BACKGROUND AND SITE-SPECIFIC GEOLOGY AND HYDROLOGY FOR THE LOVING LANDFILL SITE

prepared for

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by

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11/23/92
revised 12/21/92

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ABSTRACT

The Loving, NM, landfill site has been closed, and geological and hydrological studies of the landfill site and area have been conducted. Regional to area information has been summarized, and six wells were drilled, described, and completed for hydrological monitoring.

The landfill site is located in the western Delaware Basin, which accumulated thick sequences of sediments through the Paleozoic Era. The last deposits in this sequence, evaporitic units in several formations, underlie the site. Dissolution of salt has created evaporitic karst in the area, affecting surface features and hydrology.

More recent deposits of sediments eroded from the Guadalupe Mountains cover areas west of the landfill site. The Pecos River valley and drainage from the Guadalupes by the Black River and other draws have modified the topography further. There is no surficial evidence in this area of recent tectonic faulting, and structure contours on the top of the Bell Canyon Formation around the site area indicate a general, modest eastward dip with no offsets.

Regional ground water data indicate that flow under the site would probably be generally from west to east. Ground water depth was estimated at 75 to 100 ft below the surface at the site based on existing data; total dissolved solids were greater than 1000 ppm for all analyses of nearby ground water.

Six monitor wells drilled at the landfill site encountered the Pleistocene(?) Gatuña Formation to total depth. Lithologies ranged from claystones to sandstones and gravelly to conglomeratic sandstones or conglomerates. Sedimentary structures were

fewer than in Gatuña outcrops and cores from other locations, but they were consistent with features found in other locations. The Gatuña is more gypsiferous than it is in outcrops and cores to the north and northeast of the site. Dips and deformation indicate the Gatuña has been disturbed by dissolution of underlying beds since being deposited (probably about 500,000 years ago).

The geological data indicate general stability of the site over periods of tens to perhaps hundreds of thousands of years. The principal threat to geological stability appears to be further dissolution of underlying beds. No active karst is apparent at the site.

Ground water was found immediately in three monitor wells (M-2, M-4, M-6) in the southeastern part of the site, and water soon reached elevations of about 3060 ft in each. Three wells (M-1, M-3, M-5) in the northern and western part of the site have not reached similar elevations and may not have reached equilibrium. Apparent confined conditions for ground water in at least the three southeastern wells and fine grained sediments in each borehole suggest small potential for vertical recharge at the site.

Further testing of ground water gradients and chemistry should be deferred until water levels in the monitor wells are believed to have stablized.

BACKGROUND INFORMATION

Purpose of Report

This report provides both the general background and detail of the geology and hydrology of the Loving, NM, landfill site. It is provided to JOAB, Inc., for use in applying for a closure permit for the landfill.

Site Location

The Loving landfill site is located in the northeast ¼ of section 32, T.23S., R.28E. The landfill is approximately 1 mile south of Loving and about 10 miles southeast of Carlsbad (Figure 1).

General Physiographic Setting

The Loving landfill is located in the Pecos Valley section of the southern Great Plains physiographic province defined by Fenneman (1931). The Great Plains province is the western part of the Interior Plains major physiographic division.

The Pecos Valley physiographic section extends from the north end of the Pecos River and a part of the Canadian River valley to the south where the Pecos River enters the Edwards Plateau area. From there, the Pecos River has cut a deeper and narrower channel through the plateau until it empties into the Rio Grande River. The Pecos Valley physiographic section is a broad trough, oriented mainly north-south, due mainly to headward erosion by the Pecos River of the High Plains physiographic section, which once extended as a gently sloping plain to the mountain ranges west of the Pecos Valley section. Thus, the Pecos Valley section was developed later than the High Plains section and was superimposed on it by headward erosion.

The Pecos Valley section expresses a wide variety of topography from nearly flat plains to more extreme local relief. Several terrace levels are identifiable along the Pecos Valley, especially in the Roswell area (Kelley, 1971). Broad fan deposits have also developed along the western side of the Pecos Valley as clasts are redistributed in response to the erosional lowering and migration of the Pecos River. The entire area is drained either by the Pecos River, arroyos which lead to the Pecos, or the Black River and its tributaries, all of which also drain to the Pecos.

A triangular area between U.S. Highways 62/180 and 285 and bounded on the south by the Black River includes the Loving landfill site in its southeastern part (Figure 1). Most of the area lies between elevations of 3300 and 3000 ft above mean sea level.

The western part of the triangle is commonly underlain by gently sloping limestone gravels and conglomerates deposited in broad fans from the Guadalupe Mountains to the west. Near the Guadalupe Mountains, local outcrops of the Rustler Formation, especially the Culebra Dolomite Member, hold up some hills within the area of sloping gravels and conglomerates. East of the coarser detritus, the slope decreases and the surface is characterized by finer grained calcareous and gypsiferous soils.

