Final Technical Report

Site Investigation and Evaluation of Remediation Alternatives for the Mandi-Injecto Site, Tom Green County, Texas

(RRC Site No. 7C-50214)

Volume I

by

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1.0 EXECUTIVE SUMMARY

The Mandi-Injecto site, approximately 6.5 mi (~10.5 km) southwest of San Angelo in Tom Green County, Texas, consists of a 2-acre (0.8-hectare) area that is barren of vegetation mainly owing to salt-impacted soil, buried oil-field sludge in a disposal trench and surrounding overflow area, and a local salinity plume in shallow ground water. Recommended remedial solutions include (1) removing the contents of the disposal trench to a permitted facility and backfilling the excavation; (2) placing, grading, and vegetating a cover soil to minimize percolation of water and flushing of additional salt to the water table; and (3) monitoring the ground water to provide data needed as a basis for site closure.

The Mandi-Injecto site is made up of two separately permitted but adjacent abandoned oil-field-related facilities. The Mandi facility was an oil-reclamation plant, and the Injecto site was a saltwater storage and disposal facility. The Railroad Commission of Texas (RRC) performed cleanup actions at the Mandi-Injecto site July through November 1989, July and September 1993, and May and June 1994. The Bureau of Economic Geology (BEG) conducted additional investigations at the site between June 1996 and August 1997 on behalf of the RRC to (1) locate and identify the composition and extent of impacted media at the Mandi-Injecto site and (2) make risk-based recommendations for any site-remediation activities.

The disposal trench lies within the barren ground and includes an area of approximately 1,600 ft^2 (~150 m^2) where waste material is as much as 5.5 ft (1.7 m) thick and an adjacent overflow area of another 2,600 ft^2 (240 m^2) where waste material is as much as 3 ft (1 m) thick. As part of previous RRC cleanup actions, the trench and surrounding material were covered by 0.5 to 1 ft (0.2 to 0.3 m) of soil. The waste material, consisting primarily of basic sediment and oil-field waste, is nonhazardous, but it has elevated levels of TPH, chloride, and spot occurrences of NORM. Samples from the disposal trench had TPH of 13 to 14 percent, chloride of 8,900 to more than 10,400 mg/kg, and total barium of 410 mg/kg. All TCLP organic and metal results were well within regulatory limits. Most of the waste material had background scintillometer readings; a sample having elevated scintillometer readings exceeded exemption activity levels, with 276.52 pCi/g of radium-226, 20.37 pCi/g of radium-228, 79.77 pCi/g of lead-210, and total activity of 916.02 pCi/g. Native soil from beneath the trench, however, had a TPH of 0.02 percent, chloride of 5,490 mg/kg, and low TCLP concentrations that indicate that leaching of organic or metal constituents from the waste has been minimal.

Elevated levels of chloride were detected in soil beneath the barren ground, the Injecto area containing the largest concentrations. The soil holds as much (or more) salt as is found in the impacted ground water, showing a potential for continued release of salt to ground water. TPH was low to nondetected in soils; reported incidents of oil contamination in soil or ground water could be neither confirmed nor related to the Mandi-Injecto site.

Much of the Concho River valley in Tom Green County tends to have poor-quality ground water, owing to the natural discharge of brine from Permian-age formations that underlie the area. The site overlies the San Angelo and Blaine Formations with their naturally poor quality water. Ground water was sampled from boreholes installed at the site into Permian bedrock; the overlying 20-ft-thick (6-m) gravel and alluvium section was unsaturated. Salinity of ground water is elevated (chloride concentration as much as 16,000 mg/L) beneath and somewhat down gradient of the barren ground. This position probably reflects leaching of salt from soils at the Mandi-Injecto site, but it was noted that Permian bedrock at the site naturally yields poor-quality water. The only analyte of concern detected in ground water was chloride; volatile organics were not detected in any of the water samples, and only a trace amount of TPH and barium was detected.

Nearby water-supply wells yield poor-quality water typical of the Permian formations in the region. The presence of potable ground-water resources in the 1,000- to 1,300-ft (300- to 400-m) distance between the site and the upper reaches of Twin Buttes Reservoir is not confirmed. Whereas the brackish to saline ground water at the site could begin to reach the reservoir as early as 50 to 80 yr in the future, the annual ground-water discharge would increase reservoir salinity by a factor of only 1/10,000 to 1/1,000, which is negligible as compared with the potential for natural discharge of brine from the San Angelo and Blaine Formations.

Excavating the disposal trench and disposing of nonrecyclable waste at a permitted facility are recommended. Some of the waste having exempt-NORM content might be reusable. The excavation work will thus require confirmatory sampling to discriminate NORM-exempt waste and establish that impacted soil has been removed. Because the amount of NORM-impacted waste cannot be cost-effectively determined before excavation, transport and disposal of waste should be bid on a unit-cost, rather than lump-sum, basis to minimize cost. The excavation will need to be backfilled with clean fill. To minimize future leaching of salt from soil and additional loading of salinity in ground water, placing, grading, and vegetating a minimum of 2 ft (0.6 m) of clean, clay-rich soil are recommended. Grazing of livestock in the area should be curtailed to allow vegetation to be established.

Whereas no direct remediation of ground water is recommended, ground-water monitoring is recommended to evaluate the effectiveness of the soil cover and fate of the salinity plume. Three to six monitoring wells are planned for the first year of site cleanup; additional monitoring wells might be found necessary on the basis of new monitoring data.

2.0 INTRODUCTION

The Mandi-Injecto site in Tom Green County (RRC Site Code 7C-50214) includes two separate but adjacent abandoned oil-field-related facilities. The Mandi facility was a reclamation plant on the east side of the site, and Injecto was a saltwater storage and disposal facility on the west side of the site (fig. 2.1). For this report, these facilities will be referred to as the Mandi-Injecto site. This site was placed high on the RRC priority list because of unknown site conditions, potential for impact to nearby surface water, a registered complaint and a high public profile.

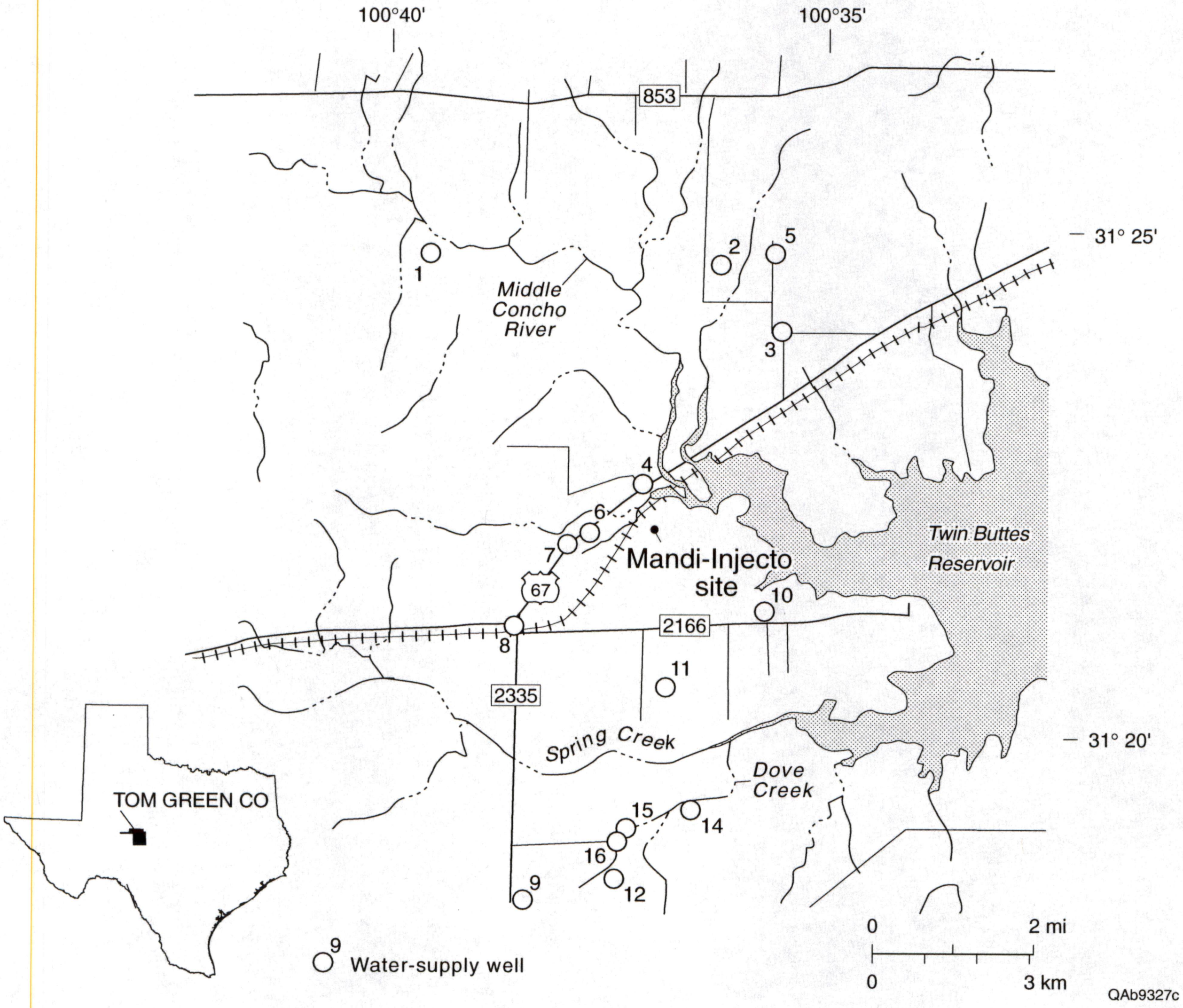

Figure 2.1. Location of Mandi-Injecto site, Tom Green County, Texas. Water-supply wells listed by map number in table 2.2.

The objectives of this study were to (1) locate and identify the composition and extent of impacted media at the Mandi-Injecto site and (2) make risk-based recommendations for site remediation. This phase of investigation included:

- reviewing RRC files and previously compiled data;
- excavating trenches and taking subsurface samples to determine the composition and extent of the waste material;
- surveying ground conductivity along four transects to assess the extent of saltwater migration;
- drilling five soil borings, targeted on the basis of geophysical characterization, for description and analysis of soil;
- sampling and analysis of ground water from four of the five site boreholes (the fifth hole did not reach the water table);
- measuring water levels at site boreholes to estimate the local potentiometric surface;
- sampling local water-supply wells to determine background water-quality characteristics; and
- evaluating risk-based options for site remediation focused on site closure.

The investigation focused on oil-field waste at the Mandi-Injecto site. Other wastes, including trash in pits or scrap metal, were considered beyond the scope of this investigation and were not evaluated. Additional phases of investigation include installation of monitoring wells, further mapping of the saline ground water, and site cleanup activities (Section 6).

RRC case files for the site were reviewed prior to development of a site-investigation plan. Site-reconnaissance visits were made by BEG personnel in October 1996 and March 1997. Site-investigation activities were performed from June 1996 through August 1997.

2.1 Site History

The Mandi-Injecto site, consisting of two separate but adjacent abandoned-oil-field facilities, is located approximately 6.5 mi (~10.5 km) southwest of San Angelo in Tom Green County, Texas, off U.S. Highway 67. The site lies on the Knickerbocker USGS 7.5-minute quadrangle approximately 1,000 ft (~300 m) southwest of the Middle Concho River branch of the Twin Buttes Reservoir, and about 0.1 mi (~0.16 km) southeast of Highway 67, adjacent to the South Orient Railroad (fig. 2.1).

The Mandi facility was a reclamation plant with one 250-bbl (~40 m^3) and two 1,000-bbl (~160 m^3) steel tanks and an unlined pit. The site operated with an RRC permit from August 1982 through February 1986. In September 1989, RRC personnel documented that the tanks onsite were leaking and in May 1992, a spill of crude oil was reported and estimated to be 30 to 50 bbl (~5 to 8 m^3). A complaint was filed by a prospective buyer of the property in July 1993.

The Injecto site was a saltwater-disposal operation consisting of one saltwater-injection well, a 45-ft-diameter (13.7-m) open-top tank, and eight steel tanks ranging in size from 200 to 1,000 bbl (~32 to 160 m^3). The saltwater-disposal operation had an RRC permit from 1968 through 1988. Complaint 7C-0954 was filed in December 1988. An RRC inspection found that the facility had been abandoned with tanks full and overflowing. At least one large-diameter tank apparently lacked a bottom (Randall Ross, personal communication, October 1996); if so, saltwater could have infiltrated into the ground under the hydraulic head in the tank. The RRC began corrective actions in July 1989 by removing fluids from damaged tanks and excavating impacted surface soils. Records indicate that in July 1989, RRC District 7C received permit PA-7C-2422 for burial of waste materials at the site. In September 1989, records show that a disposal trench was dug for the burial of oil-field waste consisting of iron-sulfide water, oil-bearing drilling mud, and bottom solids (basic sediment) removed from the onsite tanks. The saltwater-disposal well was plugged in November 1989.

The Tom Green Health Department notified the RRC in July 1993 of vandalism and resulting tank spillage at the site. The RRC carried out clean-up actions in September 1993, removing several truckloads of oily dirt from around the tanks, as well as basic sediment from an open-top tank, for offsite disposal. Eight tanks were emptied and removed, along with pipe, buckets, and barrels, in May and June 1994. In March 1994, RRC staff collected and analyzed five water samples from nearby wells and six soil samples near the tanks at the Injecto and Mandi facilities (table 2.1). Soil samples from around the tanks indicated TPH of 8.3 mg/kg, chloride (1:1 extract) of as much as 48,049 mg/L, toxicity characteristic leaching procedure (TCLP) barium of 5.08 mg/L, and total organic halogens (TOX) of 64 mg/kg. Chloride concentration in groundwater samples ranged from 527 to 2,892 mg/L (table 2.1).

2.2 Site Characteristics

2.2.1 Physical Setting, Geology, and Soil

The Mandi-Injecto site lies on a Quaternary (Pleistocene and Holocene) terrace (fig. 2.2) made up of coarse-grained alluvial deposits of the Concho River. Pleistocene alluvial deposits are mapped locally as the Leona Formation (Lee, 1986). Holocene alluvial deposits occupy the valley of the Middle Concho River incised into the older upland terrace (Blüm and Valastro, 1992).

Topographic relief on the alluvial terrace is relatively flat, gradually sloping to the northeast toward the Middle Concho River. The Mandi-Injecto site is barren of vegetation, but the surrounding ground cover consists of sparsely vegetated grass, shrubs, and mesquite. Land is currently used for hay-fed livestock. An excavation pit east of the site is used for trash disposal. The site is fenced but unlocked, and there are three residences in the vicinity of the site. Since the 1994 cleanup operation, there have been no signs of the previous operations (tanks, equipment, materials, etc.) or obvious surface contamination, other than the barrenness of the soil.

Alluvium at the site overlies Permian bedrock of the Blaine Formation (fig. 2.2). The site is near the contact between the Blaine and San Angelo Formations, which dip gently to the west

Table 2.1. Results of analysis of soil and water samples collected at the Mandi-Injecto site in 1994 by RRC. Results listed in RRC files.

Sample name	Date collected	Sample depth (inches)	TPH (%)	Barium (mg/L)	Chloride (mg/L)
Schiller well no.1	2/24/94	na	na	na	1,120
Schiller well no.2	2/24/94	na	na	na	1,185
Schiller well no.4	2/24/94	na	na	na	527
Schiller well no.5	2/24/94	na	na	na	1,237
Decoty well no.3	2/24/94	na	na	na	2,892
Mandi 3S (soil)	7/21/93	0	8.3	3.07	709
Injecto 1S (soil)	7/21/93	0	0.23	2.98	29,060
Injecto 1D (soil)	7/21/93	4	0.59	3.64	11,748
Injecto 2S (soil)	7/21/93	0	0.12	5.08	48,049
Injecto 2D (soil)	7/21/93	12	0.16	3.77	28,394
Injecto 4S (soil)	7/21/93	0	6.7	3.19	607

na = Not analyzed

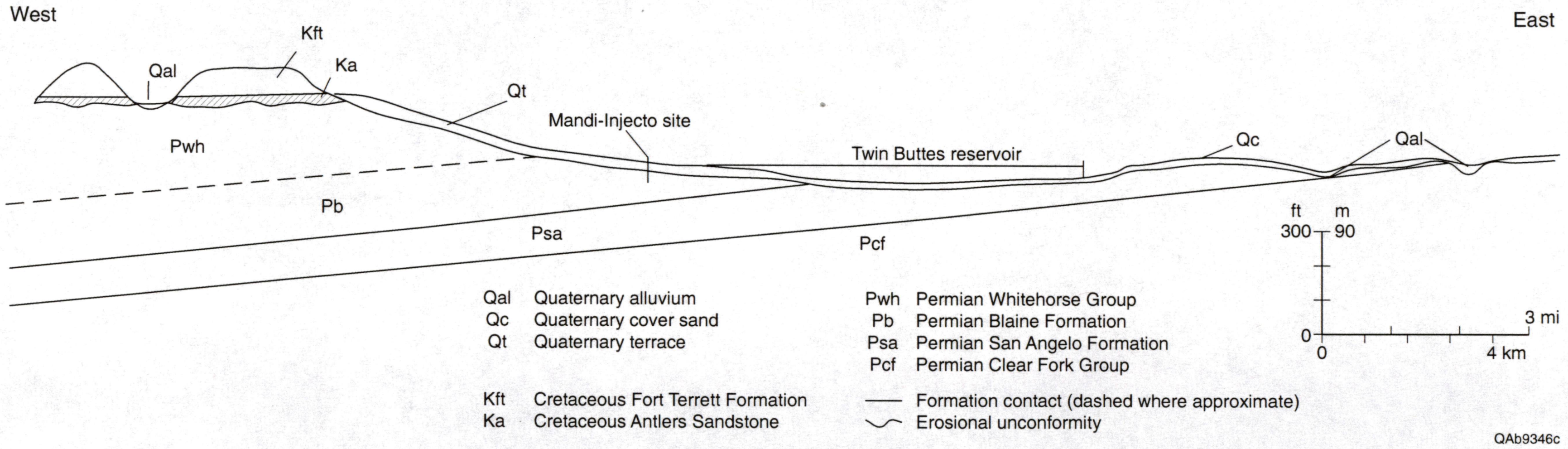

Figure 2.2. General geologic east-west cross section at the Mandi-Injecto site.

(fig. 2.2). The Blaine consists of interbedded shale, sandstone, dolomite, and gypsum, and the San Angelo consists of sandstone, shale, and conglomerate.

This part of the Concho River valley is surrounded by an upland area of erosionally dissected Cretaceous rocks of the Hill Country plateau, deposited unconformably over the Permian section. Cretaceous bedrock does not occur at the Mandi-Injecto site.

Soils mapped at the Mandi-Injecto site are Angelo clay loam on the terrace and Mereta clay loam on the 1- to 3-percent slope north of the site (Wiedenfield and Flores, 1976). Angelo clay loam, well drained, formed on level and gently sloping alluvial deposits. Pedogenic carbonate occurs at depths of 24 to 40 inches (60 to 100 cm). Mereta soil occurs in slope settings and is characterized by pedogenic carbonate horizons with low permeability at depths of 15 inches (36 cm) (Wiedenfield and Flores, 1976).

