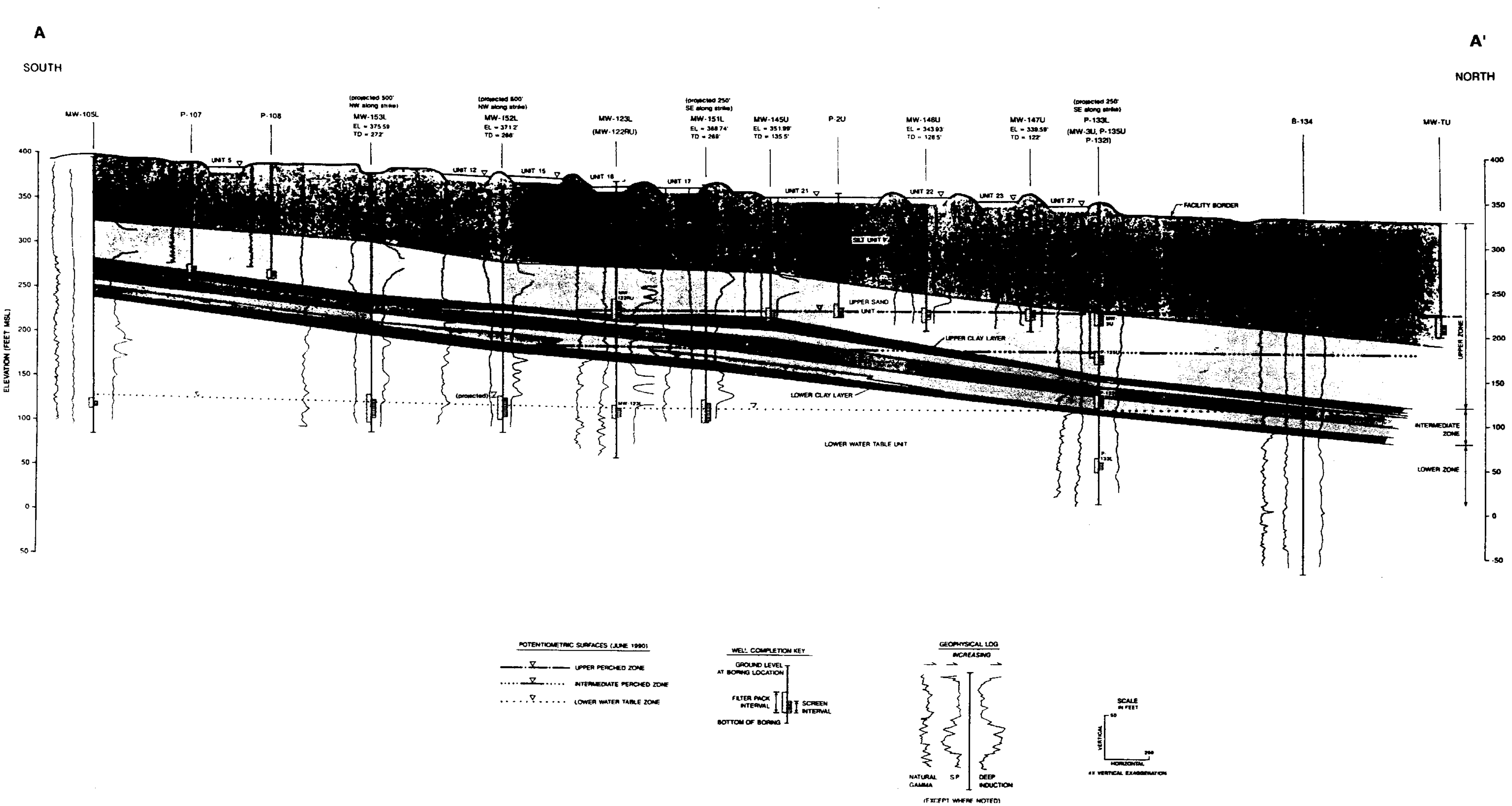

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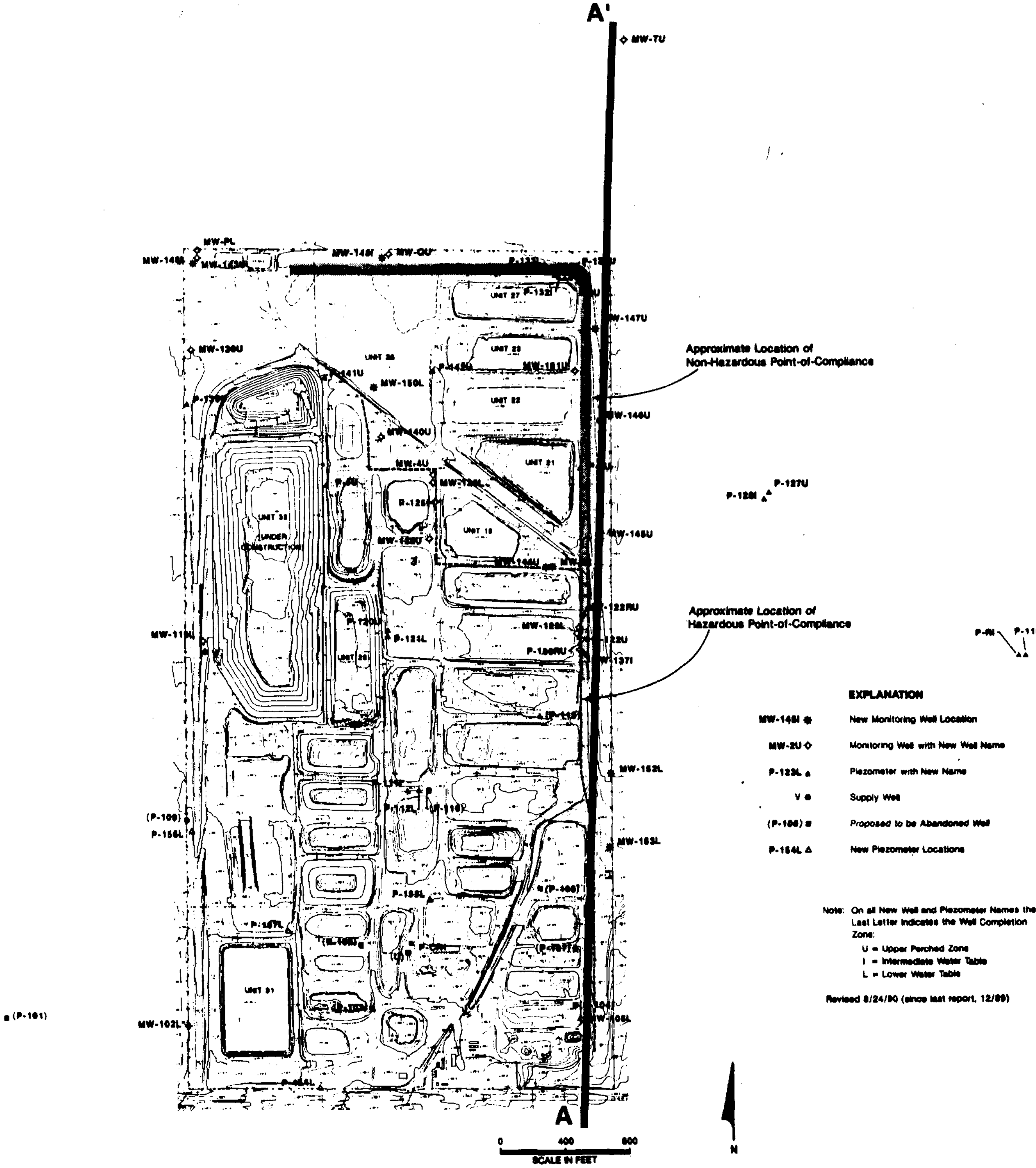
Schematic Subsurface Cross Section A - A'
Laidlaw Environmental Services (Lokern), Inc.
Buttonwillow, California

DRAWN BY	CONTRACT NUMBER	DATE	APPROVED	REVISED	FIGURE
DC	03-1107G	8/90			4



ENVIRON

Counsel in Health and Environmental Science

Ground Water Monitoring Network

Laidlaw Environmental Services (Lokern), Inc.