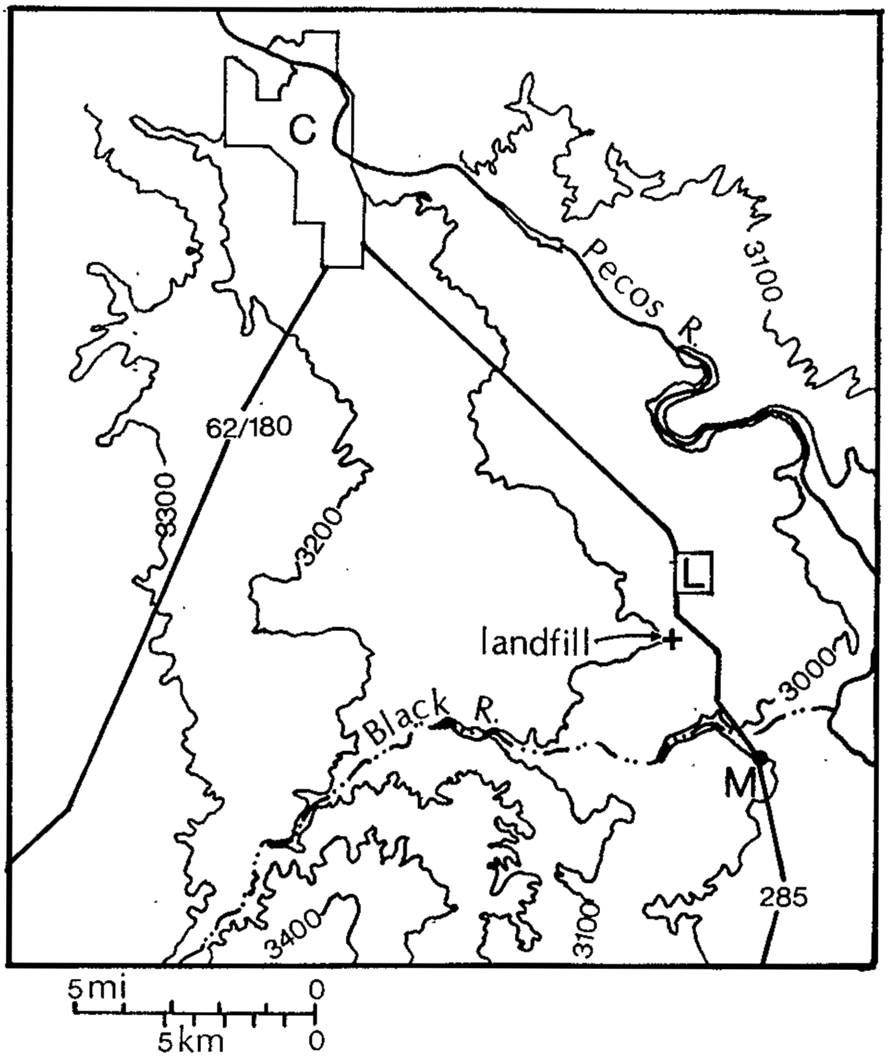
The southeastern part of the triangle is slightly more irregular topographically and is underlain by gypsum of the Rustler Formation which is weathered into gypsiferous soils.

General Geological Setting

General Geological History

The Loving landfill site is set in the ancient structural and depositional feature called the Delaware Basin. The Delaware Basin dominated the region throughout the Paleozoic Era, accumulating thousands of feet of marine sediments which include several units yielding hydrocarbons. The Paleozoic Era, and the Delaware Basin, culminated

Figure 1
General Location and Topography, Loving Landfill Site



C = Carlsbad, L = Loving, M = Malaga. Contours are in ft and are partial. U.S. Highway numbers are 62/180 and 285. Modified from Carlsbad Sheet, 1:250,000.

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with the deposition of thick (about 3000 ft) evaporites, which immediately underlie the landfill site, and red siltstones.

During the Mesozoic and most of the Cenozoic Eras, this area was mainly subject to erosion. There is a record in the eastern part of the Delaware Basin of late Triassic redbeds (Dockum Group) more than 1000 ft thick. The remnants of the Dockum Group can still be found east of the longitude of Loving, within 20 miles of the landfill, at both the surface and in the subsurface. It is quite likely that the landfill site was at one time covered with Dockum Group rocks, though perhaps not as thick as now exist in the eastern part of the basin. In addition, along Black River, Lang (1947) and Bachman (1980) noted localities with marine fossils of early Cretaceous age, indicating that some rocks of this age covered areas which probably include the landfill site. Given facies changes in Cretaceous rocks to the south and east in Texas, it is doubtful if these rocks were very thick at the landfill site. The local gap in the rock record extends from these lower Cretaceous rocks to rocks of late Tertiary age. Plio-Pleistocene(?) Gatuña Formation deposits immediately west of the landfill site in sections 31 and 32 overlie Rustler Formation units. There are no preserved Miocene Ogallala Formation rocks here, and it is difficult to estimate how much, if any, of this High Plains deposit may have extended into the area. To the north of Carlsbad, the Pecos Valley is interpreted as having been erosionally cut into the Ogallala. Ogallala deposits are rare and thinner east and southeast of Loving, however, weakening inferences about the presence or extent of Ogallala at the landfill site.

Since the end of the Permian Period, then, the landfill site has been subject mainly to erosion during the following periods: early Triassic, all of the Jurassic, most of the Cretaceous, and most of the Cenozoic. These times of erosion may account for 80 to 90% of the 250 million year geological history of the area since the end of the Permian Period and Paleozoic Era.

The times of erosion, especially after the Triassic rocks were removed, probably also contributed to dissolution of the underlying evaporites, as discussed in a later detailed section.