The average annual rainfall for the west part of Tom Green County from 1951 through 1980 was 19 inches (48 cm), and the average annual evaporation was 80 inches (203 cm); there is a net annual water deficit for the area (Larkin and Bomar, 1983).

2.2.2 Site Hydrology

Surface Water

The Twin Buttes Reservoir, completed in 1962, has a conservation storage capacity of 186,200 acre-ft (230 million m^3) (Lee, 1986). Storage ranges from 85,000 to 186,200 acre-ft (104 to 230 million m^3), depending on rainfall and demand. Twin Buttes Reservoir serves as a public-water supply source for the city of San Angelo (U.S. Geological Survey, 1990).

There is no naturally occurring surface water at the site. The Middle Concho River branch of the Twin Buttes Reservoir is located 1,000 to 1,300 ft (300 to 400 m) northeast of the site. Regional surface drainage is toward this tributary. The tributary was dry during the site visit because reservoir storage had been decreased to 110,000 acre-ft (135 million m^3) because of dam reconstruction activities.

Ground Water

Water wells in the area (table 2.2, fig. 2.1) are completed in the Leona and Blaine Formations, although some wells may receive some water from the underlying Permian formations (Lee, 1986). The Leona, composed of gravel, conglomerate, sandy lime or pedogenic carbonate, and thin layers of clay of Pleistocene alluvium, ranges in thickness from 0 to 125 ft (0 to 38.1 m) (Lee, 1986). The Blaine makes up a minor aquifer composed of sandstone and sandy clay and produces small quantities of highly mineralized, poor-quality water. Recent deterioration of ground-water quality is a concern in the county (Lee, 1986).

Wells that are completed in or receive some water from Permian formations in the Concho River valley in Tom Green County have a tendency to produce poor-quality water owing to the natural discharge of brine from Permian formations that underlie the area. Regional flow naturally transports subsurface brine from the Permian Basin to near land surface in the Concho River valley, where the brine mixes with locally recharged, shallowly circulating water (Richter and others, 1990). Ground water in Tom Green County is commonly very hard (>180 mg/L calcium carbonate), and chemical types vary in the aquifers and in different parts of the county (Dutton and others, 1989; Richter and others, 1990). Total dissolved solids (TDS) range from 200 to 3,000 mg/L, chloride ranges from about 40 to 1,000 mg/L, and sulfate ranges from about 25 to 600 mg/L. Salinity of ground water has increased over the past decades in the area west of Twin Buttes Reservoir (Richter and others, 1990). The ground water having the second-greatest TDS in Tom Green County (6,660 mg/L) was from well 43-43-302 in Tankersley, south of the site. This well is reported to produce water from the Leona aquifer, but it may also be partly completed in an underlying Permian formation.

Table 2.2. Data from water wells in vicinity of site (sources include Lee [1986] and http://www.twdb.state.tx.us/Newwell/well_info.html).

Map no.	State well number	Land surface elevation (ft)	Date drilled	Well depth (ft)	Use	Date of measure	Depth to water (ft)	Specific conductance (mS/m)	Chloride (mg/L)	TDS (mg/L)
1	4335901	1990	1925	51	S	5/17/83	21	1,040	nr	631
2	4336701	2002	nr	73	S	5/17/83	55.8	1,600	nr	956
3	4336702	1985	1920	66	P	5/17/83	59.9	1,635	nr	976
4	4336703	1953	nr	35	S	5/17/83	20.2	2,890	nr	1,700
5	4336704	2011	nr	66	N		nm	nm	nm	nm
6	4343301	1990	1957	74	S	8/24/83	67.2	1,350	1,350	811
7	4343302	1996	nr	nr	P	4/15/83	67.1	11,440	nr	6,660
8	4343303	2013	1928	37	S	7/20/83	35.1	1,090	nr	660
9	4343601	nr	nr	nr			nm	nm	nm	nm
10	4344101	1950	1920	65	S	5/26/83	24.4	3,570	nr	2,100
11	4344102	1965	nr	85	P	5/26/83	40	3,040	nr	1,790
12	4344401	1985	nr	nr	P		nm	nm	nm	nm
13	4344402	nr	nr	nr	P		nm	nm	nm	nm
14	4344403	1975	1977	52	S	3/29/83 8/25/83	15.8 nr	4,390 2,930	nr nr	2,570 1,730
15	4344404	1971	nr	75	S	7/24/87	17.2	888	74	nm
16	4344405	1971	nr	75	S	7/24/87	16.3	930	83	nm

nr = Not reported
nm = Not measured
Use = S-stock, P-public supply, N-industrial

3.0 METHODOLOGY

A variety of techniques, which included the use of surface and borehole geophysics, excavation, drilling, and sampling, were used to assess waste characteristics and environmental conditions at the Mandi-Injecto site.

3.1 Geophysics

Electromagnetic induction (EM) geophysical surveys were used as a first approximation of areas having potential salt contamination in subsurface soil and ground water. A Geonics EM-34-3 meter was used for a ground-surface survey, and a Geonics EM-39 induction probe was used to log boreholes. Borehole locations were targeted along the surface geophysical transects. Results of the geophysical surveys are discussed in Section 4.2.

3.1.1 Surface Geophysics

EM-34 survey lines were conducted at coil separations of about 32.8, 65.6, and 131.2 ft (10, 20, and 40 m) between the transmitter and receiver coils, and two coil orientations (horizontal and vertical dipole) were used. The effective penetration depth was 6 to 25 m (19.7 to 82 ft) for the horizontal dipole orientation and 12 to 50 m (39.4 to 164 ft) for the vertical dipole orientation.

Conductivity values represent "bulk" conductivities, or an average conductivity of the soil volume beneath the transmitter and receiver coils, and are plotted on profiles and on maps at the midpoint between the transmitter and receiver coils. Values obtained from the horizontal dipole orientation are weighted by the conductivity of the uppermost third of the exploration depth. The vertical dipole orientation has a deeper exploration depth, and the values are weighted by the conductivity of the middle third of the exploration depth. Soil and ground-water sampling and borehole geophysical data were used to confirm results of the surface geophysical survey.

Four geophysical transects totaling approximately 2,300 ft (~700 m) in length crossed the site (fig. 3.1). Station spacing along each line was approximately 32.8 ft (~10 m). Line 1 consisted of 24 stations in a northwest-southeast direction and bisected the Injecto part of the site. Line 2 consisted of 18 stations in a east-west direction and included both the Mandi and Injecto areas. Line 3 consisted of 16 stations in a northeast-southwest direction and crossed the Mandi part of the site and extended topographically down gradient. Line 4 consisted of 15 stations in a north-south direction and ran along a drainage extending down gradient from the site.

3.1.2 Borehole Geophysics

Down-hole geophysical logs were run in boreholes INBH-1, INBH-2, MBH-1 and MBH-2 by means of a Geonics EM-39 (fig. 3.1). The EM-39 has an approximately 1.6-ft (50-cm) separation of transmitter and receiver coils, an operating frequency of 39.2 kHz, and a formation penetration radius of about 3.3 ft (~1 m). The EM-39 measures the electrical conductivity of the soil surrounding a borehole according to an inductive electromagnetic technique. This instrument can detect changes in apparent ground conductivity related to lithology changes (for example, clay versus sand), as well as changes in salinity concentrations. All data are recorded on a portable computer for data reduction and interpretation. The EM-39 logs were correlated with the surface EM-34 readings.

3.2 Sample Characterization

3.2.1 Excavations, Boreholes, and Soil Samples

Trenches

Twelve trenches (fig. 3.1 and inset) were excavated to various depths (as much as 8 ft [2.4 m]) as needed to delineate the extent, thickness, and contents of the disposal trench and overflow area. All trenches exposed native soil beneath the waste package. The backhoe operator

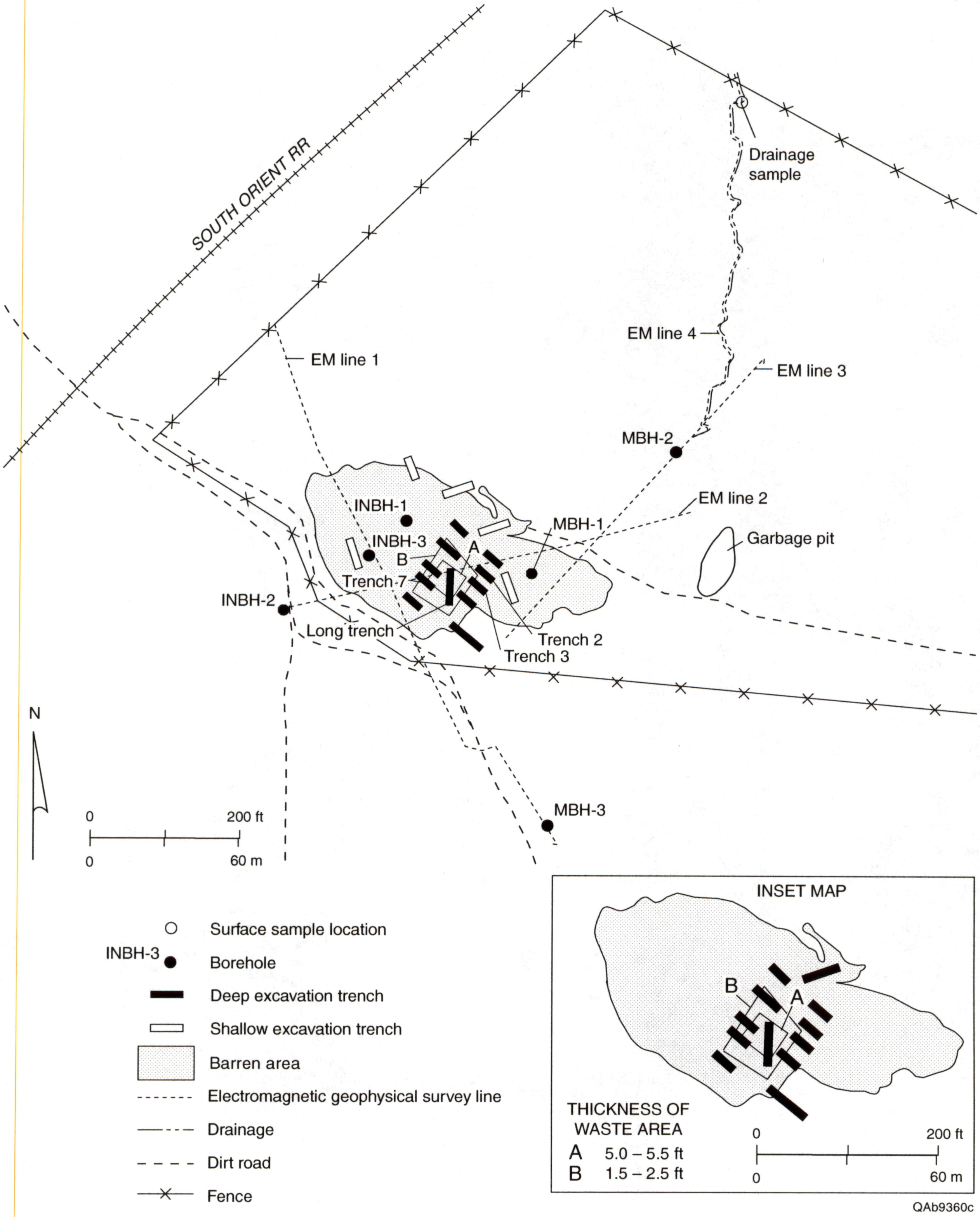

Figure 3.1. Locations of geophysical survey lines, trench excavations, and boreholes at the Mandi-Injecto site.

was experienced in environmental investigations and was trained in Hazardous Waste Operations and Emergency Response as prescribed in standard 29 CFR 1910.120. Five additional exploration trenches were excavated to 4 ft (1.2 m) below ground surface to check for buried waste at other locations. One of the five excavations detected what appeared to be oil-field-waste material; a soil boring (INBH-3) was later drilled at that location (fig. 3.1). Results are discussed in Section 4.3. No visual sign of contamination was noted in any of the other four shallow trenches.

Boreholes and Soils

Borehole locations (fig. 3.1) were targeted partly on the basis of EM-34 geophysical results and partly to evaluate site features. Boreholes include:

Borehole	**Location**
INBH-1	Highly conductive central part of Injecto area
INBH-2	Up gradient of highly conductive zone, between site and location of reported oil contamination*
INBH-3	At a spot occurrence of apparent, buried, oil-field waste found by surface excavation
MBH-1	Highly conductive central part of Mandi area
MBH-2	Down gradient of highly conductive zone
MBH-3	Up-gradient background area

* Letter dated February 25, 1994, from J. Randall Ross to John Tintera reports landowner stating that a 40-ft-deep borehole drilled for a water well had salty water and free oil.

All boreholes were subsequently backfilled with grout. Ground-surface elevation at the boreholes was surveyed relative to a local benchmark datum, which was assigned an arbitrary elevation of 100 ft (30.48 m). The survey was conducted for the purpose of estimating the local gradient in hydraulic head.

Sampling and Analyses

Six samples from the long excavation trench (table 3.1; fig. 3.1) were collected to characterize waste contaminants and define the boundaries of the disposal trench. All samples were analyzed for TPH, chloride, and electrical conductance (E.C.). One sample, considered representative on the basis of physical appearance and located in the middle of the waste package, was analyzed for total organic halogens (TOX), RCRA 8 metals, semivolatile polynuclear aromatic hydrocarbons (PAH's), volatile organic compounds (VOC's), pesticides, PCB's, TCLP metals and VOC's, landfarm parameters, reactivity, corrosivity, ignitability, and moisture.

The RRC District 7C Site Cleanup Coordinator conducted a scintillometer survey of the site and of excavated material from the disposal trench. Naturally occurring radioactive material (NORM) is defined as any solid, liquid, or gaseous material or combination of materials (excluding source material, special nuclear material, and by-product material) that in its natural physical state spontaneously emits radiation, is discarded or unwanted, constitutes, is contained in, or has contaminated oil and gas waste, and prior to treatment or processing that reduces the radioactivity concentration, exceeds exemption criteria specified by the Texas Department of Health (TDH) [16 TAC 3.94(a)(7)]. Some oil-field operations generate solid waste that contains NORM as a mineral scale (Fisher, 1995). Scintillometer readings were above background for some of the disposal-trench material. A sample of the waste material having the high scintillometer reading (sample number 3034 [table 3.1]) was submitted for analysis to the American Radiation Laboratories in Baton Rouge, LA.

Six soil borings were drilled by a CME 75 truck-mounted drilling rig using hollow-stem augering. Soil cores in boreholes were collected that had a nominal 3-inch-diameter (7.6-cm) × 5-ft (1.5-m) continuous sampling tube. Upon encountering auger refusal, the drilling rig was refitted with solid-stem augers and samples were obtained by hammering a 2-inch-diameter (5-cm) × 2-ft (0.7-m) split spoon. Cores were collected, boxed, brought to the BEG laboratory in Austin and logged. Lithologic logs of the borings are included in appendix A. Two to three samples were

Table 3.1. Ground-water, core, and trench samples collected for chemical analyses.

Sample ID	Sample number	Sample type	Sample depth (ft-bgl)	Total depth (ft-bgl)	Analyses
43-43-Sch1	3000 to 3003	Ground water	nm	unknown	VOC's, TPH, cations, and anions
43-43-Sch2	3004 to 3007	Ground water	18.47*	76.8	VOC's, TPH, cations, and anions
MBH-1	3008 to 3011	Ground water	25.9*	45	VOC's, TPH, cations, and anions
INBH-1	3012 to 3015	Ground water	30.5*	60	VOC's, TPH, cations, and anions
INBH-2	3016 to 3019	Ground water	23.1*	45	VOC's, TPH, cations, and anions
MBH-2	3021 to 3022	Ground water	21.1*	35	VOC's, TPH, cations, and anions
Drainage	3023	Core	1	1	TPH, chloride, and conductivity
MBH-2	3024	Core	35	35	TPH, chloride, and conductivity
Trench 7	3025	Trench	2.4	7	TPH, chloride, conductivity, and moisture
Long Trench	3026	Trench	4.16	8	TPH, chloride, conductivity, and moisture
Long Trench	3027	Trench	7.7	8	TPH, chloride, conductivity, and moisture
Trench 2	3028	Trench	2.25	7	TPH, chloride, conductivity, and moisture
Trench 3	3029	Trench	1.5	7	TPH, chloride, conductivity, and moisture
MBH-1	3030	Core	39.5	45	TPH, chloride, and conductivity
INBH-2	3031	Core	45	45	TPH, chloride, and conductivity
Long Trench	3032 to 3033	Trench	3.25	8	TPH, chloride, conductivity, and moisture
Long Trench	3034	Trench	3.25	8	NORM
MBH-2	3035 to 3036	Ground water	21.1*	35	VOC's, TPH, cations, and anions
MBH-2	3037 to 3038	Ground water (dup.)	21.1*	35	VOC's, TPH, cations, and anions
INBH-1	3039	Core	1	60	TPH, chloride, and conductivity
INBH-1	3040	Core	27	60	TPH, chloride, and conductivity
INBH-1	3041	Core	14	60	TPH, chloride, and conductivity
INBH-2	3042	Core	1	45	TPH, chloride, and conductivity
INBH-2	3043	Core	18.5	45	TPH, chloride, and conductivity
INBH-3	3044	Core	2.5	15.5	TPH, chloride, and conductivity
INBH-3	3045	Core	5.5	15.5	TPH, chloride, and conductivity
MBH-1	3046	Core	1	45	TPH, chloride, and conductivity
MBH-1	3047	Core	14	45	TPH, chloride, and conductivity
MBH-1	3048	Core	34	45	TPH, chloride, and conductivity
MBH-2	3049	Core	1	35	TPH, chloride, and conductivity
MBH-2	3050	Core	10	35	TPH, chloride, and conductivity
MBH-3	3051	Core	1	15.5	TPH, chloride, and conductivity
MBH-3	3052	Core	15	15.5	TPH, chloride, and conductivity

*Depth to water surface in borehole (ft below ground surface [bgl]) taken from each borehole for laboratory analysis: shallow subsurface, any interval indicating the presence of contamination, the capillary fringe if no field indication of contamination was found, and at total depth.

Samples of waste material, soil, and subsurface core were placed into precleaned glass jars equipped with Teflon-lined lids. Sample aliquots destined for different analyses or laboratories were given unique sample-identification numbers (table 3.1; appendix B). The samples were kept cool in an ice chest during storage and transportation to the RRC Surface Mining and Reclamation Laboratory and ChemSolve for chemical analysis. Chain-of-custody documentation was completed and maintained throughout transfer of samples to the laboratory. The analytical reports, chain-of-custody documentation, and quality-control-data documents are included in appendix B.