Buttonwillow, California

DRAWN BY	CONTRACT NUMBER	DATE	APPROVED	REVISED
DC	03-1107G	7/90		

FIGURE

5

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Field Trip Road Log

Herman B. Schymiczek
EMCON Associates
Fresno, California

The purpose of this road log is to guide the reader to the environmentally significant locations in Kern County, California. The filed trip will take one full day, and seven stops will be made. These stops, which are briefly described here, are identified by number on the index map (Figure 1). For more complete descriptions of each stop, the reader is referred to the pertinent papers contained in this volume. Buses and lunch will be provided for the trip.

Most roads on the route are paved, and the few unpaved ones are readily passable with two-wheel drive vehicles. Most of the field trip stops are on private property and access to the sites subsequent to the field trip must be arranged with the owners and operators in advance.

Most of the stops are at waste disposal sites, some of thick are active facilities. Additional stops may be added, if possible, to observe active remediation projects and/or liner installations. Please keep in mind that some of these sites are sensitive in terms of heath and safety considerations, so follow the directions of the field trip leaders and site operators, and stay with the group at all times.

Interval Mileage	Total Mileage	Description
0.0	0.0	Road log begins at the Red Lion Inn at the intersection of Rosedale Highway (Highway 58) and Camino Del Rio Court, going east on Rosedale Highway.
0.2	0.2	Rosedale Highway (Highway 58) becomes 24th Street (Highway 178) after passing under the Highway 99 freeway.
4.2	4.4	Proceed east on Highway 178 to the Haley Street/Mt. Vernon Avenue exit. Continue north on Haley Street
1.3	5.7	Turn east (right) on Panorama Drive and continue to China Grade Loop.
0.6	6.3	Turn north (left) on China Grade Loop and go to Round Mountain Road.
1.7	8.0	Turn east (right at Round Mountain Road. Note: at the Kern River is Gordon's Ferry State Historical Landmark.
5.2	13.2	Turn north (left) at the indicated sign to the Environmental Corporation (EPC) Eastside Disty. Note:.6 miles east of the intersection of China Grade Loop and Round Mountain Road is the Kern River ld Discover Historical Landmark.
0.4	13.6	Proceed to the EPC Eastside Disposal Facility and park at the entrance gate. **1) EPC Eastside Disposal Facility Stop** This is an excellent opportunity to see an RCRA Class II–1 facility that is undergoing active closure. This facility accepted primarily oil field wastes. It is situated on outcrops of Round Mountain Silt in an area where ground water is relatively deep, making for an excellent location for a disposal facility (Gutcher and Menzie, this volume).
	COFFEE AND DOUGHNUTS	
0.4	14.0	Backtrack down access road to Round Mountain Road. Turn west (right) on Round Mountain Road.
6.9	20.9	Round Mountain Road merges with China Grade Loop. Continue west on China Grade Loop through the Kern River oil field.
4.3	25.2	Turn south (left) on Airport Drive. Continue south to Highway 99.
2.1	27.3	Airport Drive merges onto Highway 99. Continue south on Highway 99.
1.2	28.5	Take the Rosedale Highway (Highway 58) exit. Turn west (right) on Rosedale Highway.
1.2	29.7	Turn south (left) on Mohawk Street.
1.0	30.7	Proceed south on Mohawk Street to the Texaco Refinery. **2) Texaco Refinery Stop** Here, we will see a state–of–the–art air emissions "scrubber" designed to eliminate benzene vapors. A Texaco representative will describe the basic design and operations of the equipment.
1.0	31.7	Backtrack north on Mohawk Street to Rosedale Highway. Turn west (left) on Rosedale Highway.