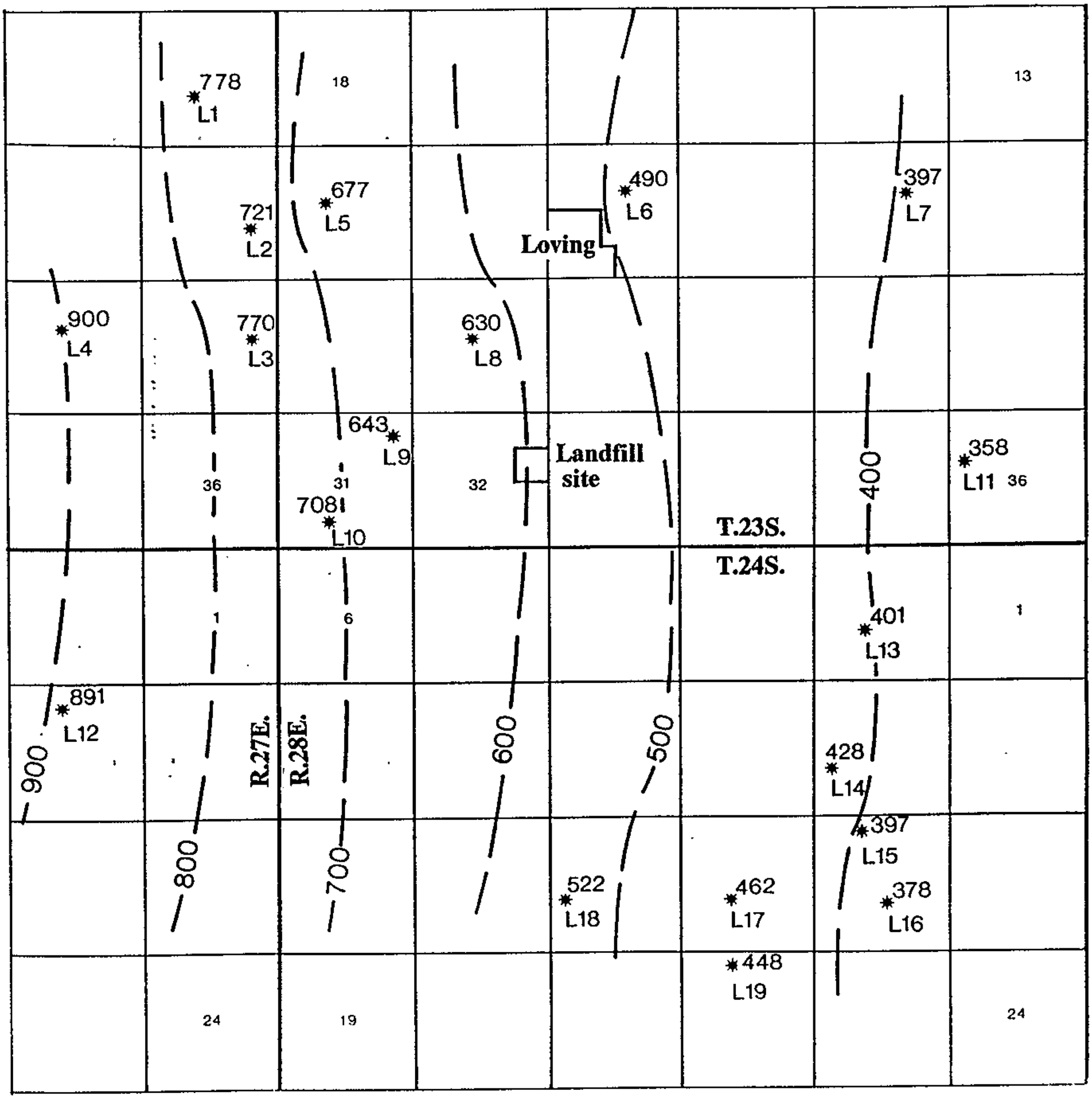
General Structural Setting

Deeper rocks under the evaporites in the Delaware Basin commonly strike nearly due north-south and dip eastward at about 100 ft/mile (e.g. Grauten, 1965; Powers and others, 1978; Borns and Shaffer, 1985). The tilt of the Delaware Basin has been attributed by some mainly to a late Cenozoic, Basin and Range event (Anderson, 1978). Others suggest a series of tilting events, beginning with two events during deposition of the Permian evaporites and including tilting events during the Mesozoic and Cenozoic Eras (Bachman, 1980; Adams, 1944).

Structure contours on the top of the Delaware Mountain Group (Figure 2), which immediately underlies the evaporites, show the deeper rocks underlying the land fill site have the same regional north-south strike, but the limited data indicate that the dip might be slightly less than the average through the western part of the Delaware Basin.

Faults due to tectonic events are not known to be later than the Permian in the western Delaware Basin area. That is, there are a few faults which appear to displace some of the lower evaporites (e.g. Powers and others, 1978), but there are none known in this area which displace the full section. On the east side of the basin, Holt and Powers (1988) interpreted significant displacement through the Rustler Formation, and possibly Dewey Lake Formation, along the western margin of the Central Basin Platform. The Triassic units do not appear to be displaced. Along the western margin of the Capitan reef and associated rocks, Kelley (1971) reported displacement along the Carlsbad and Barrera faults. These alleged faults were further examined by Hayes and Bachman (1979), who believe these linear features along the base of the eastern

Figure 2
Structure Contours of
Bell Canyon/Castile Contact



Contours in feet. L# refers to well number in Table 1; nearby number refers to elevation of Bell Canyon/Castile contact. Small numbers refer to section numbers.

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Table 1
Well Data for Bell Canyon(BC)/Castile Contact

Well ID	Location (T,R,Sec.)	Reference Elevation (ft)	Depth to BC/ Castile (ft)	BC/Castile Elevation (ft)	Well Name
L 1	232713	3101	2323	778	Burk Royalty Co., Lovelace #1
L 2	232724	3106	2385	721	Read & Stevens, Cass Draw No. 1
L 3	232725	3120	2350	770	HNG Oil Co., Chartier "25" #1
L 4	232726	3142	2242	900	Cactus Drilling Co., McRae State #1
L 5	232819	3102	2425	677	Read & Stevens, No. 1 Kimbley
L 6	232821	3040	2550	490	Belco Petroleum Corp., Kimbley #1
L 7	232823	3017	2620	397	Delta Drilling Co., South Culebra Bluff Unit #1
L 8	232829	3110	2480	630	HNG Oil Co., Pardue Farms 29-1
L 9	232831	3163	2520	643	Citation Oil & Gas Corp., Watts Federal # 1
L 10	232831	3130	2422	708	Mobil Oil Co., Pardue #1
L 11	232836	3013	2655	358	Phillips Petroleum Co., Malaga-C #1
L 12	242711	3131	2240	891	HNG Oil Co., Smith "11" Com #1
L 13	242802	2996	2595	401	Richardson & Bass, Beeman #1
L 14	242811	3018	2590	428	Aminoil Inc.-USA, CNB Comm. #1
L 15	242814	3002	2605	397	Coquina Oil Corp., Marra No. 1
L 16	242814	2998	2620	378	Pogo Producing Co., Lightfoot #1
L 17	242815	3027	2565	462	Aminoil USA, Inc., Willow Lake Unit No. 3
L 18	242816	3052	2530	522	Union Oil Co. of California, Union #1-16 State
L 19	242822	3033	2585	448	Burmah Oil & Gas Co., Willow Lake Unit #1

Logs were interpreted by Dennis Powers.