3.2.2 Ground-Water Sampling and Hydrologic Testing

Ground-water samples were obtained on June 4 and 5, 1997, from boreholes INBH-1, INBH-2, MBH-1, MBH-2 and from two private water-supply wells (43-43-Sch2 and 43-43-Sch4) near the site (table 3.1; figs. 3.1 and 3.2). Boreholes were sampled within a few hours of drilling completion. Approximately 1.5 gal (~0.006 m^3) of water was removed from each borehole prior to sampling. Water well 43-43-Sch4 is used to supply water to two trailer homes adjacent to the site. To sample this well, water was drained from the pressure tank, and the sample was then collected from the tap at the wellhead. The other sampled well (43-43-Sch2) did not have a dedicated pump. A 4-inch (10-cm) submersible pump was temporarily placed in the well to purge the well and collect a water sample for analysis. We purged approximately 260 gal (~1 m^3), or about 1.8 well-bore volumes, prior to sampling.

Water levels were measured in the boreholes and the accessible water-supply wells by means of a standard electrical wireline probe. Water-level elevations in the boreholes were calculated relative to the arbitrary local ground-surface datum and are not comparable to regional values of hydraulic head.

A test to estimate transmissivity was conducted at the 43-43-Sch2 water well in conjunction with collection of water samples for chemical analysis. The hydrologic test consisted of unsteady-state drawdown with water-level changes measured in the pumping well. Discharge rate was measured by means of a 4-L bucket and stopwatch. Ground-water samples were collected at completion of the drawdown phase of the tests. Transmissivity was estimated from specific capacity, calculated from discharge rate and the drawdown after 23 min.

Ground-water samples were analyzed for volatile organic compounds (VOC's), chloride, electrical conductivity, alkalinity, RCRA 8 metals, cations, and anions. Samples for analysis of ionic constituents and dissolved metals were filtered by a 0.45-µm cartridge filter using pressurized air or line pressure at the two pumped wells. Metals and cation samples were acidified by 6N HNO_3 (1 mL per 125-mL sample). Samples for VOC's, metals, and cations (acidified) and anions (unacidified) were collected in different containers and assigned unique sample-identification numbers (see chain-of-custody documentation, appendix B). Temperature and pH were measured in the field. All samples were placed into precleaned glass jars equipped with Teflon-lined lids, stored in a sample shuttle containing ice, and transported to ChemSolve for chemical analysis. The analytical reports, chain-of-custody documentation, and quality-control documents are in appendix B. Analytical results are discussed in Section 4.5.2.

3.3 Domestic Well Inventory

Because State well records (table 2.2; fig. 2.1) do not list all wells near the site, an inventory was made of the water-supply wells on property adjacent to the site. Wells located within a 0.4-mi (0.6-m) radius of the site are shown in figure 3.2. Water well 43-43-Sch4, 1,600 ft (490 m) south of the site, is used to supply water to two trailer homes adjacent to the site. Water well 43-43-Sch2, 1,200 ft (365 m) northwest of the site, is not used. The landowner indicated that he had drilled a number of other wells into the same ground-water zone at various locations on his property that were never completed because of unfavorable water quality. Well 43-43-W1 is located 700 ft (210 m) southeast of the site for residential water supply. The pump in well 43-43-Ry1 (fig. 3.2) located on an adjacent property east of the site did not have power, and the well was not sampled in this study.

3.4 Global Positioning System Survey

Global positioning system (GPS) data, compass, bearing, and distance measurements were combined with aerial photography to generate site maps. The GPS survey utilized a Omni Star real-time differential receiver in conjunction with a Trimble Pathfinder GPS receiver. A private service wide-area network was used for differential corrections to increase location accuracy. At selected locations (water wells and geophysical transect end points), a real-time differential global positioning system (DGPS) was used in a static mode to acquire as many as 180 positions at a rate of about 1/s. These data were averaged to yield positions accurate to within 3 ft (1 m). Road intersections were also surveyed to provide ground-control points for georeferencing vertical aerial photography. A kinematic (walking) DGPS survey of roads, a trash pit, and the barren area was also conducted. Borehole and trench locations were determined by using aerial photography and measurement of the distances and directions from locations surveyed by DGPS using a tape and compass.

Positional data were organized, evaluated for accuracy, and transferred to ArcView, a Geographic Information System (GIS) software. We computer scanned a 1:24,000-scale, black-and-white, vertical aerial photograph taken on November 21, 1991. This scanned image was georeferenced, mathematically corrected for distortion, and imported into the GIS. The photograph served as a backdrop to the positional data and allowed the on-screen digitizing of features not measured in the field.

4.0 RESULTS

4.1 Site Stratigraphy

There are four stratigraphic units interpreted at the site (fig. 4.1). Unit 1, at a depth of about 20 ft (~6 m) below surface, is tentatively identified as weathered Permian bedrock, although because of low recovery, the lithology was poorly known. Fragments of core from the lower part of unit 1 are interbedded clay and muddy sand stained yellow by limonite. Red clay in INBH-2 and sand containing pedogenic carbonate recovered in INBH-1 could be Blaine Formation or the oldest of the alluvial units. Low core recovery prevents determination of the presence of fractures in this interval. Regional characteristics of the Blaine Formation suggest that fine-grained silty clay layers within the section are probably areally extensive and may have low vertical hydraulic conductivity; however, core recovery was insufficient to assess thickness and number of clay beds and their hydraulic properties.

Units 2 and 3 represent presumably Pleistocene-age sediments deposited on eroded bedrock. Unit 2 is a cobble to granule gravel with a well-developed (Class III or IV) pedogenic carbonate at the top, 12 to 15 ft (3.7 to 4.6 m) below ground level. Clasts include rounded and angular limestone and chert that were probably derived from Cretaceous carbonates and clasts of soft carbonate that may be pedogenic carbonate or weathered Cretaceous carbonates. Rounding indicates fluvial transport; other clasts may be locally derived. The well-indurated pedogenic carbonate at the top of the gravel and the dramatic change in grain size indicate that the contact between unit 2 and the overlying unit 3 was unconformable. Because some of the core from this interval was recovered by hammering, the presence of natural fractures could not be determined. Pedogenic carbonate and clay matrix occlude pore throats in the gravel near the top of the unit and may limit vertical permeability. Sandy gravel is interbedded with clay in the lower parts of the unit.

Unit 3 is a thick unit composed of a complex of fine to coarse-grained alluvial sediments with moderately well developed soil texture and a weak to moderately developed (Class I to III) pedogenic carbonate horizon at the top. The westernmost two boreholes (INBH-1 and INBH-2)

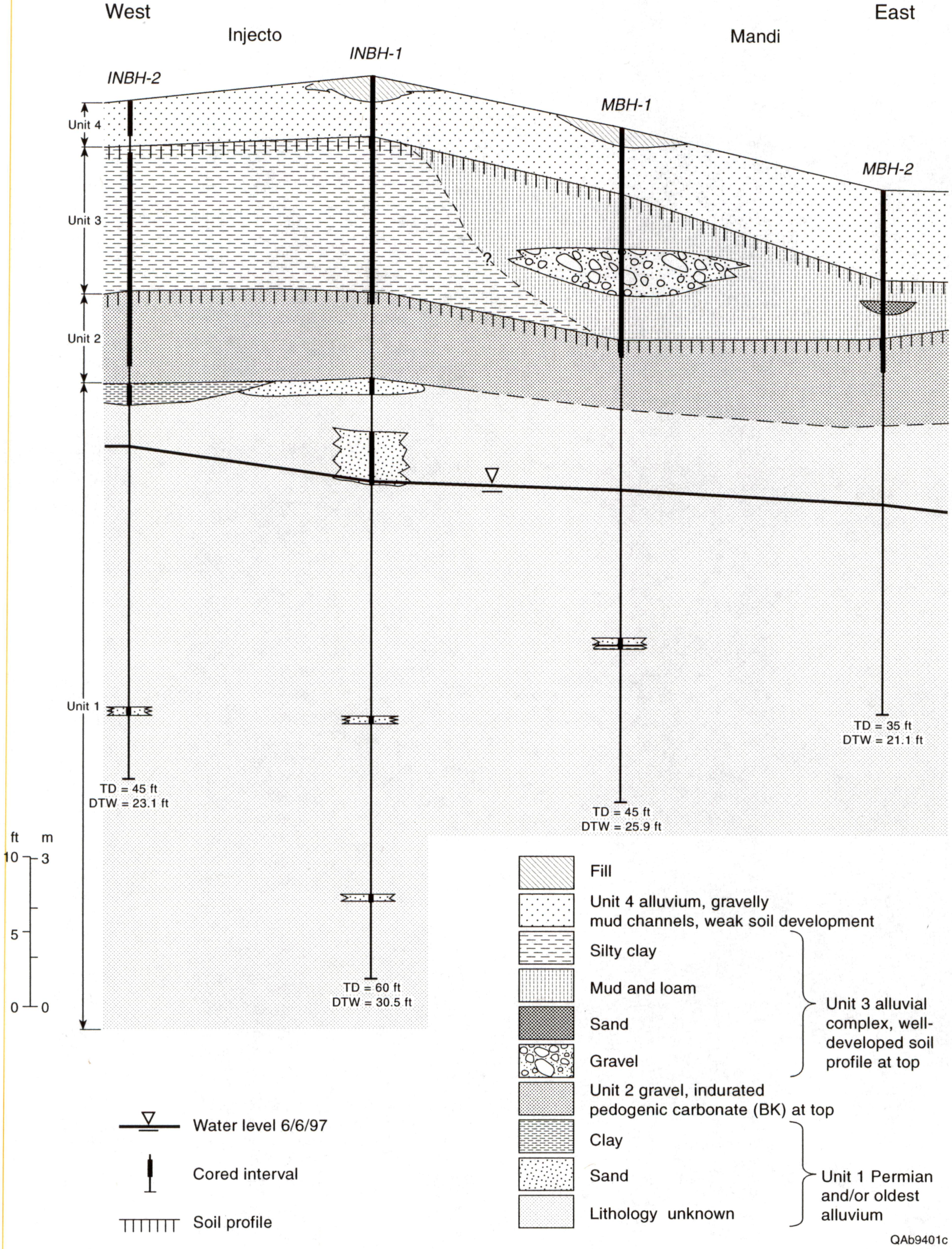

Figure 4.1. Cross section of the shallow subsurface at the Mandi-Injecto site. Cored intervals and cuttings from four boreholes. TD – total depth, DTW – depth to water in borehole.

penetrated fairly homogeneous reddish-brown loam containing pedogenic carbonate nodules and cements. The eastern two boreholes (MBH-1 and MBH-2) penetrated sand and gravel channel fills overlain and underlain by clayey sediments. Internal stratigraphy of this unit is complex. Soil peds and root tubules that developed during soil formation may function as preferential flow paths through this zone under unsaturated conditions. Matrix permeability probably varies according to texture.

Unit 4, from ground surface to a depth of 6 ft (1.8 m), is a loam that has carbonate granules and pebbles presumably of Holocene age. A weakly developed soil profile has an organic concentration at the top but minimal clay or carbonate accumulation and little development of soil structure. A gravel unit having an upward-fining grain size at INBH-2 indicates that unit 4 was also probably deposited by alluvial processes. Surface sediments cored at MBH-1 appear to be fill material.

4.2 Geophysical Survey

Four geophysical transects consisting of 406 data points and four down-hole geophysical logs were analyzed. Surface geophysical data depict

(1) high conductivity beneath the barren ground and lateral decrease in conductivity away from the center of the barren area (fig. 4.2a, c),

(2) decrease in conductivity with depth beneath the barren area, and

(3) increase in conductivity with depth at the end of the transects lateral to the barren ground (fig. 4.2a, c, f, i).

Borehole locations were targeted along the geophysical lines to provide additional data where subsurface conductivity is high beneath the barren ground and where conductivity falls off adjacent to the barren ground. Down-hole geophysical data agree with the surface geophysical results and indicate the following:

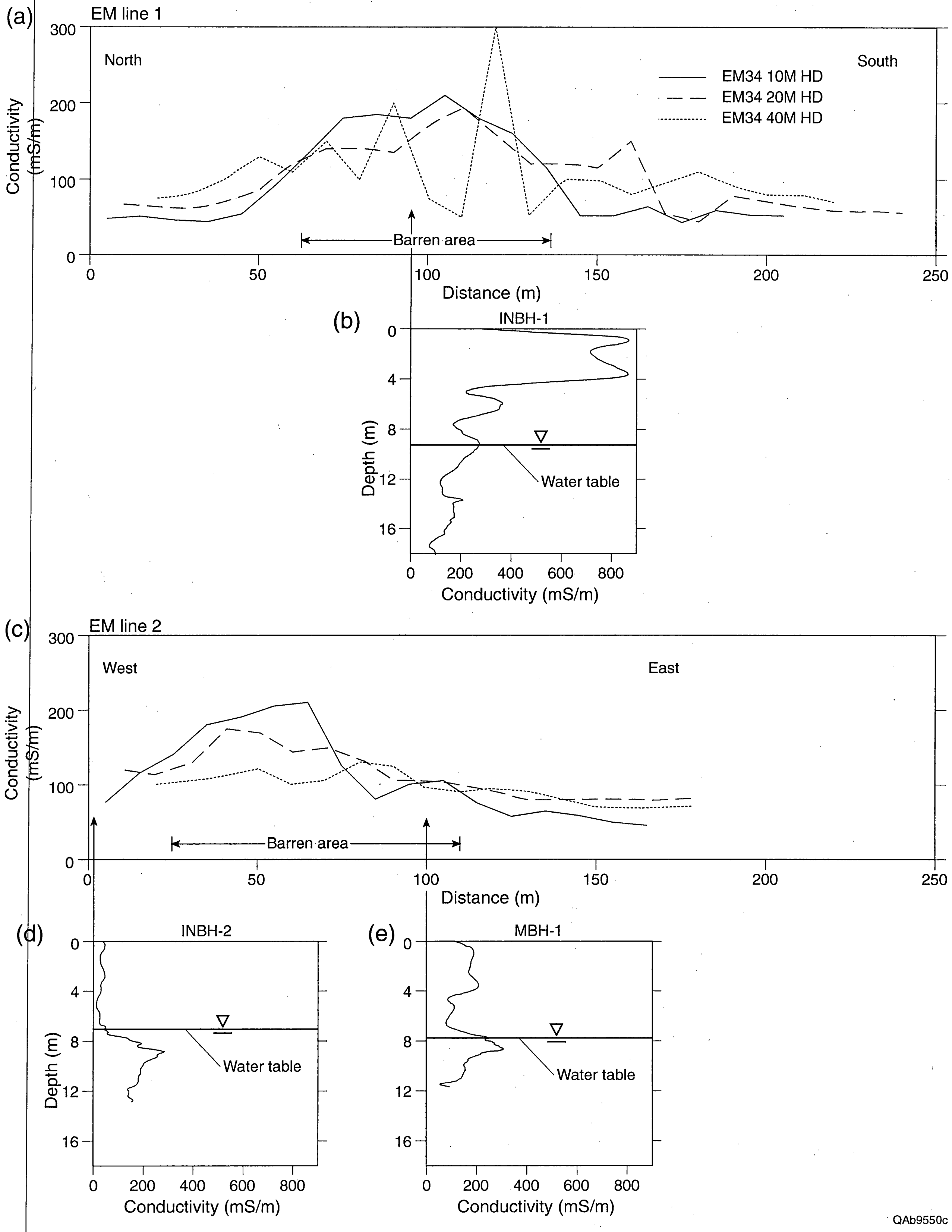

Figure 4.2. Results of EM 34-3 (a, c, f, and i) and EM 39 (b, d, e, g, h, and j) borehole electromagnetic geophysical surveys. Survey lines and borehole locations shown in figure 3.1.

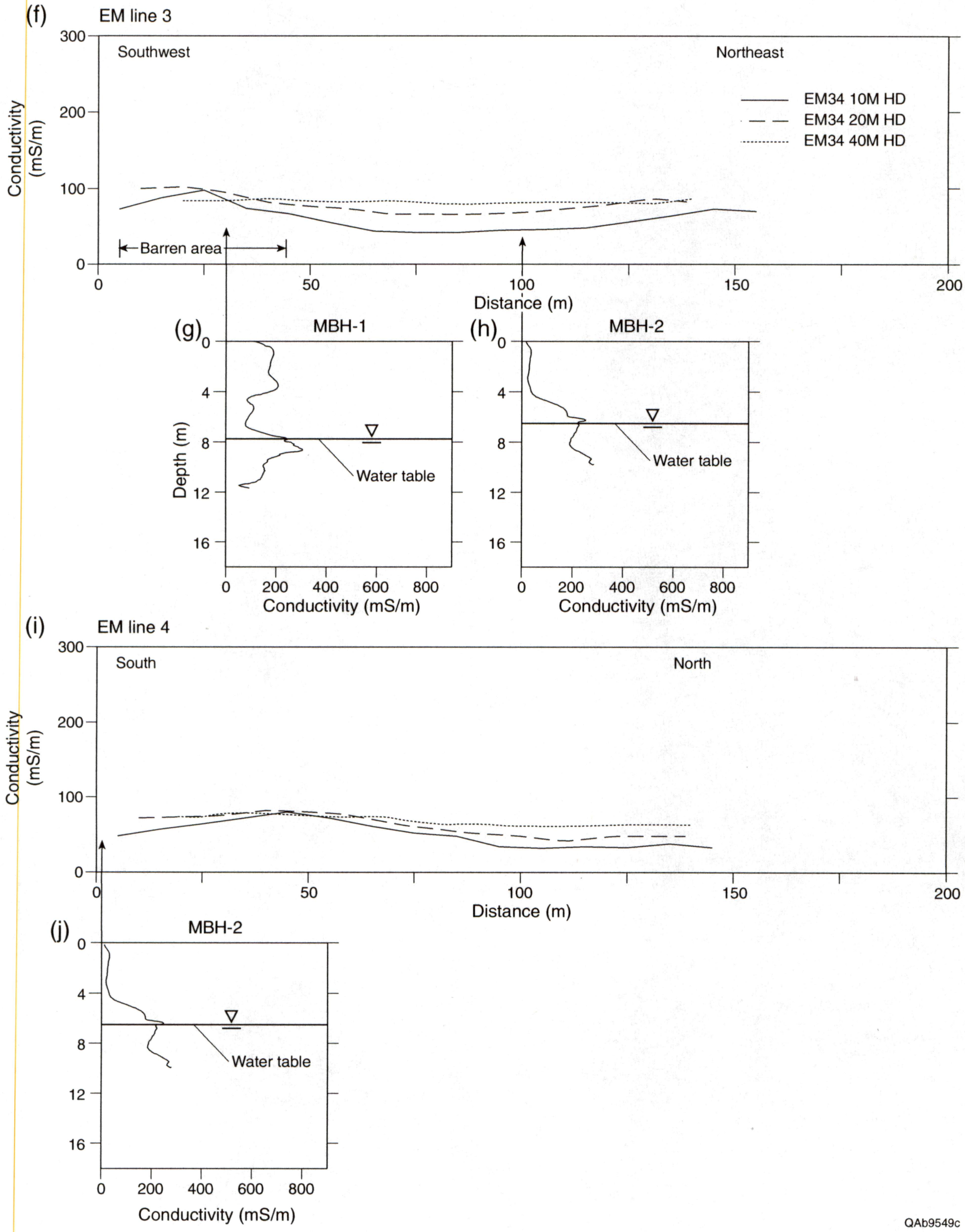

Figure 4.2 (continued). Results of EM 34-3 (a, c, f, and i) and EM 39 (b, d, e, g, h, and j) borehole electromagnetic geophysical surveys. Survey lines and borehole locations shown in figure 3.1.