0.5	32.2	Turn south (left) on Fruitvale Avenue.
0.5	32.7	Fruitvale Avenue turns west and becomes Fruitvale Extension. Park cars at the EPC Fruitvale Injection Facility. **3) EPC Fruitvale Injection Facility Stop** This facility processes and disposes of primarily oil field production water through a series of filtration and settling units and injected into the Etchegoin Formation (Gutcher, this volume).
0.5	33.2	Backtrack on Fruitvale Extension/Fruitvale Avenue to Rosedale Highway. Turn west (left) on Rosedale Highway.
10.3	43.5	Turn south (left) on Enos Lane (Highway 43).
2.0	45.5	Turn west (right) on Stockdale Highway.
6.1	51.6	Turn south (left) on Morris Road.
1.5	53.1	Turn west (right) on Station Road.
0.5	53.6	Turn south at the marked entrance to the Tule Elk State Reserve. Park in marked stalls. **4) Tule Elk State Reserve Stop** The Tule Elk State Reserve protects a herd of Tule Elk, the smallest member of the elk family in North America. A resident State Ranger will present an overview of the site history and operations.
	LUNCH	
0.5	54.1	Depart Tule Elk State Reserve, turning west (left) on Station Road.
6.5	60.6	Turn south (left) on Tupman Road. Tupman Road gradually curves southeast. Proceed to intersection with Taft-Bakersfield Highway (Highway 119).
10.1	70.7	Turn southwest (right) on the Taft-Bakersfield Highway.
6.8	77.5	Turn west (right) on Midway Road, which becomes Mocal Road after crossing the Westside Highway (Highway 33).
0.6	78.1	Turn north (right) on Shale Road. Turn east (right) on short access road and park at entrance gate to the Westside Disposal Facility owned by Santa Fe Energy Resources. **5) Westside Disposal Facility Stop** This facility is undergoing active closure. An 80-acre site located in Midway Valley within the boundaries of the Midway-Sunset oil field, this facility accepted primarily oil field wastes. In addition, small quantities of plating wastes containing constituents listed as hazardous under the Resource Conservation and Recovery Act (RCRA) were accepted (Knott, Krieger, and Uribe, this volume).
0.5	78.6	Continue north on Shale Road. Turn northeast (left) on the Westside Highway (Highway 33).
9.3	87.9	Turn west (left) on the Santa Maria Valley Highway.
0.4	88.3	Turn south (left) at the marked entrance to Liquid Waste, Inc. (now Sanifill) disposal site and park. **6) Liquid Waste, Inc. Disposal Site Stop** This is an active Class II Disposal site, which accepts primarily oil field wastes generated by westside producers. This facility is undergoing expansion, and it is hoped that we will be able to observe a liner installation (see Prasad, Hullings, and Von Pein, this volume).
5.2	93.5	Continue west on the Santa Maria Valley Highway. Turn northeast (right) on Reward Road.
5.2	98.7	Turn north (left) on the Westside Highway (Highway 33). Note: 3.5 miles east of the intersection of Santa Maria Valley Highway and Reward Road is the McKittrick Brea Pit State Historical Landmark.
6.9	105.6	Turn east (right) on Lokern Road.
4.8	110.4	Turn north (left) through the entrance gate of the Laidlaw Environmental Services (Lokern) Inc. facility and park. **7) Laidlaw Environmental Services (Lokern) Stop** This 320-acre facility operates as a treatment and disposal facility for hazardous and non-hazardous wastes. A wide variety of designated and hazardous wastes generated in petroleum exploration, production, refining, and marketing operations are currently disposed at the facility (see Buoni, Hayes, and Harnish, this volume).
2.5	112.9	Continue east bound on Lokern Road to where it merges with Bakersfield-McKittrick Highway (Highway 58). Proceed east on the Bakersfield-McKittrick Highway.
16.2	129.1	Turn south (right) on Enos Lane (Highway 58 and 43).
1.0	130.1	Turn east (left) on Rosedale Highway (Highway 58).
11.7	141.8	Turn south (right) on Camino Del Rio Court and return to the Red Lion Inn.