Guadalupe escarpment as mainly vegetation and erosional features with no demonstrable faulting or displacement.

Within the Delaware Basin, however, there are local areas which show faults at the surface which appear attributable to subsidence and collapse of overlying rocks when the underlying evaporite rocks are dissolved. It is more common that rocks overlying the evaporites are deformed and distorted by subsidence rather than being noticeably faulted. Bachman (1980, 1981) mapped and reported on these features in Nash Draw and along the Pecos River valley, including areas east and southeast of the Loving landfill site. Along the Black River, south of the landfill site area, probable Salado and Rustler units are distorted and deformed by subsidence due to dissolution. South and southeast of Malaga, the surface shows many domal to synclinal forms in the exposed Rustler Formation units due to the same processes. Though these rocks are only sparingly exposed nearer to the Loving landfill site, it is most probable that the near-surface rocks will also be similarly deformed due to dissolution and collapse.

SITE AREA GEOLOGY

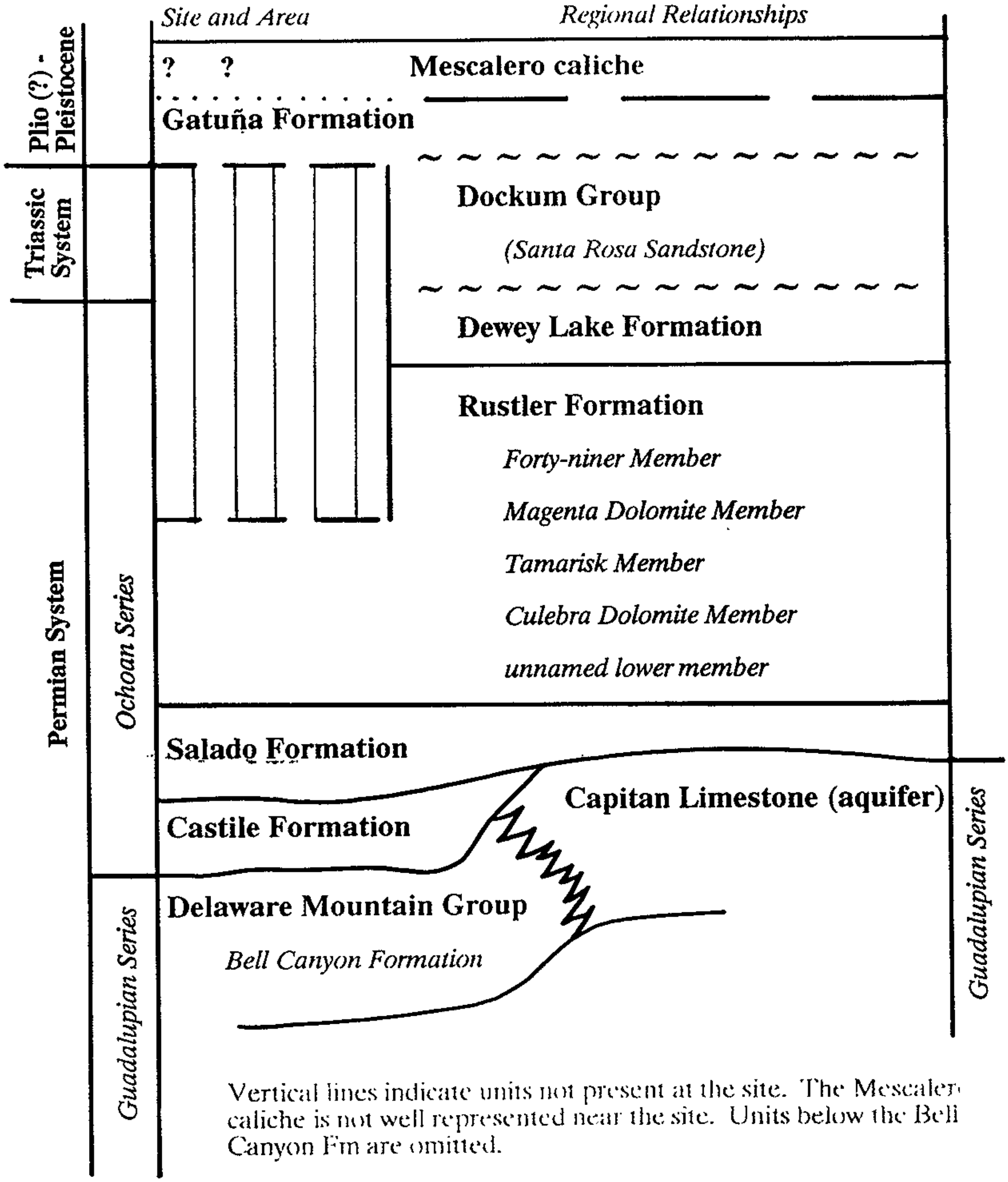
Introduction

The site area geology has been examined by including information from several square miles around the landfill. Most of this information is from outcrops and from geophysical logs of boreholes drilled for hydrocarbon exploration. These are readily interpreted for deeper stratigraphic units; the units above the Castile Formation are more disturbed by both depositional variations (Holt and Powers, 1984, 1988) and dissolution processes, and they are less readily interpreted. The rock unit relationships of most importance for the site and area are presented in Figure 3.