(1) There is a zone of elevated conductance (salinity) in the top 13 ft (4 m) across the barren area, the Injecto area having the highest conductance. For example, figure 4.2b is a down-hole EM induction log in borehole INBH-1 at the center of the barren area. It shows elevated conductivity (>400 mS/m [>40,000 mmho/cm]) at depths of less than 13 ft (<4 m) and lower conductivity (<200 mS/m [<20,000 mmho/cm]) at depths greater than 33 ft (>10 m). At MBH-1 (fig. 4.2e), conductivity is highest in the top part of the unsaturated section. The decrease in conductivity seen with depth in these boreholes matches the results of the EM-34 surface geophysical survey, in which the 10-m survey (shallow penetration) readings are greater than the 20-m survey (deeper penetration) readings.

(2) Subsurface conductivity falls off away from the center of the barren area. The borehole induction logs in INBH-2 and MBH-1 (fig. 4.2d, e) show lower conductivity than do the logs in INBH-1 (fig. 4.2b). These match the lateral changes in conductivity shown in the surface survey (fig. 4.2a, f).

(3) Conductivity increases with depth at the end of the transects away from the barren ground (compare borehole log in MBH-2 [fig. 4.2h] with line 3 survey [fig. 4.2f]). In other words, conductivity in the unsaturated zone is elevated mainly beneath the barren ground, whereas conductivity of ground water is high beneath and somewhat down gradient of the barren ground.

In INBH-2 and MBH-2, conductivity remains relatively low with depth down through unit 2 and increases only in Permian bedrock (unit 1) or beneath the water table. Conductivity is elevated in the upper part of the unsaturated zone at INBH-1 and MBH-1 (fig. 4.3). We infer the decrease in conductivity at a depth of about 13 ft (~4 m) to coincide with the base of unit 3. Low-permeability cement in the gravel at the top of unit 2 might retard the downward movement of water from unit 3. Immediately below the water table in unit 1, conductivity remains high but appears to decrease with depth. The water table does not exactly correspond to the increase in

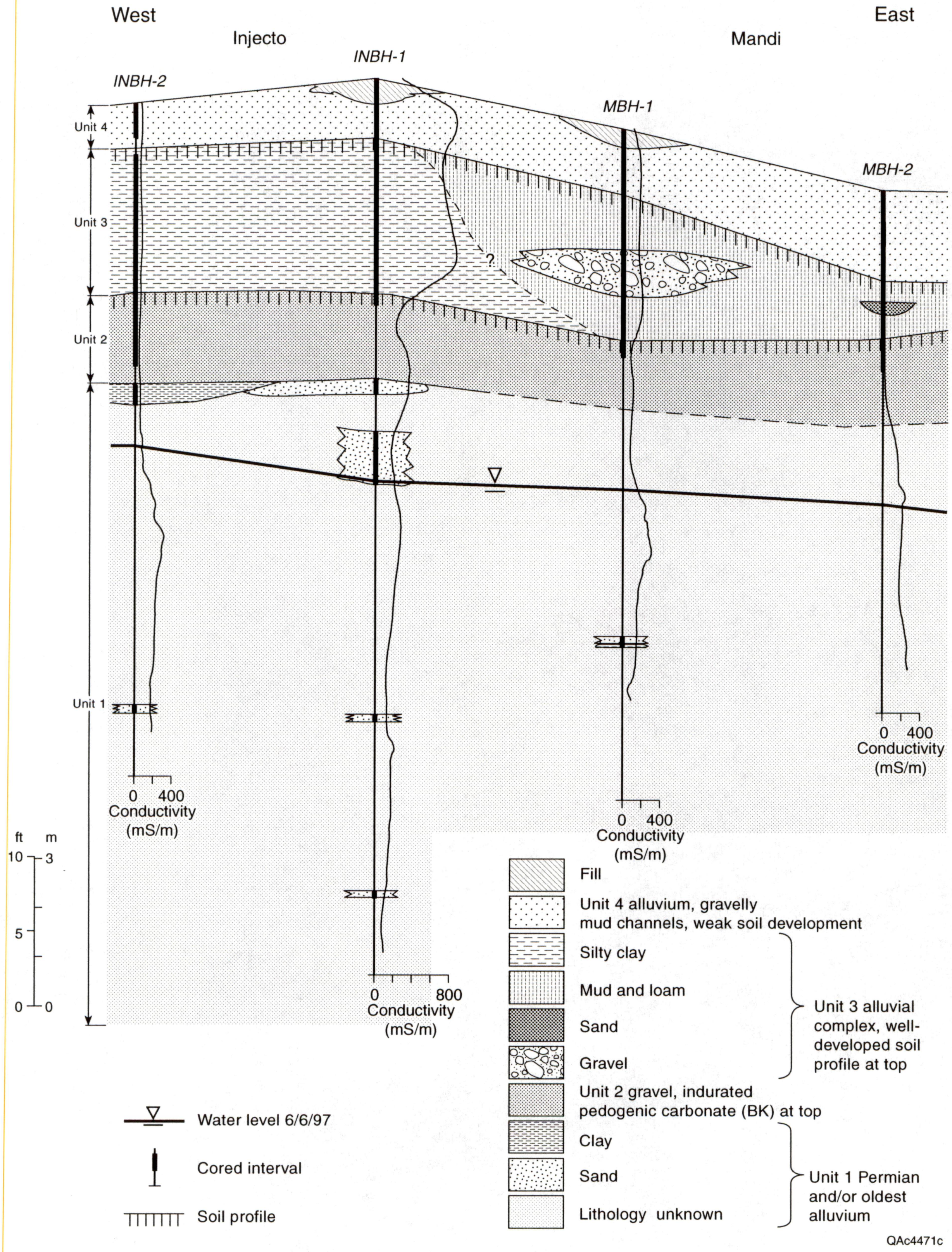

Figure 4.3. Relationship between borehole conductivity and site stratigraphy and hydrology. EM-39 induction log run in PVC pipe temporarily set in open boreholes.

conductivity with depth within unit 1, possibly because the water-table profile reflects a measurement on one date, whereas the composition of ground water is a long-term average.

Readings from the surface geophysical surveys suggest that background soil salinity is reached within the length of the transect lines (fig. 4.4). Analytical results from soil and water samples, however, indicate that a salinity plume in ground water extends down gradient at least as far as MBH-2, as discussed in Section 4.5.2.

4.3 Waste Package

The waste package at the Mandi-Injecto site consists of the disposal trench (area A) and surrounding overflow area (area B) (fig. 3.1 inset). Analytical results indicate that the waste, generally nonhazardous, has elevated levels of TPH, chloride, and spot occurrences of nonexempt NORM. TCLP results indicate that leaching potential for organic or metal constituents from this waste is minimal.

Trench excavations dug by a backhoe served to delineate the boundary of the disposal trench, determine its depth and volume of contents, and provide visualization (inspection and sampling) of its contents. The disposal trench and surrounding overflow area are estimated to contain no more than 475 yd^3 (360 m^3) of waste material, 275 yd^3 (210 m^3) in area A and 200 yd^3 (150 m^3). This amount is about twice the volume estimated in the RRC file from the 1989 cleanup action. The disposal trench (area A, fig. 3.1 [inset]) covers an area approximately 40 × 40 ft (~12.2 × 12.2 m) or 1,600 ft^2 (150 m^2). The thickness of the waste package in the disposal trench is 5 to 5.5 ft (1.5 to 1.7 m). Native soil was exposed beneath the waste package in all 12 trench excavations (fig. 3.1). The waste material found in the disposal trench consists primarily of basic sediment and oil-field waste. Other waste material was not found. The overflow area B underlies approximately 2,600 ft^2 (~240 m^2) around the disposal trench and contains additional waste material as much as 3 ft (1 m) thick (fig. 3.1). The disposal trench and surrounding material was found to be covered by 0.5 to 1 ft (0.2 to 0.3 m) of soil.

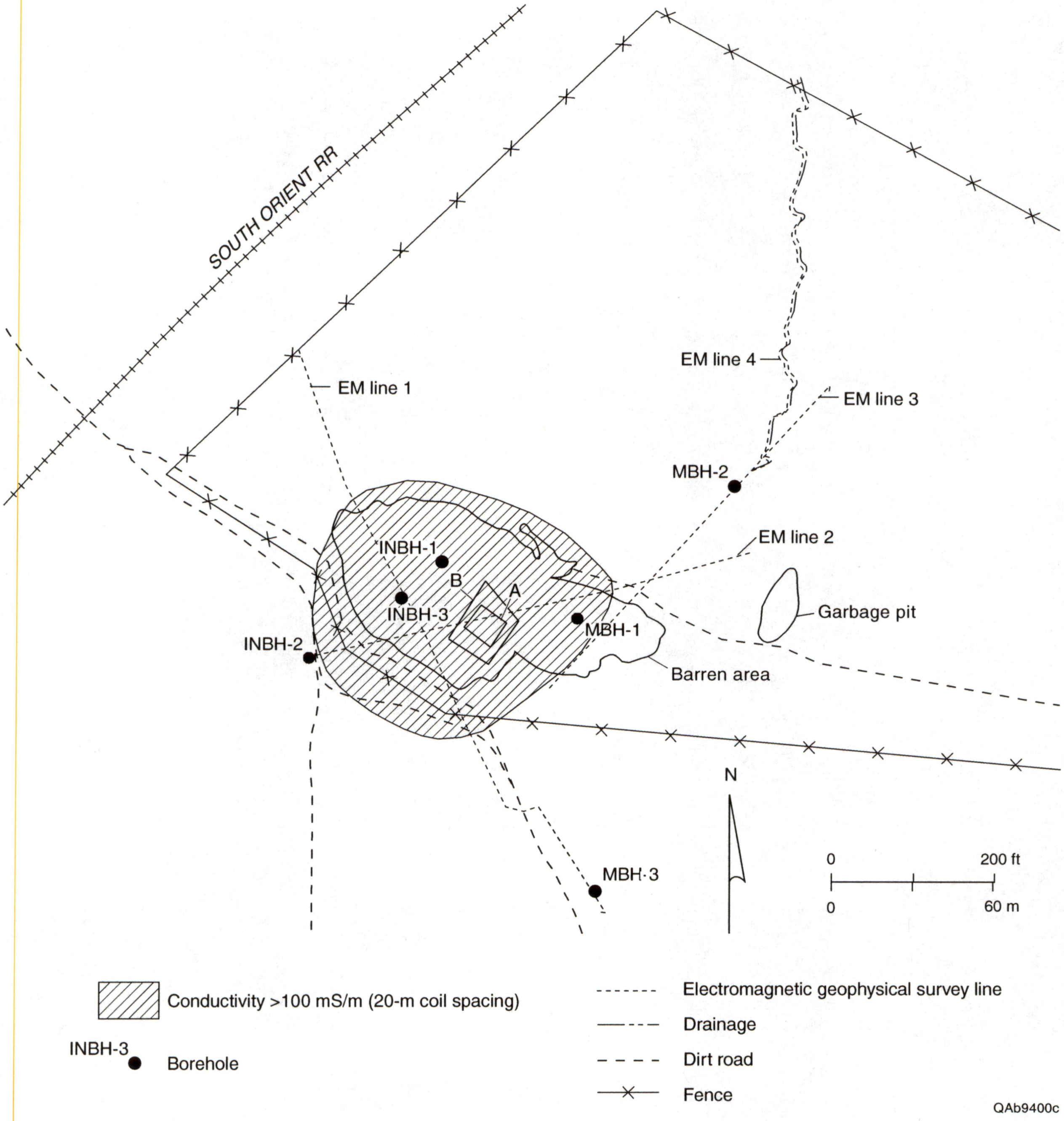

Figure 4.4. Area of elevated conductivity in the unsaturated zone inferred on the basis of EM 34 data (20-m coil spacing) and analyses of borehole samples.

The waste material in the disposal trench had TPH of 13 to 14 percent, chloride of 8,900 to 10,417 mg/kg, total barium at 410 mg/kg, and a TCLP barium of 12 mg/L (table 4.1). Note that the TPH analyses of 13 to 14 percent at depths of 3.25 to 4.16 ft (1 to 1.3 m) reported by two laboratories are consistent. Volatile organic compounds were below detection limit (table 4.2) partly because of high TPH; laboratory estimates of ethylbenzene, naphthalene, xylene, and toluene were all between 1.5 to 4.5 mg/kg, well below action levels for leaking petroleum-storage tanks (Texas Natural Resources Conservation Commission, 1996a). Other metals above the detection limit but well below any guidance level include chromium, copper, lead, nickel, and zinc. TCLP analytes above detection limits include cadmium, mercury, and benzene, but all TCLP levels were well within regulatory limits for nonhazardous waste (table 4.2). Samples from the overflow area surrounding the disposal trench had TPH levels ranging from 2.9 to 6.1 percent and chloride ranging from 2,326 to 6,721 mg/kg. Sample 3027 of the native soil from beneath the disposal trench had a TPH of 0.02 percent and chloride of 5,490 mg/kg (table 4.1).

A NORM sample (no. 3034) having above background scintillometer readings taken from the disposal trench contained Ra-226 at 276.52 pCi/gm, Ra-228 at 20.37 pCi/gm, Pb-210 at 79.77 pCi/gm, and total activity of 916.02 pCi/gm. Under TDH's Texas Regulations for Control of Radiation (TRCR) Part 46.4(a)(1) and (2), NORM materials are exempt if one or more of the following three criteria are met:

(1) if the radon emanation rate is less than 20 picocuries per square meter (pC/m^2) and the concentration of technologically enhanced radium-226 or radium-228 does not exceed 30 picocuries per gram (pC/g) in media other than soil or averaged over any 1,076 ft^2 ($100\ m^2$) and the first 0.5 ft (15 cm) of soil below the surface,

(2) if the radon emanation rate is greater than or equal to 20 pC/m^2 and the concentration of technologically enhanced radium-226 or radium-228 does not exceed 5 pC/g in media other than soil or averaged over any 1,076 ft^2 ($100\ m^2$) and the first 0.5 ft (15 cm) of soil below the surface, or,

Table 4.1. Results of analysis of soil and waste material from excavation trenches.

Sample ID	Sample number	Depth (ft)	TPH (%)	Chloride (mg/kg)	Conductivity (mmhos/cm)	Moisture (%)
Long Trench	3033*	3.25	13	8,900	22.6	16.2
Long Trench	3026	4.16	14	10,417	32	32
Long Trench	3027	7.7	0.02	5,490	17	12
Trench 2	3028	2.25	6.1	2,919	9.7	19
Trench 3	3029	1.5	2.9	6,721	21	18
Trench 7	3025	2.4	4.8	2,326	8.2	19

*Analyzed by ChemSolve; all others by RRC Surface Mining and Reclamation Laboratory

Table 4.2. Analytical results for disposal-trench sample 3032-3033 taken at a depth of 3.25 ft. Multiple sample numbers assigned to aliquots taken for different analyses or laboratories.

Analyte	**Results**	**Units**	**PQL**	**Method**	**Regulatory standard (mg/kg)**	**Reference**
Volatile organic compounds	bdl					
Polynuclear aromatic hydrocarbons	bdl					
TPH	130,000	mg/kg	2,250			
Total organic halogens	1.2	mg/kg	1	9020		
Pesticides/PCB	bdl					
Chloride	8,900	mg/kg	0.5	300.1		
pH	8.2			9045		
Electrical conductivity	22.6	mmhos/cm				
Ignitability	>150	°F	22	1010		
Reactivity cyanide	<10	mg/kg	0.02	7.3.3.1		
Reactivity sulfide	<10	mg/kg	10	7.3.3.2		
Moisture	16.2	% dry weight		ASA		
Metals						
Arsenic	3.5	mg/kg	0.1	6010	36	TNRCC (1996b)
Barium	410	mg/kg	0.1	6010	2000	TNRCC (1996b)
Cadmium	0.15	mg/kg	0.1	6010	10	TNRCC (1996b)
Chromium	19	mg/kg	0.1	6010	100	TNRCC (1996b)
Copper	15	mg/kg	0.1	6010		
Lead	22	mg/kg	0.1	6010	30	TNRCC (1996b)
Mercury	<0.02	mg/kg	0.02	7470	4	TNRCC (1996b)
Nickel	4.5	mg/kg	0.1	6010		
Potassium	1,900	mg/kg	2	6010		
Selenium	<0.005	mg/kg	0.1	6010	20	TNRCC (1996b)
Silver	<0.01	mg/kg	0.1	6010	100	TNRCC (1996b)
Zinc	55	mg/kg	0.1	6010		
Ammonia-N	80	mg/kg	1	350.2		
Kjeldahl-N	1,190	mg/kg	1	351.3		
Nitrate-N	<0.5	mg/kg	0.5	300.1		
Ortho-Phosphate	<0.5	mg/kg	0.5	300.1		
Total organic nitrogen	1,110	mg/kg	0.1			

Table 4.2 (cont.). Analytical results for disposal-trench sample 3032-3033.

Analyte	Results	Units	PQL	Method	Regulatory standard (mg/L)	Reference
TCLP Parameters						
TC Arsenic	<0.005	mg/L	0.005	6010	5	EPA (40CFR261.24)
TC Barium	12	mg/L	0.001	6010	100	TNRCC (1996b)
TC Cadmium	<0.005	mg/L	0.005	6010	1	EPA
TC Chromium	0.0092	mg/L	0.005	6010	5	EPA
TC Lead	<0.005	mg/L	0.005	6010	5	EPA
TC Mercury	0.0006	mg/L	0.0002	7470	0.2	TNRCC (1996b)
TC Selenium	<0.005	mg/L	0.005	6010	1	EPA
TC Silver	<0.005	mg/L	0.005	6010	5	EPA
TC 1,1-dichloroethene	<0.005	mg/L	0.005	8260	0.7	EPA
TC 1,2-dichloroethane	<0.005	mg/L	0.005	8260	0.5	EPA
TC 1,4-dichlorobenzene	<0.005	mg/L	0.005	8260	7.5	EPA
TC 2-butanone(MEK)	<0.05	mg/L	0.05	8260	200	EPA
TC Benzene	0.041	mg/L	0.005	8260	0.5	TNRCC (1996b)
TC Carbon tetrachloride	<0.005	mg/L	0.005	8260	0.5	EPA
TC Chlorobenzene	<0.005	mg/L	0.005	8260	100	EPA
TC Chloroform	<0.005	mg/L	0.005	8260	6	EPA
TC Tetrachloroethene	<0.005	mg/L	0.005	8260	0.7	EPA
TC Trichloroethene	<0.005	mg/L	0.005	8260	0.5	EPA
TC Vinylchloride	<0.005	mg/L	0.005	8260	0.2	EPA
TC 2,4-dinitrotoluene	<0.020	mg/L	0.01	8270	0.13	EPA
TC 2-methyphenol	<0.020	mg/L	0.01	8270		
TC 3&4-methylphenol	<0.020	mg/L	0.01	8270		
TC Hexachlorobenzene	<0.020	mg/L	0.01	8270	0.13	EPA
TC Hexachlorobutadiene	<0.020	mg/L	0.01	8270	0.5	EPA
TC Hexachloroethane	<0.020	mg/L	0.01	8270	3	EPA
TC Nitrobenzene	<0.020	mg/L	0.01	8270	2	TNRCC (1996b)
TC Pentachlorophenol	<0.100	mg/L	0.05	8270	100	TNRCC (1996b)
TC Pyridine	<0.040	mg/L	0.01	8270	5	TNRCC (1996b)

bdl = Below detection limit
EPA PMCL = Primary maximum contaminant level
EPA SMCL = Secondary maximum contaminant level

(3) for any other NORM radionuclide, if the concentration does not exceed 150 pC/g in media other than soil or 150 pC/g averaged over 1,076 ft^2 (100 m^2) in soil ([TRCR Part 46.4(a)(1)).