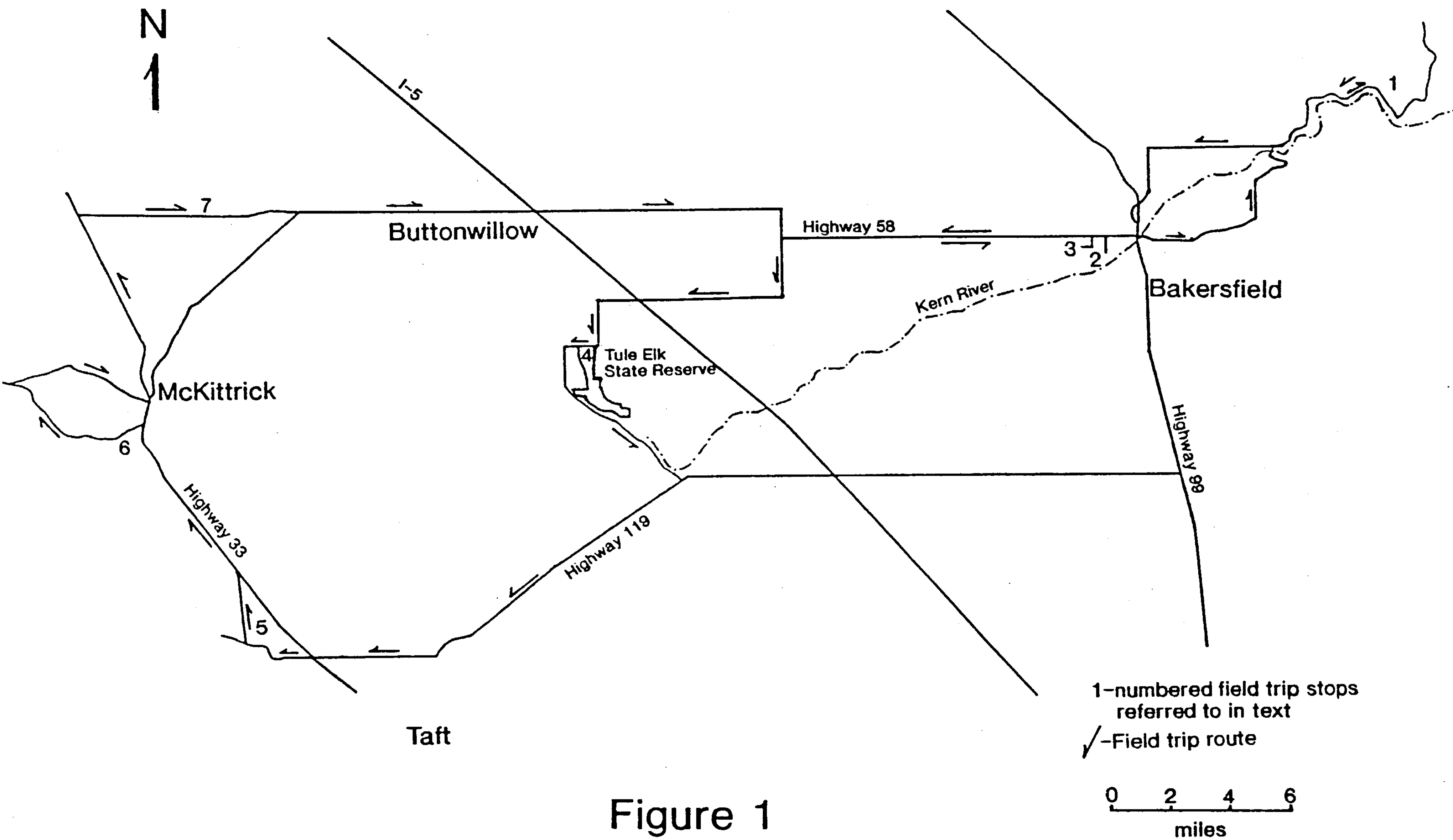

Figure 1

Significant Environmental Locations
in Kern County, California