Units Underlying the Evaporite Beds (sub-Castile)

Precambrian crystalline "basement" rocks are not known to have been drilled in the vicinity of the Loving landfill site. About 1.5 mile west southwest of the landfill, Mobil Oil Corporation Pardue #1 well (L10, Table 1) was drilled to a total depth of 13,906 feet. Sub-Castile rocks in this borehole are 11,484 feet thick. About 3 miles east of the landfill site, Phillips Petroleum Company Malaga C #1 (L11, Table 1) was drilled to a total depth of 13,468 feet. Sub-Castile rocks in this borehole are 10,813 feet thick. The Mobil well appears to be drilled to Silurian age rocks just below the Devonian Woodford Shale. Near the WIPP site, Powers and others (197[illegible]) estimated the depth to Precambrian below the Woodford to be about 2,400 feet. The depth to the base of apparent Woodford Shale in the Mobil well is about 13,750 feet. The 2,400 feet thickness of the sub-Woodford is a reasonable approximation of the same interval at the Mobil well. From this, we can infer a total depth of about 16,150 to the Precambrian at the Mobil well and a sub-Castile sedimentary rock thickness of about 13,725 feet. These estimates are reasonably applied to the Loving landfill site.

Figure 3
Important Stratigraphic Relationships at and near the Loving Landfill Site



Vertical lines indicate units not present at the site. The Mescalero caliche is not well represented near the site. Units below the Bell Canyon Fm are omitted.

Pre-Permian rocks in this area are about 5,000 feet thick, based on inferences from geophysical logs and data included in Hills (1984), Haigler (1962), and Powers and others (1978). Basal sedimentary units are expected to be the Ellenburger Dolomite of Ordovician and possible late Cambrian age. The Simpson and Montoya Groups are also included in the Ordovician System. Silurian age rocks, dominantly dolomite and limestone, may be unnamed or attributed to the Fusselman Dolomite. The Devonian System in the area are attributed to the Thirtyone Formation (Hills, 1984) and Woodford Shale. The Mississippian System includes a lower, thicker limestone which commonly is unnamed and an upper unit called the Barnett Shale. The Pennsylvanian System consists of more heterogeneous units of sandstone, siltstone, and limestone commonly named the Morrow, Atoka, and Strawn Series from bottom to top. These units are important hydrocarbon producers in the Delaware Basin and site area.

The Permian System is divided into four series in the Delaware Basin: Wolfcampian, Leonardian, Guadalupian, and Ochoan Series, from base to top. The first three series include the pre-Castile formations. The Ochoan Series includes the evaporite and overlying redbeds of Permian age. Ochoan Salado and Rustler Formations are at the surface and in the near-subsurface around the Loving landfill site.

The Wolfcampian Series consists of heterogeneous rocks of shale and carbonate with minor sandstones on the order of 1000 feet thick. The Leonardian Series consists of beds of sandstone and limestone about 3000 feet thick. Part or all of the series is commonly called the Bone Spring Limestone. The Guadalupian Series in the area is very well known from different facies in the basin, under the site area, and in the Guadalupe Mountains. In the Guadalupe Mountains, the series is represented by formations which expose the reef to backreef facies made famous over the years by numerous studies (e.g. Newell and others, 1953) and the development of the Carlsbad Caverns in the reef rocks. Along the eastern escarpment of the Guadalupe Mountains, rocks are exposed showing the transition from the backreef to reef to basin facies. The basin facies are named the Delaware Mountain Group, which is subdivided into the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations from base to top. The Delaware Mountain Group is commonly about 4000 feet thick in the basin.

Evaporite Formations

The Ochoan Series in the northern Delaware Basin is divided into four formations: Castile, Salado, Rustler, and Dewey Lake Formations, from base to top. The Dewey Lake Formation has not been observed in the vicinity of the site, though it is well known and mapped east of the Pecos River. About one mile west of the landfill site, the depth to the base of the Castile is about 2520 feet in Citation Oil and Gas Company Watts Federal # 1 well (L9, Table 1). The natural gamma and density log through most of this interval is inside casing; though not very reliable as a basis for interpretation, the log shows what appears to be a relatively intact evaporite section below about 950 feet depth. This section is probably mostly equivalent to the Castile Formation. The upper 950 feet are not reliable for basic interpretation of the stratigraphy. Bachman (1984, Fig. 3, p. 9) shows an isopach of the Castile of about 1600 feet at the landfill site location. This is consistent with the better geophysical logs from around the site.

From exposures and drilling around the site, the Salado and Rustler Formations immediately underlie the surface of the site. West of the site, along the county road, sulfate outcrops most probably belong to the Rustler Formation, although outcrops and site drilling (see later section) reveal considerable gypsum in the Gatuña Formation. Two small hills, about ½ and 1 mile west of the site and along the south side of the road, expose mostly red siltstones and sandstones of the Gatuña Formation of probable Plio-Pleistocene age (see below).

Surficial and Near-Surface Geology

The surficial and near-surface geology of the Loving landfill site is dominated by the erosion, solution, and weathering of the late Permian evaporite beds of the Salado and Rustler Formations. The Gatuña Formation deposited a veneer of sediments more recently (?Pliocene to Pleistocene), and these beds have also been subsequently distorted by solution of the underlying evaporites. The soils and surface deposits reflect both less soluble constituents of the evaporites, the fan-like deposits off the Guadalupe Mountains, and the influence of Pecos River drainage system.