The TRCR defines “technologically enhanced” to mean that the chemical properties or physical state of natural sources of radiation have been altered or the potential exposure pathways of natural sources of radiation to humans have been altered (TRCR Part 46.3). At this site the potential exposure pathways to humans have been altered from their natural source condition; NORM-bearing oil-field waste is considered technologically enhanced. The Mandi-Injecto waste material sample exceeds 30 pCi/g for Ra-226 and does not satisfy the exception criteria presented in TRCR Part 46.4(a)(1).

No visual sign of oil-field waste was noted in four of the five additional trench excavations at various locations around the site. One trench excavation, however, encountered apparently degraded oil-field waste material. TPH was not detected in core samples from INBH-3 at that location, either at a depth of 2.5 ft (0.8 m) in the waste material or at a depth of 5.5 ft (1.7 m) beneath the waste material (table 4.3), which suggests that the oil-field waste material was old and unrelated to the disposal trench. Soil-chloride concentrations were slightly higher in the sample beneath the waste.

4.4 Soils

Soils at the site were sampled in each borehole and at the end of the drainage down gradient from the barren area (fig. 3.1). TPH in soil in the shallow subsurface is very low or below detection limit (fig. 4.5; table 4.3), which partly reflects the previous site cleanup by the RRC. TPH was not detected in deeper soils at the site (fig. 4.5; table 4.3). There was no evidence of TPH or petroleum contamination in core from borehole INBH-2, sited between the Injecto site and the location of a reported oil-contaminated borehole drilled in 1994.

Table 4.3. Analytical results of borehole core samples.

Sample ID	Sample number	Depth (ft)	TPH (%)	Chloride (mg/kg)	Conductivity (mmhos/cm)
INBH-1	3039	1	0.43	6,600	17.02
INBH-1	3041	14	<0.001	9,500	10.76
INBH-1	3040	27	0.0019	1,600	4.17
INBH-2	3042	1	<0.001	230	1.93
INBH-2	3043	18.5	<0.001	120	2.16
INBH-2	3031	45	0.01	459	1.8
INBH-3	3044	2.5	<0.001	1,700	3.98
INBH-3	3045	5.5	<0.001	2,000	5.05
MBH-1	3046	1	0	1,246	4.3
MBH-1	3047	14	0	540	2.1
MBH-1	3048	34	0.01	389	1.5
MBH-1	3030	39.5	<0.001	230	1.57
MBH-2	3049	1	0	5	0.22
MBH-2	3050	10	0	37	0.33
MBH-2	3024	35	0	1793	6.1
MBH-3	3051	1	0	85	0.16
MBH-3	3052	15	0	36	0.58
Drainage	3023	1	0.01	15	0.37

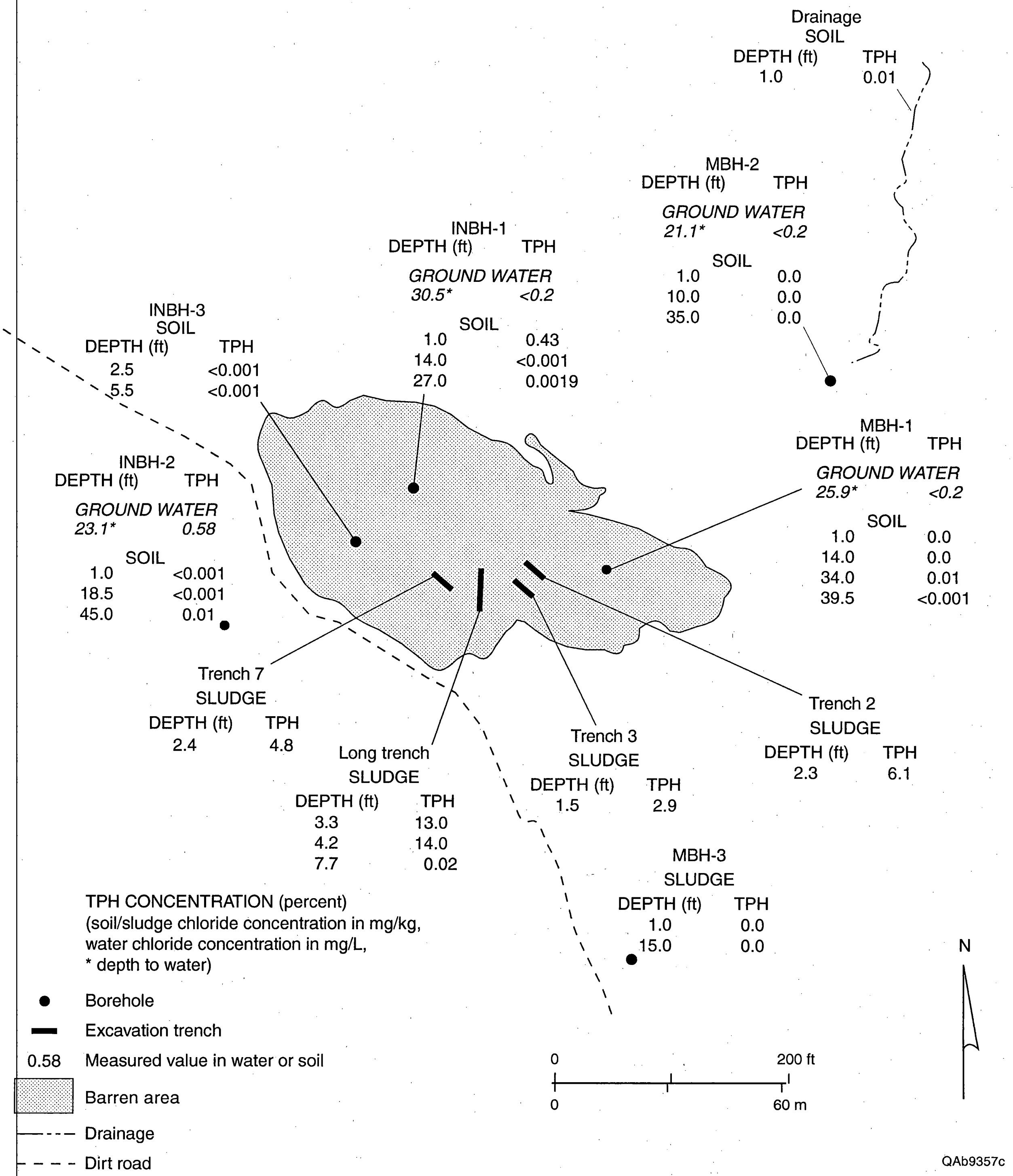

Figure 4.5. TPH concentration measured in soil and ground-water samples.

Elevated levels of chloride concentrations were detected throughout the site (fig. 4.6; table 4.3). The sample from a depth of 14 ft (4.3 m) in INBH-1 contains the highest chloride concentration (9,500 mg/kg). The sample is from the base of the high-conductivity zone logged in borehole INBH-1 (fig. 4.3b). INBH-1 was located in what appears to have been the main contaminated area (figs. 4.2 through 4.4). Chlorides generally decrease with depth through the unsaturated zone.

On the bases of readings from the geophysical survey, borehole log results, and analytical data from the core, we interpreted the area of elevated chloride in soil to be approximately 83,600 ft^2 (~7,770 m^2) (fig. 4.4). The geophysical signature is defined by values greater than the baseline 100 mS/m (10,000 mmho/cm) at the 20-m coil spacing (figs. 4.2 and 4.4). Total mass of chloride in soil above the water table is estimated to be approximately 230 metric tons. This estimate assumes an average thickness of the unsaturated zone of 28 ft (8.5 m), area of elevated salinity of 83,600 ft^2 (7,770 m^2), average soil chlorinity in the impacted area of approximately 2,290 mg/kg (table 4.3), and soil bulk density of 1,500 kg/m^3.

MBH-3 is a background boring, and background levels of chloride are below 100 mg/kg. In surficial samples taken down gradient from the site in the drainage, chloride was 15 mg/kg and no TPH was detected. Down-gradient surface materials, and, by inference, surface runoff, do not contain elevated levels of contaminants; surface runoff was not directly sampled or measured.

4.5 Ground Water

4.5.1 Ground-Water Hydrology

Depth to water in boreholes rose by as much as 7 to 20 ft (2.1 to 6 m) from the initial level measured when the boreholes were drilled to final static levels. It is unknown whether the rise in water level reflects (a) occurrence of water under semiconfined condition or (b) recovery of water in the borehole from low-yielding aquifer materials. Water-level elevations calculated for the boreholes (table 4.4) are relative to the arbitrary local ground-surface datum and are not comparable

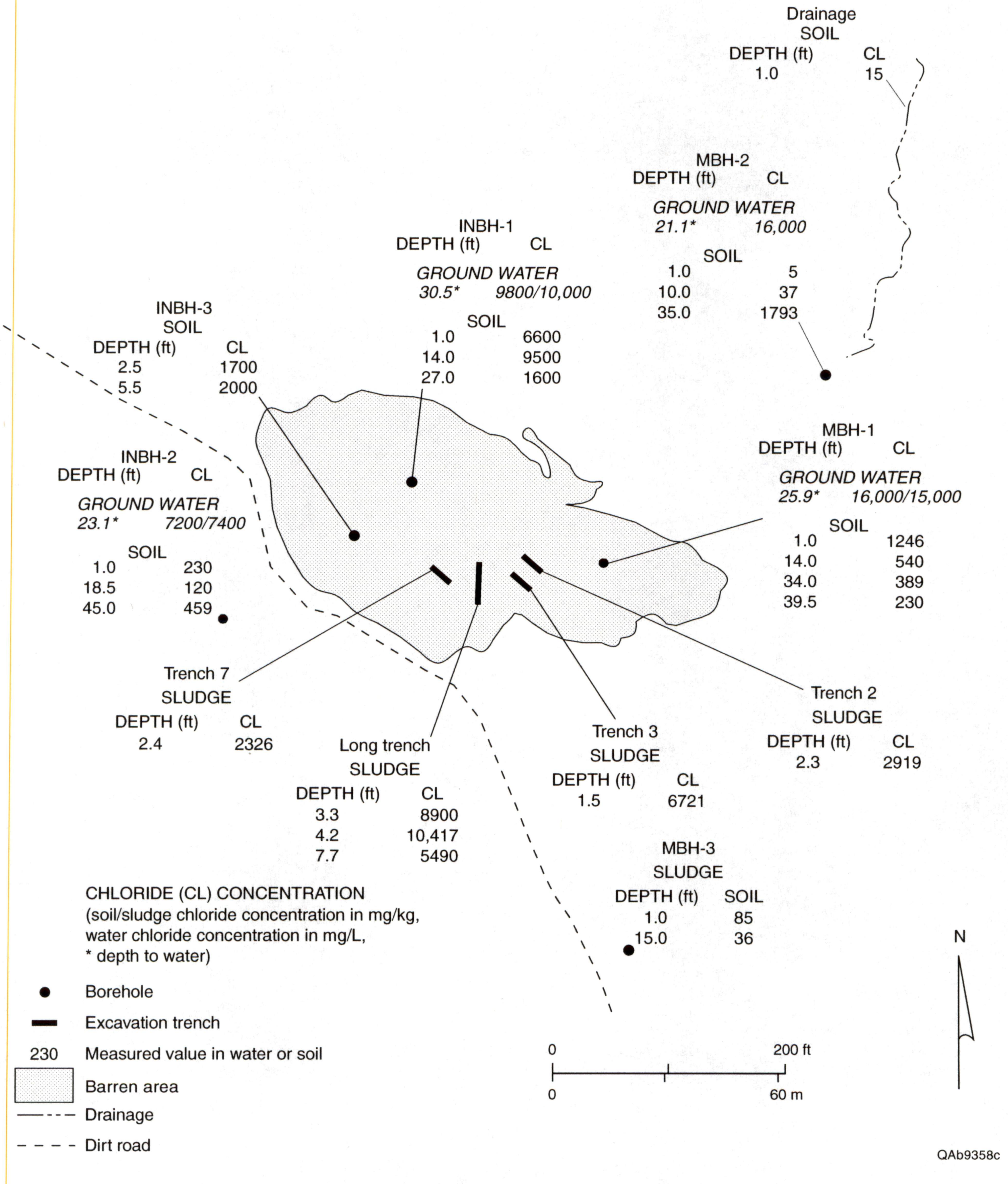

Figure 4.6. Chloride concentration measured in soil and ground-water (INBH-1, INBH-2, MBH-1, and MBH-2 only) samples.

Table 4.4. Measurements of water levels at boreholes and water wells in June 1997.

Well name	Borehole depth (ft)	Relative ground surface elevation (ft)*	Initial depth to water (ft)	Static depth to water (ft)	Relative water level elevation (ft)*
INBH-1	60	100.97	43	30.45	74.5
INBH-2	45	99.94	43	23.05	76.9
MBH-1	47	97.53	35	25.90	73.6
MBH-2	35	93.29	28	21.10	72.2
43-43-Sch1	unknown	nm	unknown	unknown	nm
43-43-Sch2	76.8	nm	unknown	18.47	nm

* Elevation measured relative to local benchmark datum assigned arbitrary elevation of 100 ft. Relative elevations given for purpose of determining local hydraulic-head gradient and not for comparison with regional values of hydraulic head.

nm = Not measured

to regional values of hydraulic head. The local gradient in hydraulic head of the shallow ground water measured in the boreholes is oriented northeast at an inclination of 0.009 (fig. 4.7).

Transmissivity estimated at 43-43-Sch2, derived from a specific-capacity test, was approximately 4 to 13 ft^2/d (~0.4 to 1.2 m^2/d), assuming a saturated thickness of 59 ft (18 m) and a storage coefficient of 0.01 to 0.1. The range in estimated transmissivity is due to unknown completion data from the well. The average linear velocity of ground water at the site, assuming hydraulic conductivity of 0.07 to 0.2 ft/d (0.2 to 0.6 m/d), a porosity of 20 percent, and a hydraulic-head gradient of 0.009, was estimated to be 0.003 to 0.009 ft/d (0.001 to 0.003 m/d), or 1.2 to 3.3 ft/yr (0.35 to 1.0 m/yr). Assumed values of hydraulic conductivity and porosity are more uncertain than the hydraulic-head gradient. A slightly greater velocity is predicted from the apparent length of the salinity plume, as discussed in the next section.

4.5.2 Ground-Water Quality

The chemical composition of waters from the Mandi-Injecto site (fig. 4.8) consists of a mixed-cation–chloride hydrochemical facies (Back, 1966), which was the same as that shown for ground waters in the valley of the Middle Concho River by Richter and others (1990, fig. 4.8). Among all ground-water samples from the Concho River valley, chloride and sodium concentrations are correlated (fig. 4.9a), reflecting the prevalence and predominance of sodium-chloride brine discharging from the Permian basin (Dutton and others, 1989; Richter and others 1990). Ground waters from the Mandi-Injecto site lie along the same trend; as previously noted the samples from the four boreholes are intermediate between typical ground waters and representative oil-field brines, and the samples from the two nearby wells are similar to the typical poor-quality ground waters in the area. Dutton and others (1989) used a bivariate plot of ion ratios—Cl/SO_4 versus Na/Ca—to distinguish (a) brines co-produced with oil from Permian (Pr) and Pennsylvanian (Pn) oil fields and (b) saline ground waters in the area. The samples from the Mandi-Injecto site plot somewhat closer to the “Permian” than “Pennsylvanian” oil-field brine end

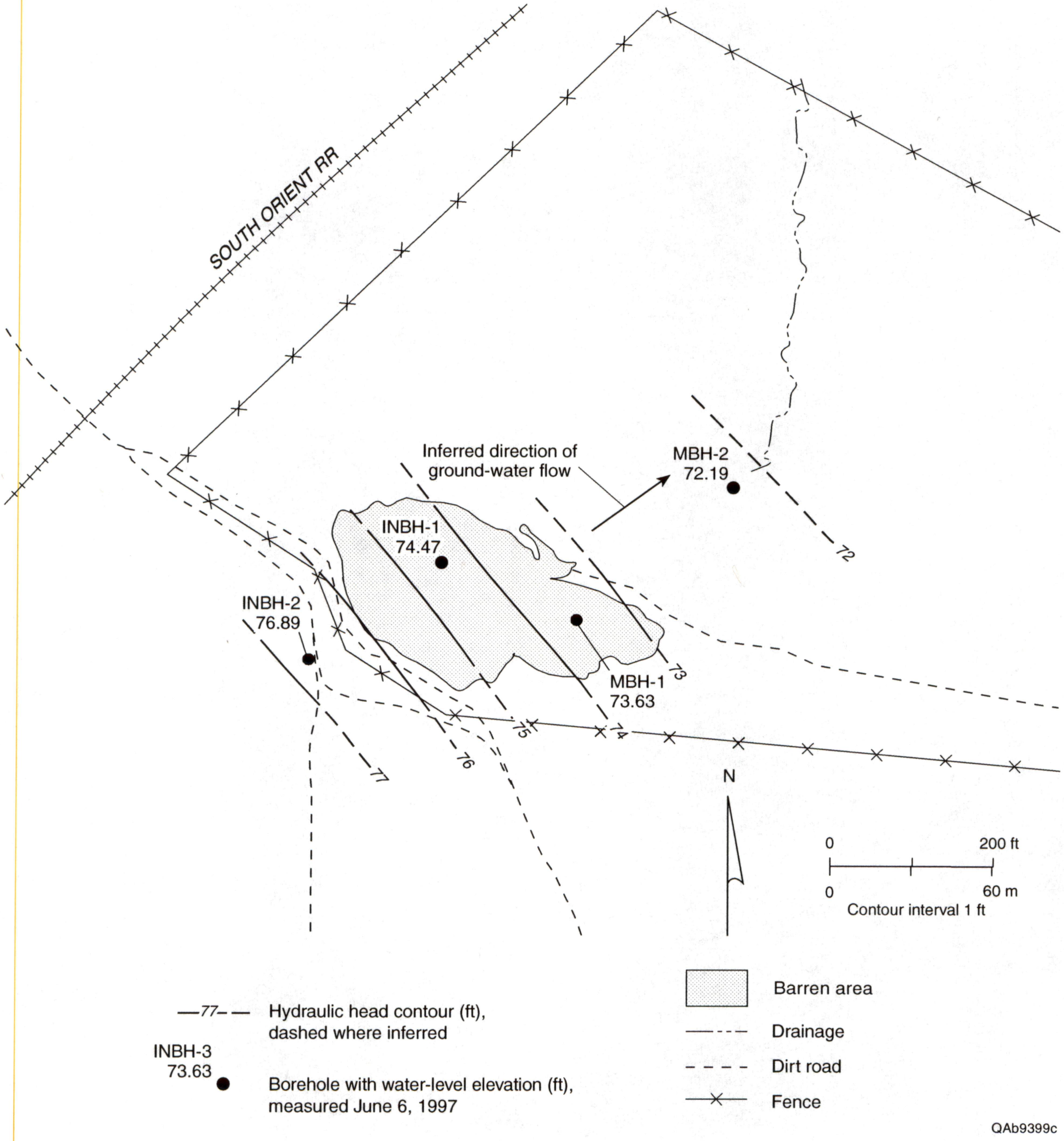

Figure 4.7. Map showing inferred elevation of water-table surface calculated for boreholes at the Mandi-Injecto site. Data given in table 4.4. Elevations, surveyed relative to an arbitrary, local ground-surface datum, are not comparable to regional values of hydraulic head. Inferred direction of horizontal ground-water flow assumes uniform hydrologic properties.