Sulfatic beds are exposed both within the trench of the Loving landfill (late in 1991, now filled), along the road ditch west of the landfill site, and as outcrops and boulders in a borrow pit west of the landfill. There are no specific internal features to identify uniquely some of these beds. At distances of a few miles around the landfill site, lower Rustler units and upper Salado units are exposed, though deformed by dissolution and collapse. The Culebra Dolomite Member of the Rustler is identifiable in outcrops, and the broader structure on this units indicates it underlies the Loving site. I have identified neither outcrop nor clasts of the higher Magenta Dolomite Member of the Rustler Formation, indicating it was probably erosionally removed before the Gatuña was deposited. Nearby gypsum beds, to the west, are interpreted as possible Tamarisk Member of the Rustler Formation, while noting the gypsum encountered in the Gatuña Formation during drilling.

Within the landfill, the sulfate crops out as a large block which is probably rotated from horizontal. This is a possible clast of Rustler gypsum incorporated during collapse. In the nearby borrow pit, outcrops of the Gatuña also appear to be rotated, perhaps as much as 90° from original position; these rocks are also highly gypsiferous. The rocks are deformed by dissolution and collapse, as the underlying Bell Canyon and Castile Formations show no evidence of tectonic features other than the regional eastward dip.

The Gatuña Formation unconformably rests on several formations in the Delaware Basin. West of the landfill, the Gatuña rests on apparent Rustler sulfate beds. In the landfill, the Gatuña consists of thinly bedded sandstone and sandy siltstone, some thin gypsum beds and fracture fillings, and some argillaceous siltstones. These beds are rotated as much as 90° from the horizontal, but the dip is not uniform even through the length of the trench. The Gatuña crops out on two hills approximately ½ and 1 mile west of the landfill site. At both of these locations, the Gatuña is mainly siltstones and claystones. At the hill about ½ mile west of the landfill site, the Gatuña appears to be about horizontal and is capped by gravel and conglomerate composed of mainly Permian limestone clasts from the Guadalupes. The gravel and conglomerate does not appear to be rotated or distorted. It is possibly the same age as the Mescalero caliche or younger based on cementation. The Gatuña at the more westerly location ranges from apparently horizontal to dipping to the west. Blocks of conglomerate near the middle of the borrow pit at this hill overlie the Gatuña in apparent conformity. The gravel may have been deposited in a low or channel through a collapsed or collapsing area on the Gatuña, though it may also have been modestly and uniformly lowered since gravel deposition.

The implication of these formations is that solution of the underlying evaporites, while hardly continuous or uniform, occurred both before and after the deposition of the Gatuña Formation. In Nash Draw, the Mescalero caliche (which began to form about 570,000 years ago; Rosholt and McKinney, 1980) overlies the Gatuña, indicating the Gatuña there was deposited by this time. Without other evidence, that is taken as the most likely upper limit to the age of the Gatuña in the landfill area. It can be inferred then that the most recent episode of solution and collapse around the landfill area may have occurred as recently as about 500,000 years ago. It may have been earlier, as the Gatuña is clearly of variable age. Significant solution and collapse seems unlikely to be much more recent than a half million years ago in the immediate area, as I have observed no evidence of modern collapse features (sinkholes, karst). The cemented gravels (conglomerates) do not indicate rotation either, and these beds were likely cemented at the same time as the Mescalero caliche or later.

Soils

The soils of the landfill site area are mapped as the Reeves-Gypsum (RG) complex, with slopes of less than 3% (Chugg and others, 1971; sheet 119). The surrounding areas are also commonly mapped as part of the Reeagan association. The Reeves complex developed on gypsiferous units of the Rustler Formation, while the Reagan soils locally reflect the more calcareous alluvial source material from the Guadalupes brought in and deposited over the remains of the Rustler Formation.

Geomorphology

The site lies near the eastern end of a low ridge area or topographic high without well-developed drainage. The topography is due to both the local areas of more resistant highly cemented conglomerates and the remains of the Rustler sulfate beds. The sulfates continue to be weathered rapidly in geological time, and the low relief and fluffy soils are a consequence. Cass Draw, to the north, and Black River, to the south, are well integrated drainages from the west, drawing virtually all runoff from the Guadalupe Mountain area upslope of the landfill site. The site thus is protected from runoff and the underlying rocks are weathered mainly by direct prcipitation and infiltration. For the immediate geological future, this topographic high will continue to exist. Secondary drainage from Cass Draw and the Black River will eventually form to remove runoff from direct precipitation and accelerate the weathering, solution, and erosion of these rocks, but this development will require considerable time (tens to hundreds of thousands of years) barring greatly increased precipitation.

West of the site, a gravel apron or fan developed off the Guadalupe Mountains during the Quaternay. Parts of the apron became highly cemented by carbonate and hold up high points parallel to Cass Draw. The rest of the gravel apron is being modified by erosion and reworking, mainly by Cass Draw, to lower positions as Cass Draw adjusts to the Pecos River.

Areas north, south, and east of the landfill site show evidence of evaporite karst developed on the Rustler Formation (Bachman, 1980). Rustler carbonate units hold up rounded hills or surround crescent shaped lows. These karst mounds and domes (Bachman, 1980) developed from the resistant plugs of former collapse areas (mounds) or as remaining highs (domes) as the surrounding areas underwent dissolution and collapse. The most obvious examples of these features exist southeast of Malaga in the Queen Lake area. In the far future, erosion is likely to expose some of these same features in the general area of the landfill, though there is no direct evidence. These features are not considered to be actively forming in this area today.

SITE AREA HYDROLOGY

The site hydrology can be generally inferred from the study by Hendrickson and Jones (1952).

As indicated above, the surface hydrology is dominated to the north by Cass Draw and to the south by Black River. Both are tributaries to the Pecos River about 4 miles east of the site. Because these two tributaries drain the Guadalupes uphill of the landfill site, there is little likelihood of a new, major drainage developing across the site. Instead, minor and poorly developed drainage from the site area can drain into these larger drainages. Given the low rainfall and nature of the soils, the site area is not expected to develop significant additional drainage in a short time (less than tens to hundreds of thousands of years).

Hendrickson and Jones (1952, Fig. 7) show the depth to water under the landfill site to be in the range from 75 to 100 ft. The depth to water decreases to the east, toward the Pecos River, and increases to the west under the sediment apron in front of the Guadalupe Mountains. The elevation of the water table also increases to the west, however, and Hendrickson and Jones (1952, Pl. 3) infer a northeasterly flow direction for the shallow ground water to the site area and thence east to the Pecos River. Almost all of the wells in the site area are reported within alluvial sediments. At greater depths, the Culebra Dolomite is also likely to transmit water, though its characteristics for this area were practically unknown at the time Hendrickson and Jones completed their study. Geohydrology Associates, Inc. (1978) report no information useful for this landfill site beyond that provided by Hendrickson and Jones (1952).

Hendrickson and Jones (1952, Table 3) report water quality for several wells in T.23S., R.27 and 28E. All of the reported wells were between 1,000 and 10,000 ppm total dissolved solids, exceeding present standards for human consumption but usable for irrigation. In the vicinity of Malaga Bend on the Pecos River, water quality can be much poorer, especially on the east side of the Pecos River. This stretch of the Pecos River is in the general direction Hendrickson and Jones (1952) expected shallow ground water to flow.

The Capitan aquifer, at considerable distance to the west and north of the landfill site, is geologically isolated from the shallow and deeper hydrology of the landfill site. The Capitan limestone, formed as a reef, fringes and helps define the Delaware Basin. There appears to be very little interconnection between the Capitan and equivalent rocks, the Delaware Mountain Group, in the basin. The Delaware Mountain Group underlies the site at a depth of about 2500 ft. The gradient would also cause flow from Capitan to the site area (Mercer, 1983, Fig. 9), if any flow exists.

SITE GEOLOGY AND HYDROLOGY

The site specific geology and hydrology reported here (see Appendices 1 and 2 for details) have been developed through the drilling program for establishing monitor wells and subsequent measurements of water levels. The drilling and completion program was carried out under the general plan (Appendix 3) for monitor wells provided to the Environment Department prior to beginning field work.

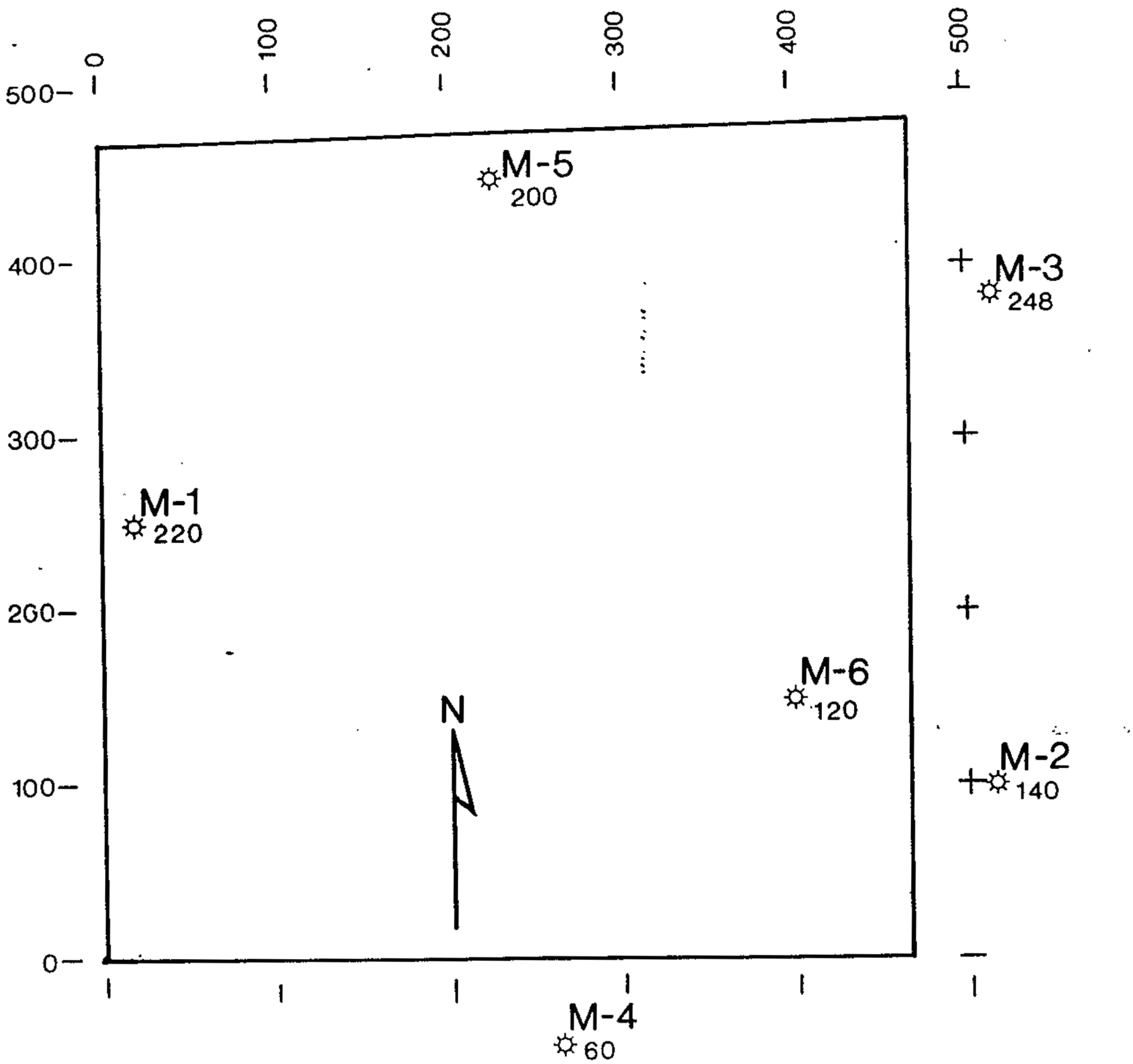
Drilling included both coring and rotary drilling with tricone bits. The geological data are based on core descriptions as well as more general descriptions of cuttings which were obtained from the return air/fluid flow. Coring was limited as the principal purpose of the program was to develop monitor wells. Rocks exposed in the sides of trenches were also inspected during the drilling program.