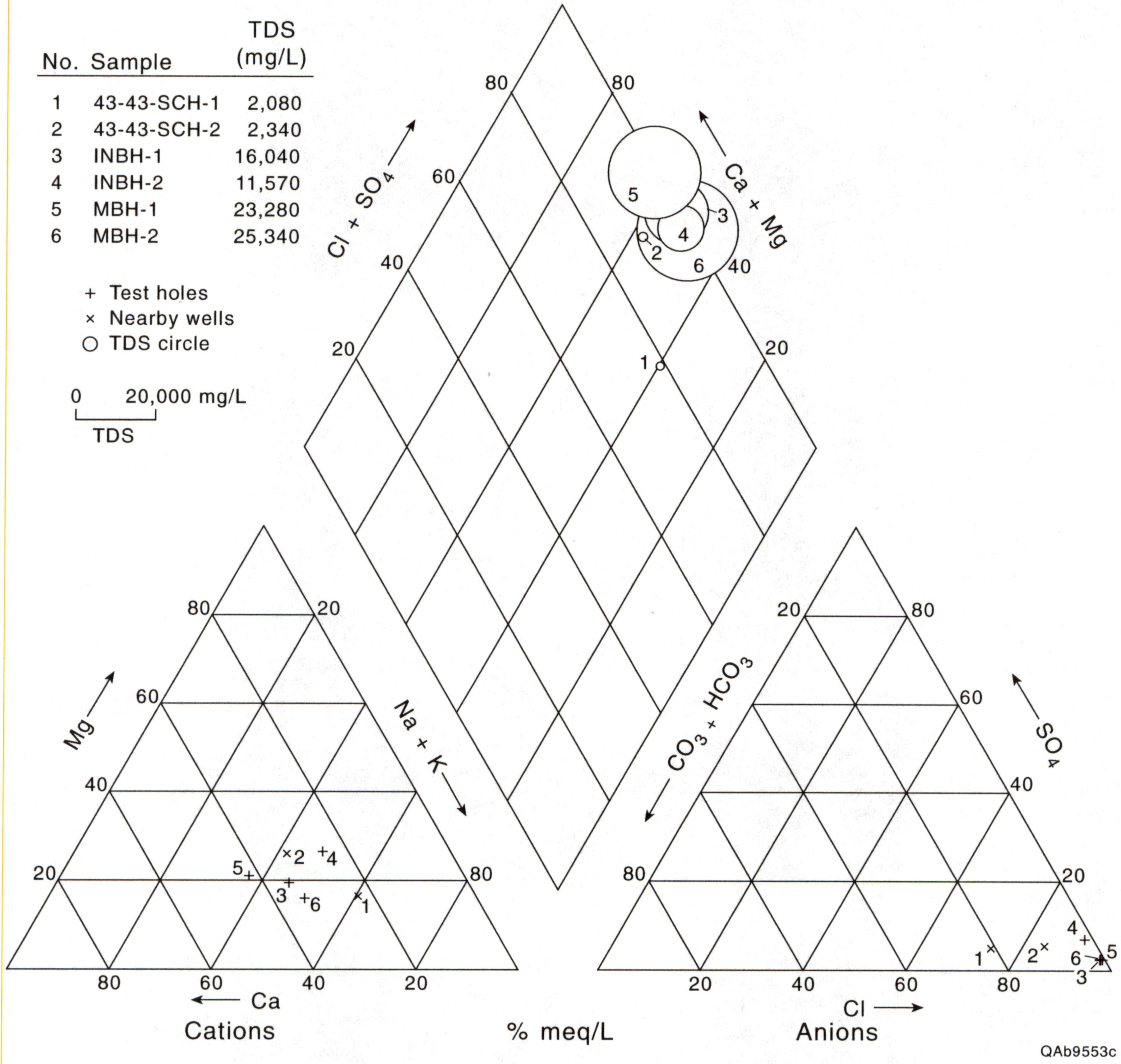

Figure 4.8. Trilinear diagram of cation and anion abundance in ground water from boreholes and nearby water-supply wells.

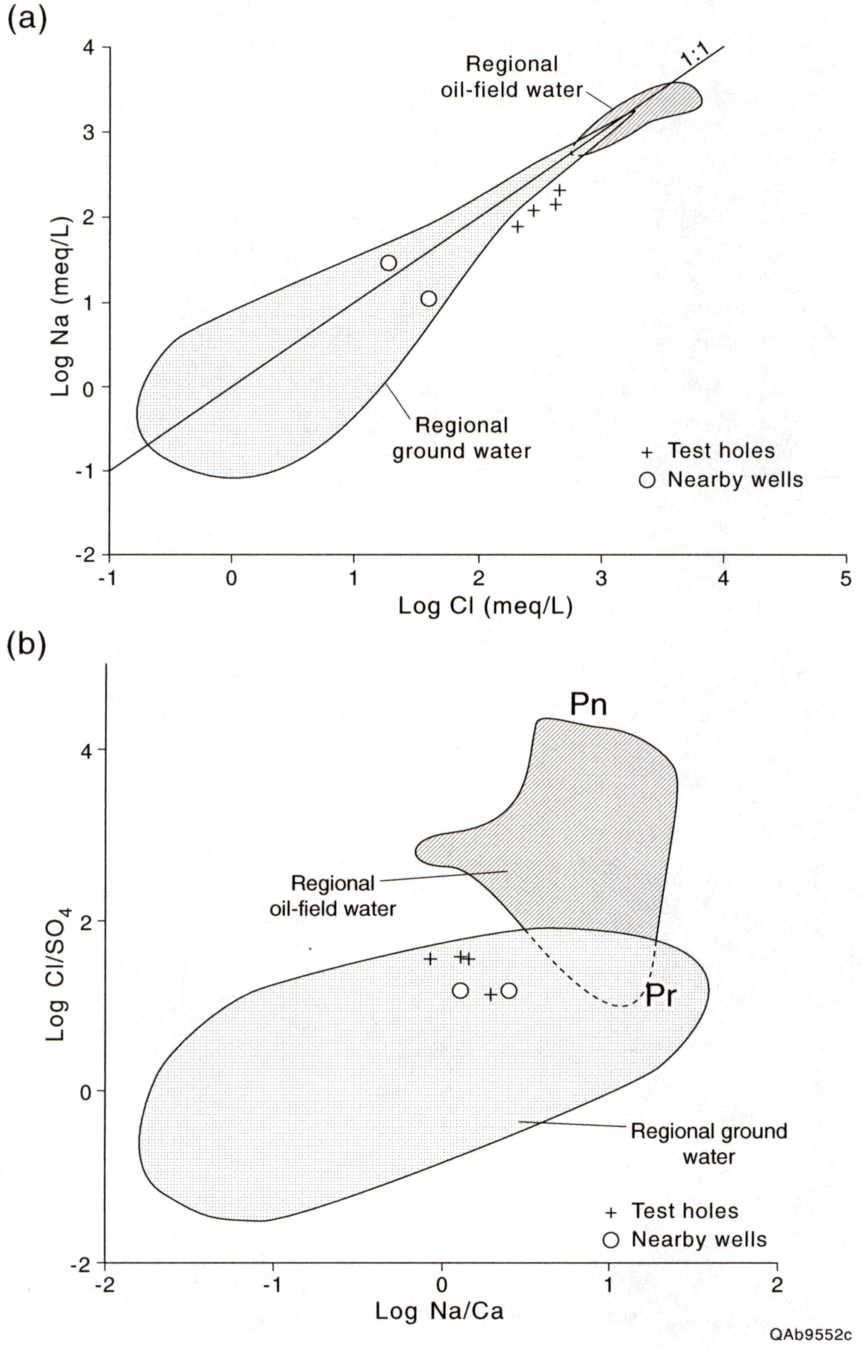

Figure 4.9. (a) Variation in sodium and chloride concentrations and (b) variation in Cl/SO_4 and Na/Ca ratios in water samples collected at the Mandi-Injecto site. Pluses are from onsite boreholes, and circles are from nearby wells. Shaded areas depict regional ground water and oil-field water modified from Richter and others (1990), including Permian (Pr) and Pennsylvanian (Pn) end members of oil-field brine.

member (fig. 4.9b), suggesting that brines brought to the site for disposal were predominantly but not exclusively from Permian oil fields.

Volatile organics were not detected in any of the water samples at the Mandi-Injecto site (table 4.5). A trace amount of TPH was detected in INBH-2 and in water well 43-43-Sch4, which is 1,600 ft (490 m) up gradient of the site. There is no apparent reason to relate the TPH in well 43-43-Sch4 to the site or to other oil- and gas-field activities in the area. Of the RCRA 8 metals, only trace amounts of barium, which were below action level, were detected in the ground water.

The only analyte of concern detected in ground water was chloride; chloride concentration ranges from 7,400 to 16,000 mg/L (table 4.5; fig. 4.6). Chloride concentrations were significantly greater in samples from the boreholes than from the two nearby water-supply wells (670 to 1,400 mg/L), but intermediate between typical ground waters and representative oil-field brines in the region (fig. 4.10). The chloride concentration in the two samples from nearby water-supply wells (43-43-Sch2 and 43-43-Sch4, table 4.5) matches typical, poor-quality ground waters in the area (compare fig. 4.10b and 4.10a, respectively; Richter and others [1990, their fig. 13]). The Concho River valley in Tom Green County tends to have poor-quality ground water owing largely to the natural discharge of brine from Permian formations that underlie the area (Dutton and others, 1989; Richter and others, 1990).

The chloride concentration at MBH-2 is 16,000 mg/L, the same as that at MBH-1 (fig. 4.6), suggesting that whereas the geophysical survey circumscribed the area of elevated soil salinity, it did not completely encompass the area with above-background ground-water salinity, at least east of the barren ground. A minimum estimate of the mass of chloride in ground water at the site is approximately 142 metric tons. This calculation assumes that the areas of elevated ground-water salinity and elevated soil salinity are the same, the thickness of the impacted zone equals the sampled interval thickness of 25 ft (7.6 m), chlorinity is 12,000 mg/L, and porosity is 20 percent. The extrapolated plume shown in figure 4.11 contains an area that is twice the area of elevated soil salinity, which might thus include 280 metric tons of dissolved chloride. Using the apparent plume

Table 4.5. Analytical results of ground-water samples.*

Borehole or well number Sample ID**	43-43-Sch2 3004 to 3007	43-43-Sch4 3000 to 3003	NBH-1 3012 to 3015	INBH-2 3016 to 3019	MBH-1 3008 to 3011	MBH-2 3021 to 3022	MBH-2 3035 to 3036	MBH-2 3037 to 3038	PQL	Method	Regulatory standard	Reference
VOC's	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl				
TPH	<0.2	0.58	<0.2	0.58	<0.2	<0.2	<0.2	0.78	0.2	418.1	5	TNRCC RG-17
pH	6.97	6.68	6.66	7.21	6.64	6.15	nm	nm			6.5 to 8.5	EPA SMCL
TDS	2,133	2,079	16,037	11,562	23,278	25,343	nm	nm			500	EPA SMCL
Conductivity†	3.92	2.13	19	15.9	25	27.4	27.4	26.5				
Arsenic	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	nm	nm	0.005	6010	0.05	EPA PMCL
Barium	0.081	0.053	0.19	0.14	0.24	0.46	nm	nm	0.005	6010	2.0	EPA PMCL
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	nm	nm	0.005	6010	0.005	EPA PMCL
Chromium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	nm	nm	0.005	6010	0.1	EPA PMCL
Lead	<0.005	<0.005	<0.005	0.015	<0.005	<0.005	nm	nm	0.005	6010	0.015	EPA action level
Mercury	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	nm	nm	0.001	7470	0.002	EPA PMCL
Selenium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	nm	nm	0.005	6010	0.05	EPA PMCL
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	nm	nm	0.005	6010	0.1	EPA SMCL
Barium	0.081	0.053	0.19	0.14	0.24	0.46	nm	nm	0.005	6010	2.0	EPA PMCL
Calcium	170	230	1,900	810	3,200	2,800	nm	nm	0.1	6010	na	na
Magnesium	83	100	640	520	970	810	nm	nm	0.1	6010	na	na
Potassium	6.5	18	73	10	33	48	nm	nm	1	6010	na	na
Sodium	250	670	2,800	1,800	3,200	4,700	nm	nm	0.05	6010	na	na
Strontium	1.4	2.9	20	12	25	29	nm	nm	0.005	6010	na	na
Total alkalinity	300	330	210	250	200	280	nm	nm	10	310.1	na	na
Bromide	<1	1.1	24	<10	70	56	nm	nm	0.1	300.1	na	na
Chloride	1,400	670	10,000	7,400	15,000	—	16,000	4,700††	0.05	300.1	250	EPA SMCL
(duplicate)	1,200	570	9,800	7,200	16,000	16,000	—	—	0.05	300.1	250	EPA SMCL
Sulfate	130	61	370	760	580	620	nm	nm	0.05	300.1	500	EPA PMCL

* = Concentrations in mg/L unless otherwise noted
** = Multiple sample numbers from a given borehole or well for aliquots taken for different analyses or laboratories
† = Conductivity in mS/cm (mS/cm = mmhos/cm)
†† = Anomalous value does not fit chloride-conductivity trend
VOC's = Volatile organic compounds
TPH = Total petroleum hydrocarbons
bdl = Below detection limit
na = Not applicable
EPA PMCL = Primary maximum contaminant level
EPA SMCL = Secondary maximum contaminant level

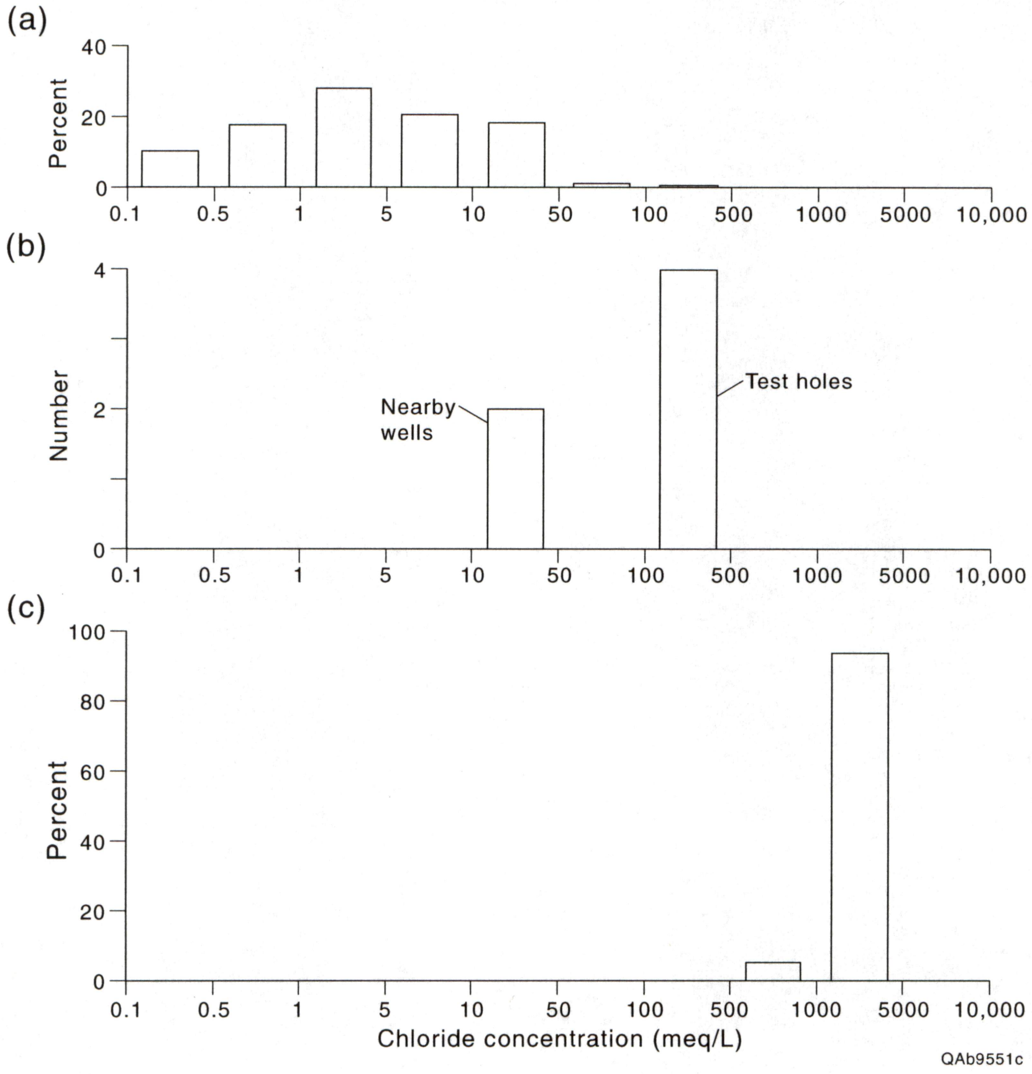

Figure 4.10. Comparison of histograms showing chloride content of ground waters from (a) wells throughout Tom Green and eastern Irion Counties (708 samples), (b) test holes and nearby wells at the Mandi-Injecto site, and (c) oil-field brines from Permian and Pennsylvanian formations in Tom Green and eastern Irion Counties (17 samples); a and c from data in Richter and others (1990). Multiply meq/L (milliequivalents per liter) by 35.45 to convert to mg/L (milligrams per liter) for dissolved chloride.

length to estimate ground-water velocity yields an estimate of 16.4 to 32.8 ft/yr (5 to 10 m/yr), versus 1.2 to 3.3 ft/yr (0.35 to 1.0 m/yr) derived from a Darcy's law calculation. The former estimate assumes that the plume is 400 to 800 ft (122 to 244 m) long and began forming between 1968 and 1973.

5.0 ENVIRONMENTAL ASSESSMENT

This section assesses potential risks to human health and environmental impact related to oil-field activities and waste at the site.

5.1 Site Summary and Classification

Potentially impacted environmental media at the site include soils, ground water, and air, and currently the land is used for hay-fed livestock. The surrounding property is agricultural and residential, three residences being located to the south and east (fig. 3.2). It is assumed that future land use will remain the same. Exposure of humans to impacted media appears to be minimal. There is no surface exposure of potentially contaminated media as a result of a previous cleanups at the site conducted by the RRC between 1989 and 1994, and the onsite disposal trench containing oil-field waste is covered by 0.5 to 1 ft (0.2 to 0.3 m) of soil. The closest water well 43-43-W1 is approximately 700 ft (~215 m) southeast of the site in a direction perpendicular to the hydraulic-head gradient. There are no residences or water wells onsite or between the site and the reservoir.

5.2 Constituents of Concern

Constituents of concern (COC's) at this site are defined as those organic and inorganic compounds detected above method detection limits in soil and ground water and in waste materials located in the disposal trench. In samples from the disposal trench, no volatile organic compounds were detected and no RCRA 8 metals were detected above guidance limits (table 4.2). Spot occurrences of NORM material exceeded exemption activity limits. Chloride, nitrogen, and TPH were also detected at elevated levels in the waste materials from the disposal trench (tables 4.1 and 4.2). Total organic halogens (TOX) was detected but was below the guidance limit. TPH is very low to nondetected in all native soils at the site (table 4.3; fig. 4.5).

Chloride concentration in soil, however, was detected at elevated levels. On the basis of readings from the 20-m geophysical surveys and results of soil analyses, we interpreted the extent of soil contamination by oil-field brine to be approximately 83,600 ft^2 (~7,770 m^2) (fig. 4.4). The zone of soil contamination is reflected by values greater than the baseline 100 mS/m (10,000 mmho/cm) at the 20-m coil spacing (fig. 4.2). Total mass of chloride in soil in the unsaturated zone is about the same as the mass in ground water at the site (estimate of 230 metric tons in the unsaturated zone and 140 to 280 metric tons in ground water). The concentration of chloride in soil in the unsaturated zone at the center of the barren ground (that is, at INBH-1), however, is about four to five times that found in the underlying ground water (determined by converting mg/kg weight units for soil samples to comparable dissolved concentration units, assuming bulk density of 1,500 kg/m^3, porosity of 20 percent, and water saturation of 80 percent). This ratio suggests that there is potential for ongoing leaching of salt out of the soil down into the ground water at the site.

The area in which ground-water chloride concentration is above background and as much as 16,000 mg/L appears to extend outward and down gradient from the zone of elevated soil salinity (fig. 4.11). Low levels of TPH were detected in ground water in two locations—one onsite boring (INBH-2, 0.58 mg/L) and one residential well (43-43-Sch4, 0.58 mg/L). We found no reason to associate the TPH in well 43-43-Sch4 with the site. Regardless, these TPH values are well below the TNRCC guidance level of 5 mg/L for leaking petroleum-storage tank (LPST) sites (Texas Natural Resources Conservation Commission, 1996a). Of the RCRA 8 metals, only barium was detected in ground water above method detection limits, but at a level much lower than the MCL of 2 mg/L. Volatile organic compounds were not detected in any wells or borings. In addition, ground-water samples from boreholes INBH-2 and INBH-3 showed no sign of petroleum contamination. INBH-2 had been targeted partly to evaluate a report of oil contamination in a borehole drilled for a water well, whereas INBH-3 was targeted where a shallow excavation showed evidence of old, buried oil-field waste.

No constituents considered in risk-based corrective-action analysis were detected at concentrations above guidance levels. Although chloride is discussed in Section 5.5, it is not a factor in risk-based analyses. Because no constituents were detected above guidance levels and the constituents had low mobility, we concluded that no constituents would produce direct risk to human health.

5.3 Potential Receptors and Migration Pathways

Potential receptors at the site include residents, the landowner, and site visitors (for example, lease game hunters). These potential receptors may come in contact with soils, use local ground water, or both.

The baseline risk-assessment pathways that are significant to this site are listed in table 5.1. Currently no exposure pathways are completed, and there is no surface exposure of potentially contaminated media. Waste materials in the disposal trench are buried, so there is a very low likelihood of exposure through soils or air particulates.

5.4 Assessment Results

Because of the lack of complete exposure pathways and detected constituents, which might pose a risk to current or future receptors at the site, we concluded that a modeled risk assessment was not required for the Mandi-Injecto site. Other factors relevant to potential remediation are discussed in the following sections.

Table 5.1. Potential migration pathways and likelihood of pathway completion.

Pathway	Potential receptors	Constituents detected	Limits exceeded?	Pathway complete?
Outdoor air (volatile and particulates)	Residents, visitors	None in source materials	No	No
Onsite soil	Residents, visitors	None in surface soils	No	No
Offsite soil	Offsite residents	None in surface soil	No	No
Ground water	Future residents	Yes, but at low level	No	No current receptors

5.5 Environmental Impact of Saltwater

The two main issues related to the presence of saline ground water at the Mandi-Injecto site are (1) potential impact on potable ground-water resources between the site and the Middle Concho River and (2) potential impact on water quality in the Twin Buttes Reservoir located as close as 1,000 ft (300 m) down gradient from the site. The fact that the region of the Concho River valley surrounding and including the Mandi-Injecto site naturally has poor-quality ground water bears on these issues. Dutton and others (1989) and Richter and others (1990) described several sources of salinity that affect ground-water quality in the Concho River watershed:

- natural discharge of formation brine from the Permian Basin;
- movement of brine from leaking, abandoned oil wells and former brine disposal pits; and
- movement of brine from deep, unplugged, exploratory boreholes drilled for water wells.

Findings from this investigation at the Mandi-Injecto site are consistent with the results of the previous studies reported by Dutton and others (1989) and Richter and others (1990). As previously noted, the area of the site is underlain by the Blaine and San Angelo Formation (Section 2.2), formations long known to bear saline water. Richter and others (1990, p. 22) cited an example of a test hole drilled into the San Angelo Formation from which they sampled water that had a chloride concentration of 33,140 mg/L at a depth of 68 ft (20 m). A landowner at the Mandi-Injecto site reported having difficulty finding a good supply of potable water on his property in spite of drilling a number of wells (C. Schiller, personal communication, June 1997). The two samples of "potable" water from water-supply wells located near the Mandi-Injecto site have chloride concentrations of 670 to 1,400 mg/L (table 4.6, fig. 4.10b), which exceed the maximum concentration level (MCL) of 250 mg/L. There is no apparent reason to relate the chloride content in these water-supply wells to the site. Rather, their elevated chloride results from naturally occurring salinity in the host formations and the hydrologic setting of that part of the Concho River valley.

Superposed on the regional trend of poor-quality water, however, are spot occurrences of especially saline water, which might be associated with former brine-disposal pits, abandoned wells that have leaked saltwater, or locations where natural discharge of subsurface brine is focused along preferential flow paths. Seepage from brine-disposal pits has caused soil salinization in many parts of West Texas and other oil-producing states (see references cited in Richter and others [1990, p. 25]). The impact of Mandi-Injecto site operations on ground-water salinity can be viewed as a variation on the typical impact of a brine-disposal pit. In this arid region, saltwater and precipitated salts can remain in the shallow subsurface long after sites are abandoned, and these contaminants can be remobilized in successive events when water infiltrates the soil after rainfall (Pettyjohn, 1982). The extent of both the saltwater-contaminated soil and the saline-water plume beneath the site, which were delineated on the basis of surface and borehole geophysics and borehole samples, probably reflects the residual contamination resulting from the handling of saltwater during previous disposal operations. We found no evidence that the saltwater-injection well had contributed to contamination at the site.

The hydraulic gradient indicates that a saltwater plume will move from the site to the northeast toward the Middle Concho River (fig. 4.7). The presence of any potable ground-water resources between the site and the Middle Concho River that might be impacted in the future by the movement of the salinity plume has not been confirmed. As previously noted, a landowner at the site reported difficulty finding a good supply of potable ground water, and given that the site lies over the outcrop of the Blaine and San Angelo Formations, there is generally a poor prospect for finding low-salinity water in the immediate area of the site.

On the basis of the geophysical survey and borehole hydrogeological data, we estimated the amount of chloride present in unsaturated and saturated soils beneath the Mandi-Injecto site to be about 370 to 500 metric tons. In comparison, Richter and others (1990, p. 27) estimated that there was 66 metric tons of chloride in the soil above the water table beneath a group of former brine-disposal pits at the Tankersley oil field, which is located just a few miles from the Mandi-Injecto site.

To evaluate the potential of the Mandi-Injecto site's impact on the Twin Buttes Reservoir, we (1) calculated the incremental annual loading of chloride owing to discharge of the saline ground water, which might in the future reach the Twin Buttes Reservoir, and (2) compared the total mass of chloride at the site with the mass of chloride in the reservoir. First, the calculated annual flux of chloride to the reservoir is based on the velocity of ground water and the concentration of dissolved chloride. The zone of ground-water salinization at the Mandi-Injecto site has moved as much as 400 to 800 ft since site operations began in 1968. Ground-water velocity is estimated within an order-of-magnitude certainty of between 1.2 and 16.4 ft/yr (0.35 to 10 m/yr). The diameter of the saltwater plume, as defined by the EM 20-m survey conductivity of 100 mS/m (10,000 mmho/cm) (fig. 4.3), is approximately 360 ft (110 m). At the maximum velocity, the leading edge of the saline plume could begin to reach the Middle Concho River, about 790 ft (~240 m) down gradient, within the next 50 to 80 yr. In traveling to the Middle Concho River the saltwater plume would decrease in concentration owing to dilution and dispersion and to influx of infiltrating recharge water along its flow path, so that the salinity of water that might reach the Middle Concho River would be less than that measured at the Mandi-Injecto site. The flux of saltwater at the discharge point and impact on the reservoir is estimated by assuming that:

- rate of discharge of the saltwater plume into the Middle Concho River is the same as its velocity at the site,
- salinity of the plume at the discharge point is undiminished (that is, not taking into account the effects of dilution and dispersion),
- water level in the reservoir is at lowstand and storage is 85,000 acre-ft (~104 million m^3),
- surface water in the reservoir has a typical chloride concentration of 114 mg/L (D. Jonston, City of San Angelo, personal communication, August 1997), and
- a range in possible velocities estimated from apparent plume length and Darcy's law.

Given these assumptions, the flux of chloride carried by ground water to the discharge point eventually might reach 400 to 13,200 kg/yr. The maximum annual incremental loading of chloride to the reservoir owing to discharge of ground water from the site amounts to approximately 0.01 to 0.1 percent of the ambient chloride content of the reservoir.

If all the subsurface chloride at the site (370 to 500 metric tons) were immediately added to the reservoir, the calculated maximum impact on the reservoir would be 3 to 4 percent. This calculation assumes that all of the site chloride is added to the reservoir at its minimum level of water in storage (85,000 acre-ft [~104 million m^3]) and is intended to illustrate the maximum possible impact.

6.0 REMEDIAL EVALUATION

The scope of work for this project included evaluation of feasible remediation alternatives and recommendation of an appropriate approach for remediation of the Mandi-Injecto site. Site-specific conditions considered in evaluating remedial alternatives included mitigation of potential environmental impacts and the apparent cost effectiveness of different methods. Site-remediation recommendations are based on remedial alternatives, anticipated success level, potential risk to public health and the environment, cost effectiveness, and other possible physical or regulatory limitations that relate to the site.

6.1 Interpretation of Mandi-Injecto Contamination

6.1.1 Summary of Site Conditions

The main areas of concern at the Mandi-Injecto site, as previously discussed, are the waste package in the disposal trench and the chloride concentrations in the soils and ground water. Characteristics of the waste package are summarized in table 6.1. Native soil below the waste material remains unaffected by metals or organics but shows an elevated chloride content. Metals other than barium that registered above the detection limit but that were well below any guidance level include chromium, copper, lead, nickel, and zinc. Other TCLP analytes above detection limits

Table 6.1. Summary of characteristics of oil-field waste in the disposal trench.

Parameter	**Area A (main part of trench)**		**Area B (overflow area)**	
Area	1,600 ft^2	(~150 m^2)	2,600 ft^2	(~240 m^2)
Thickness	5 to 5.5 ft	(1.5 to 1.7 m)	<3 ft	(<1 m)
Volume	275 yd^3	(~7.8 m^3)	200 yd^3	(~5.7 m^3)
Contents	Basic sediment and oil-field waste		Basic sediment and oil-field waste	
Soil-cover thickness	0.5 to 1 ft	(0.2 to 0.3 m)	0.5 to 1 ft	(0.2 to 0.3 m)
TPH	13 to 14 percent (average 8.2 percent)		2.9 to 6.1 percent	
Chloride	8,900 to 10,417 mg/kg (average 6,256 mg/kg)		2,326 to 6,721 mg/kg	
Barium	Total 410 mg/kg TCLP 12 mg/L			
Underlying native soil TPH	0.02 percent			
Underlying native soil chloride	5,490 mg/kg			

include cadmium, mercury, and benzene, although all TCLP levels were well within regulatory limits for nonhazardous waste (table 4.2). NORM sample test results indicated levels of Ra-226 at 276.52 pCi/gm, Ra-228 at 20.37 pCi/gm, Pb-210 at 79.77 pCi/gm, and total activity of 916.02 pCi/gm. Under TDH's Texas Regulations for Control of Radiation (TRCR) Part 46.4(a)(1) and (2), this NORM material is not exempt from TDH regulation and must be managed and disposed of in accordance with RRC rule 3.94, regarding Disposal of Oil and Gas NORM Waste.

Soil samples throughout the site contained elevated levels of chlorides, which ranged from 5 to 9,500 mg/kg. The highest chloride levels are 6,600 and 9,500 mg/kg, at depths of 1 and 14 ft (0.3 and 4.3 m) in boring INBH-1. These are the only two soil samples with chloride concentrations above the RRC Rule 8 limit of 3,000 mg/kg for onsite landfarming or burial of drilling fluids without a permit. The estimated total mass of chloride in the soil above the water table is 190 metric tons.

Volatile organics were not detected in any of the water samples at the Mandi-Injecto site (table 4.5). Only a trace amount of TPH was detected in INBH-2 and 43-43-Sch4. The TPH in 43-43-Sch4, which is 1,600 ft (490 m) up gradient of the site, most likely is unrelated to the site. Of the RCRA 8 metals only trace amounts of barium were detected in the ground water.

The only analyte of concern detected in ground water was chloride. Dissolved chloride concentrations from onsite boreholes ranged from 7,400 to 16,000 mg/L. The secondary MCL for chloride is 250 mg/L. Chloride concentrations were significantly greater in the onsite boreholes than in nearby water wells. Total mass of salt in soil above the water table is five times the amount in the ground water, reflecting appreciable potential for continued leaching of salt into the local ground water.

6.1.2 Source Identification

The first step in any remedial process is to identify and address the contaminant source. Previous Mandi-Injecto operations were obvious sources of saltwater and oil-field waste. The residual source areas remaining onsite from the operations are the contents of the disposal trench and chloride concentrations remaining in onsite soils and ground water. Another possible source of salinity considered at the Mandi-Injecto site is the plugged saltwater disposal (SWD) well. The soil and surface geophysical data, however, did not implicate the SWD well as a source of contamination. The distribution of conductivity with depth shown in the EM 39 borehole logs and EM 34 survey readings suggests that the saltwater source was at the ground surface, not in the shallow subsurface.

6.2 Remedial Options

Destruction, immobilization, and extraction technologies are available to address residual source areas the Mandi-Injecto site. The remedial alternatives reviewed for the site include:

- No corrective action
- Onsite bioremediation of waste materials
- Excavation and removal of waste materials
- Capping and ongoing ground-water monitoring
- Cover-soil placement
- Ground-water extraction

Each of these alternatives also includes ongoing ground-water monitoring, which is an essential component of any remedial action where ground-water contamination is a concern. Monitoring consists of sampling ground water at monitoring wells on a regular basis, interpretation of results with regard to remedial objectives, and a site reevaluation after a specific time period.

The excavation and removal of waste materials option for the disposal trench and cover-soil placement to mitigate the effects of chlorides in soils were determined to be the most cost effective. The reason for this finding and a summary of each alternative is given in the following section.

6.2.1 No-Action Alternative

The no-action alternative is taking no action to remediate the site, thereby leaving the site in its present condition, with natural attenuation processes controlling contaminant fate and rate of remediation. Under a no-action alternative, the waste materials with elevated chlorides, NORM, and TPH would remain in place, the elevated chlorides in the soils would continue to be a source of chloride contamination in the ground water, and the ground-water plume will continue to be a concern. As part of a no-action alternative, long-term monitoring is generally required. Because of the potential for continued environmental impact from the salt remaining in soil in the unsaturated zone, the no-action alternative is not considered appropriate for the Mandi-Injecto site.

6.2.2 Destruction Techniques

Two types of destruction techniques, land treatment and dilution burial, were evaluated for the site. Both types use a combination of waste dilution and biodegradation.

Land Treatment

Land treatment is a technology frequently used for treatment and disposal of oil-field wastes (Deuel and Holliday, 1994). Land treatment involves dilution and biodegradation to reduce constituents to an acceptable contaminant level. In land treatment, the waste solids are spread upon the land surface to a designated thickness, mixed with the soil, amended as necessary, and allowed to remain until biodegradation occurs. Nutrients and/or microbial cultures may be added to speed up the rate of bioremediation (U.S. Environmental Protection Agency, 1991).

In past cases (Jill Hybner, personal communication, RRC, 1997), the RRC has applied maximum soil values of 1 to 5 percent TPH as a prerequisite for cleanup. If bioremediation is proposed, the contaminated material must be mixed with clean soils to lower the TPH levels to

5 percent and have as much as 1 yr to accomplish the final cleanup standard of 1 percent TPH (RRC Rule 3.91).

This option can be used at the site, but it would be cost prohibitive to dilute the waste to 1 percent TPH. If waste is diluted to 5 percent TPH, there is no guarantee that biodegradation will decrease TPH to 1 percent. Chloride can also hinder biodegradation.

The TPH content of the waste package at Mandi-Injecto is above 1 to 5 percent. On the basis of a target concentration of 5 percent TPH to initiate biotreatment of the wastes, the trench wastes would require approximately a mixture ratio of 2 parts clean soil to 1 part waste, and the surrounding overflow area would require approximately a 1:1 mixture ratio. To accomplish cleanup levels of 1-percent TPH based on mixture only, not considering a reduction in TPH due to bioremediation, the mixture ratio of clean soil to trench waste would be approximately 14 parts to 1 part, and the overflow area would require approximately a 6:1 mixture ratio.

RRC Rule 8 limits chloride concentrations to 3,000 mg/L or less for onsite landfarming without a permit. The chloride level in the waste exceeds this concentration. It would take a mixture of greater than 2:1 to reduce chloride levels to within regulatory limits. Considering a 2-part clean soil to 1-part waste ratio for the trench waste, assuming uniform mixture and a clean soil-chloride level of less than 100 mg/kg, chlorides for that mixture would be approximately 3,250 mg/kg. Owing to the elevated chloride concentrations and the high mixture ratios that would be required, land treatment of the waste at the Mandi-Injecto site is not recommended.

Dilution Burial

Dilution burial is another technique frequently used for treatment or disposal of oil and gas wastes. In dilution burial, the waste is mixed with soil to dilute constituent concentrations below an acceptable level and the resulting mixture is then buried. Dilution burial is not recommended when the depth to ground water from the base of the waste–soil mixture is less than 5 ft (<1.5 m). Depth to ground water at the site, however, is more than 15 ft (>4.5 m [table 4.4]). In addition, it is recommended that a minimum of 5 ft (1.5 m) of soil cover be placed above the waste–soil mixture. Because of the anaerobic conditions that occur in dilution burial, it is recommended that oil and grease concentration of the waste–soil mixture not exceed 3 percent by weight (Deuel, and Holliday, 1994).

The waste at Mandi-Injecto is not recommended for dilution burial. The average electrical conductivity of the waste, 16.6 mmhos/cm, exceeds the recommended level of 12 mmhos/cm (Deuel and Holliday, 1994). In addition, the average oil and grease level, 10.8 percent, exceeds the recommended level of 3 percent. An approximately 3:1 ratio of a clean-soil–waste mixture would be required. Site soil has an elevated chloride content and would not be suitable for use as a clean soil in the dilution-burial mixture.

Furthermore, for dilution burial, the waste materials would have to be excavated, mixed with soil to suitable diluted levels, placed in a larger excavation, and covered with 5 ft (1.5 m) of soil. The small amount of NORM-exempt waste material at the site would not justify the capital cost of setting up equipment to carry out the soil mixing and burial activities.

6.2.3 Immobilization Techniques

Immobilization techniques restrict contaminant migration and include methods such as solidification and stabilization and capping.

Solidification and Stabilization

Solidification processes use additives to modify a liquid or semisolid waste package to a solid phase or to physically immobilize constituents of concern in a contaminated material. Stabilization processes use additives physically or chemically to immobilize certain constituents of concern, generally metals, in a contaminated material. These processes do not destroy the contaminants but rather stabilize constituents and reduce mobility.

Stabilization processes are not recommended at the Mandi-Injecto site. The constituents of concern in the waste package are the elevated TPH and chlorides, and stabilization is not a preferred remedial option for either of these constituents (U.S. Environmental Protection Agency, 1991). Stabilization processes would not aid remedial efforts because the waste material is already competent.

Capping

Capping is a containment technique that provides a low-permeability layer that separates the waste material from the ground surface. This technique removes the risk of surface contact with the waste. By providing a low-permeability layer in the cap, infiltration and percolation of water are greatly retarded, thereby reducing water percolation and subsequent leaching of contaminants to ground water. Capping is frequently performed in conjunction with other remedial techniques (U.S. Environmental Protection Agency, 1991).

Capping is a feasible but not recommended technology for use at Mandi-Injecto. A nominal cap profile includes a clean-soil cover layer (6 inches [0.15 m] thick), which serves as a bedding layer, and a geosynthetic (geomembrane or bentonite mat) cover layer placed over the site soil to provide an impermeable barrier. To protect this impermeable barrier, a soil layer is placed above the geosynthetic layer and shallow-rooted grasses are grown over the capped area to keep the soil in place.

Capping the barren ground, however, is not preferred at the Mandi-Injecto site because of the site environment and land use. A primary and costly element of an engineered cap, the impermeable layer, is not particularly beneficial at Mandi-Injecto. Net evaporation in this area is approximately 80 inches per year; percolation potential is low. The geosynthetic layer, in addition to providing an impermeable barrier, would also function as a root break. In this arid environment, most native vegetation is not shallow rooted, and difficulties in establishing vegetation over the capped area are anticipated. In addition, current land use includes grazing livestock, and it would be difficult for grasses to get established. Whereas the surface could be completed with gravel or caliche as an alternative to vegetation, this alternative does not ensure that the barrier layer would be protected from the existing land use over the long term.

Cover Soil without Engineered Cap

Placement of a layer of clay-rich cover soil over the barren area is a cost-effective alternative to the engineered cap. The soil cover would not have an impermeable barrier like that of a geosynthetic layer, but it would decrease permeability due to high clay content, as well as enhanced runoff away from the impacted area. Minimizing infiltration and percolation of water is effected by (1) grading the soil to drain runoff away from the site and (2) including a minimum thickness of 2 ft [0.6 m] of clay-rich soil cover. This cover soil would provide a stable surface layer and greater separation of the waste from the ground surface.

The existing salt-impacted soil would be mitigated by addition of gypsum before the soil cover is added. Whereas deeper rooted vegetation could be used with the cover-soil layer, it is anticipated that as the roots reach deeper, the high chloride in the in situ soils could have a negative effect upon the vegetation. Tilling of the shallow subsurface and conditioning with agricultural gypsum prior to placement of the cover soil layer in the barren area counteract the potential for vegetative impact from the high-chloride soils. Use of salt-tolerant vegetation would also be appropriate. Russian-thistle (*Salsola iberica*) and Saltbrush (*Atriplex*) are salt-tolerant plants that are well adapted to drought condition (Panel on Saline Agriculture in Developing Countries, 1990). Although salt tolerance at germination is low, vegetation should be well established in the clean soil before roots reach the high-chloride soils. Plants that have been established in the soil cover should be able to extend their roots downward into the gypsum-mitigated buried soil. Land-use practice at the site would need to be modified, at least temporarily; livestock grazing would prevent the vegetation from becoming established and lead to erosion of the cover and loss of cover integrity.

6.2.4 Extraction Techniques

A conventional method of addressing subsurface fluid contamination is an extraction system utilizing vertical wells, horizontal wells, French drains or a combination of these methods. Once extracted, fluids are treated or disposed of. The potential for impact of the salinized ground water on either the nearby reservoir or local ground-water supplies, however, seems too small to justify the cost of these extraction techniques.

Ground-Water Extraction

Ground-water extraction for this site would include the removal of ground water through extraction wells and subsequent treatment or disposal. Remediation of the ground water is not recommended because the only contaminant in the ground water is chloride, which is nontoxic and noncarcinogenic; regional and local ground water is chronically of poor quality; and projected possible impact on reservoir quality would be negligible. Costs would be extremely high for a minimal benefit.

Soil Flushing

Soil flushing is a technique that may be used to remove organic and inorganic materials, including the elevated chlorides, from soils. A fluid, generally water, is used to flush contaminants from the waste in the unsaturated zone. Soil flushing may be conducted in situ in conjunction with ground-water recovery or may be performed ex situ with recovery of flushed contaminants through an underdrain system. The benefit of soil flushing is that contaminants are removed from the waste materials. Disadvantages include the potential impact to ground water and cost associated with construction of flushing and recovery systems and treatment of the flushing fluid (U.S. Environmental Protection Agency, 1991).

Soil flushing is not recommended at the Mandi-Injecto site. In situ chloride flushing and subsequent ground-water removal are not considered a feasible remedial option. Ex situ soil flushing is not recommended because of the costs of construction of a flushing system and treatment of the flushing fluid.

Calcium amendments, such as calcium nitrate or agricultural gypsum, are sometimes used to reduce chloride contents. These amendments, however, are used primarily as a means to reduce chloride content to a level where it no longer inhibits bioremediation, not as a primary treatment for large waste masses with elevated chlorides (Deuel and Holliday, 1994).

Excavation and Reuse of Waste Material

Petroleum-contaminated soils have been used as additives in asphalt mixtures and substituted for filler material in base courses of roadways. Basic tank bottoms sediment has also been used in road construction. Highway departments that allow for the use of petroleum-contaminated soils in bituminous stabilized base courses often limit the contaminated material to 20 percent of total material and require petroleum-contaminated soils to be nonplastic, with a maximum of 5 percent clay and clay lumps (Meegada and others, 1996). Texas Department of Transportation does not have a standard specification for use of petroleum-contaminated soils in road materials (Texas Department of Transportation, 1995).

This remedial alternative is favorable in that it provides for destruction of site wastes while providing a beneficial use of the waste material. The alternative is sufficiently feasible to be presented as an option to construction projects scheduled near the site. The volume and characteristic information presented in tables 4.1 and 4.2 can be used to evaluate the feasibility of trench material as an additive in a specific road project.

Judging from estimates, the approximately 200 yd^3 (~150 m^3) of shallow material from the overflow area (B, fig. 3.1 inset) could possibly use this disposal option. Contaminated soils containing NORM materials in area A cannot be disposed of by this method. Amounts may vary when materials are excavated and evaluated in detail for NORM. In addition to the waste characteristics, the viability of using these materials in road construction depends upon project-specific considerations, such as the performance requirements, the road section profile, the asphalt mixture, and general material availability. Additional tests would need to be run for a specific reuse project.

Excavation of Waste and Offsite Disposal

Excavation of the waste material from the disposal trench area (area A, fig. 3.1 [inset]) and disposal of the material at an offsite facility are a recommended remedial option. The advantage to excavation and removal of the waste material is that the source of potential contamination has been removed from the site and the potential for future exposure or contamination would be eliminated. The disadvantages to excavation and removal of waste materials are the costs associated with removal, handling, and disposal.

As with any excavation-type remedial effort, confirmation sampling while excavating should be included to verify removal of the contaminants. After excavation of the waste materials, additional soil samples should be taken to confirm clean conditions.

6.3 Remedial Recommendations

Three remediation recommendations for the Mandi-Injecto site include:

(1) removal of waste material from the disposal trench and overflow area and its disposal at a permitted facility;

(2) soil treatment, additional of soil cover, and grading; and

(3) ground-water monitoring.

6.3.1 Removal of Waste Package

Waste material from the disposal trench and surrounding overflow area (~475 yd^3 [~360 m^3]) should be excavated and removed to a permitted facility. RRC-permitted commercial disposal facilities are located in Andrews, Borden, and Ector Counties. As much as 200 yd^3 (150 m^3) of shallow material, however, might qualify for reuse in asphalt mixtures and filler material in base courses of roadways. An RRC-permitted disposal facility in Andrews County is also permitted to accept NORM waste.

Because it is not cost effective to determine the amount of NORM-affected waste prior to excavation, material that is excavated from the trench should be monitored in the field so that any excavated material containing NORM can be segregated and disposed of separately. The 275-yd^3 (210-m^3) volume of area A (fig. 3.1, inset) might be a grossly conservative estimate of NORM-impacted material; actual volume most likely is much less. Contaminated soils and waste material from area A of the disposal trench found not to contain NORM contamination should also be evaluated for recycling in road-base material. To minimize cost of disposal, service bids for transport and disposal of waste from the trench should be obtained on a unit-cost rather than lump-sum basis. The contractor's work plan should specify how waste will be monitored, segregated, and handled for offsite transport.

Permitted disposal methods include disposal in an injection well specifically permitted for disposal of oil and gas NORM waste under 16 TAC § 3.9 (Disposal Wells). According to 16 TAC § 3.94(g), a surface-disposal facility permit may be granted for oil and gas NORM waste under 16 TAC § 3.8 (Water Protection). Permitted disposal methods require additional information regarding protection of public health, safety and the environment, and information regarding the waste characteristics. In addition to waste-disposal constraints, excavation and handling of all the waste material from the trench at the Mandi-Injecto site must be in a manner that provides workers with protection from NORM radiation. TDH regulations require procedures such as air monitoring, monitoring of radiation levels, and record keeping. Some confirmation samples should be collected beneath and adjacent to the waste material. The contractor's work plan should specify workers' personal protection for the excavation and handling of waste materials.

6.3.2 Capping and Grading

The excavation should be backfilled with clean fill material. A cost-saving measure would be to use soils from an adjacent or nearby property. Agricultural gypsum should be applied to the surface within the barren area and tilled into the surface soil. Surface grades should be established such that drainage is away from the Mandi-Injecto site. A minimum of 2 ft (0.6 m) of clean, clay-rich soil should be placed over the barren area, maintaining drainage away from the Mandi-Injecto site. The soil cover is intended to decrease the leaching and transport of salts from the surficial soil at the site (fig. 6.1). With the soil cover in place, leaching of salt should be significantly decreased. With markedly less percolation of saline water from the soil zone, (a) the center of the saline ground water will move farther from beneath the source and (b) the concentration of chloride and other salts in the plume will decrease (fig. 6.1b). After site grading has been completed, the surface should be seeded or planted with salt-tolerant plants, fertilized, and watered as necessary to establish vegetation.

6.3.3 Ground-Water Monitoring

Remediation is not recommended for the ground water at the site. As discussed in previous sections, the only contaminant of concern in the ground water is chloride, which is nontoxic and noncarcinogenic; regional and local ground water is chronically of poor quality; and projected possible impact on reservoir quality would be negligible.

Ground-water monitoring is recommended for the site to document the effectiveness of the soil cover (fig. 6.1). Monitoring wells should be installed and sampled to track the position and concentration of salts in the ground-water salinity plume (fig. 6.1b). Wells should be approximately 35 ft (~10 m) deep to penetrate at least 10 ft (3 m) beneath the water table. An

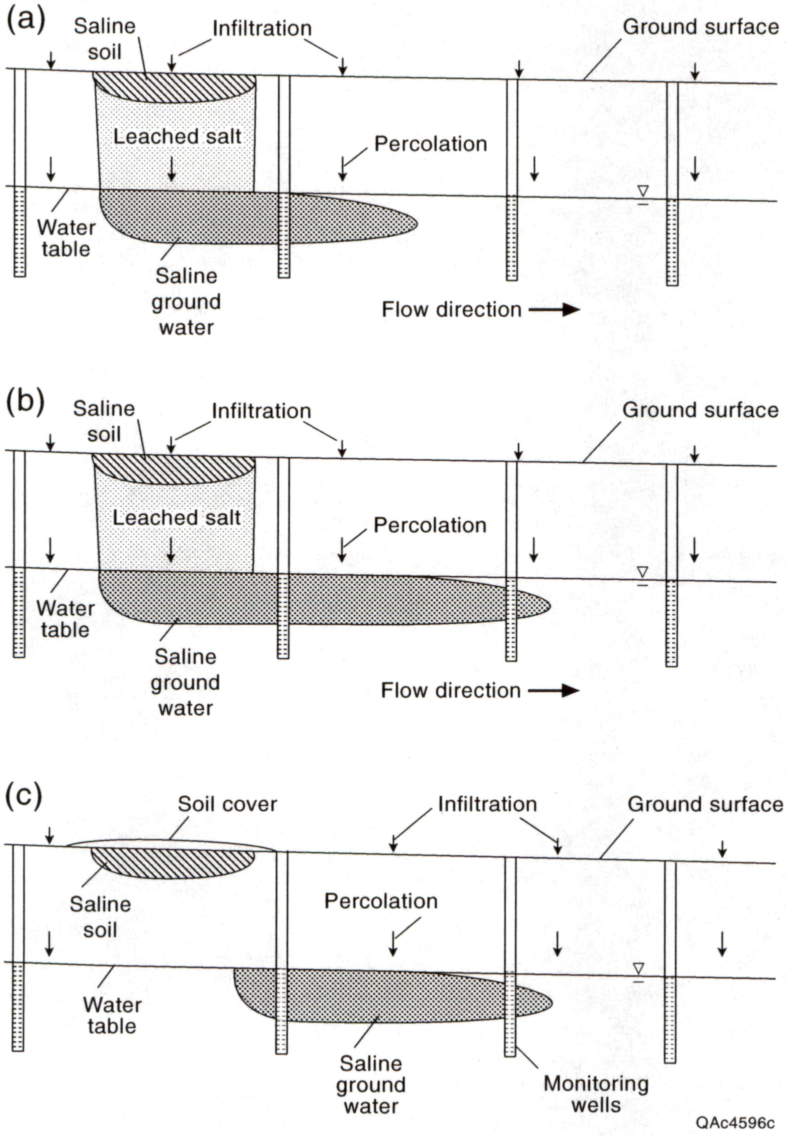

Figure 6.1. (a) Present and (b and c) possible future conditions at the Mandi-Injecto site without and with a soil cover to reduce infiltration and percolation through the saline soil. (b) Without a soil cover or other design feature to reduce infiltration, water percolation will continue to leach salt from the soil and carry it to the water table, and the zone of saline ground water will grow. (c) A soil cover is designed to restrict infiltration and resulting downward percolation. Little saltwater will be added to the saline plume, which will continue to move down gradient. Monitoring wells will detect and track the movement. No measureable impact is expected on the river or reservoir.

upgradient monitoring well is needed for tracking the background salinity of water moving to the site. At least two monitoring wells should intersect the plume to monitor its change through time. Another monitoring well might be placed downgradient from the plume to provide additional data on the rate of movement of the plume. Two additional monitoring wells might be placed to the sides of the plume to provide data on possible lateral dispersion of saltwater. Further evaluation of data from these monitoring wells might justify additional monitoring wells in the future. Ground-water monitoring is recommended, therefore, with the sequential addition of three to six monitoring wells to provide an evaluation of the effectiveness of the soil cover and fate of the salinity plume.

7.0 CONCLUSIONS

The assessment of the Mandi-Injecto site included characterization of the waste package contained in the disposal trench and surrounding overflow area, surface and subsurface soils, and on- and offsite ground water. Residual sources of contamination at the Mandi-Injecto site are the waste package in the disposal trench and the chloride concentrations in the soils and ground water.

Waste-package results indicate that the waste, although nonhazardous, has elevated levels of TPH, chloride, and NORM. TCLP concentrations and analytical results from below the disposal trench indicate that leaching of organic or metal constituents from this waste is minimal. The most diligent remedial action would be to excavate the waste package and surrounding overflow area (~475 yd^3) and dispose of the excavated material at a permitted facility. Possibly 200 yd^3 could be reused in road construction.

The Concho River valley in Tom Green County tends to have poor-quality ground water owing largely to the natural discharge of brine from Permian formations that underlie the area. Chloride concentrations in the soils are concentrated in the Injecto part of the site. Chloride concentration in ground water appears to be locally impacted by the site. The approximate total area of the salinization plume is 7,770 m^2 (83,600 ft^2). No remedial action is recommended for the impacted ground water at the site, however, because the only contaminant in the ground water is chloride, which is nontoxic and noncarcinogenic; regional and local ground water is chronically of poor quality; the amount of potable water immediate downgradient of the salinization plume probably is insignificant; and projected possible impact on reservoir quality would be negligible. A ground-water-monitoring program is recommended for the site. Soil cover would retard leaching of chloride from the unsaturated zone and help leaching of additional salinity to ground water.

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