The rocks penetrated during the drilling at the Loving landfill site are all attributed to the Pleistocene(?) Gatuña Formation. The Rustler Formation and/or Salado Formation residues are expected to underlie the Gatuña, but neither is believed to have penetrated during the drilling.

Gatuña Formation

The Gatuña Formation was originally proposed by Lang (in Robinson and Lang, 1938) as a formation based on deposits in the Gatuña Canyon area of Clayton Basin. Bachman (1974) described a type section about 54.5 ft thick in the canyon. More recently, Powers (in Holt and others, in prep.) described Gatuña outcrops and lithologic associations from the type area to Pierce Canyon; Powers (1992) also described cores of Gatuña from the geologic and borehole drilling during characterization of the Sand Point site being investigated as a potential landfill site for Eddy County and

Figure 4
Loving Landfill Boundaries and
Location of Monitor Wells



Grid line markers are at 100 ft intervals; initial point (0,0) is southwest corner of fenced portion marked by solid lines. **M-#** refers to monitor well number. Modified from base map by Wehran EnviroTech for JOAB, Inc. Small numbers near well location refer to total depth drilled.

are interpreted to be beds of gypsum within the Gatuña. The alternatives are to interpret the unit as partially belonging to the lower Rustler or Salado Formations, or to interpret these as possible blocks transported from nearly outcrops. The attendent lithologies and sedimentary structures are much more consistent with interpreting these as lithofacies of the Gatuña rather than as unusual deposits within the other formations. The minor sandstones and relatively rare conglomerates or gravels in the monitor wells are consistent with the Gatuña as well, and they are not consistent with other units in the area.

Available cores and trench exposures reveal zones with extensive parallel laminae to thin beds, a single cross-bedded unit, some concretions, some wavy bedding, minor bioturbation and MnO_2. These features are consistent with the Gatuña. Some of these features are found in other units, such as the Dewey Lake Formation, but the combination is only consistent with the Gatuña. Diagnostic features of the Dewey Lake are not present, however.

Site Hydrology

The regional hydrology suggests that ground water should be about 75 to 100 ft below the landfill surface if the hydrology of the Pecos valley fill continues under the site. The general flow regime is estimated to be from west to east under the site. Initial drilling was planned for an upgradient (west) borehole and downgradient (east/southeast) boreholes. The wells were drilled and completed under the provisions of the monitor well drilling plan (Appendix 2, Figures 2-1 through 2-5; Appendix 3).

During drilling, three boreholes (M-1, M-3, M-5) did not show any immediate evidence of ground water. Each of these monitor wells has subsequently produced water, and the water levels have been measured several times (Table 2). Three boreholes (M-2, M-4, and M-6) returned water to the surface during drilling, and the water level in each reached approximate equilibrium very quickly (Table 2), based on several measurement since the well completion.

M-2, M-4, and M-6 all show ground water level to have risen relatively rapidly (within hours) to levels above the depth at which water was first observed. M-2 and M-6 rose about 70 to 50 ft, respectively, above the initial encounter, while the level in M-4 rose less than 5 ft above the depth at which water was encountered. At least in M-2 and M-6, the ground water behaves as a confined aquifer. M-4 is also probably confined, but it is less obvious. During the final drilling of M-6, pressure in the borehole built up after ground water was initially observed. The water level in M-2

Table 2
Summary of Recent Measurements of Ground Water Levels, Loving Landfill

Borehole	Shroud Cap Elevation (JOAB - Magee) ft	Ground Water Depths (ft) 09/29/92 (time)	10/05/92 (time)	10/14/92 (time)
LL M-1	3113.91	112.12 (1714)	111.88 (1429)	111.51 (0901)
LL M-2	3110.73	50.52 (1743)	50.42 (1407)	50.71 (0845)
LL M-3	3113.12	84.58 (1752)	84.47 (1358)	84.26 (0837)
LL M-4	3110.50	50.47 (1737)	50.34 (1411)	50.51 (0852)
LL M-5	3113.11	111.88 (1722)	110.52 (1433)	110.03 (0907)
LL M-6	3114.22	53.92 (1731)	53.83 (1439)	54.10 (0913)

All water depths were measured by Dennis Powers with the same probe supplied by JOAB, Inc. Depths were based on repeated changes in strength of audio signal, and the measurement was by sighting across the top of the well shroud in each well.

The shroud elevations were measured by Marvin Magee of JOAB, Inc.

was observed to rise during the pressure buildup and to fall when the pressure was removed. The ground water level was not observed to change in M-4 during this pressure increase in M-6. This indicates very good hydraulic connections between M-2 and M-6, possibly through a fracture system within the isolated (confined) unit. M-1, M-3, and M-5 systems may require additional development and testing after ground water levels have stabilized to determine if the units are interconnected.

DISCUSSION AND IMPLICATIONS

The broad geology of the Loving site indicates it has a common geological history with much of southeastern New Mexico. Permian age evaporites deposited within the Delaware Basin are a controlling feature of the present landscape and geological processes because they are now at or near the surface. These units are rather soluble compared to other minerals, resulting in local evaporite karst and deformation features unrelated to broader tectonic processes. The evaporites are also likely to prevent or minimize the possibility of earthquakes fracturing the rock units to provide hydrological continuity between deeper units and near surface units. There are no nearby faults known to be recent and of tectonic origin.

The geology of the Loving landfill site indicates that main geological processes in the last few hundreds of thousands to a few (1 or 2?) million years have been weathering and erosion of the then exposed Rustler Formation, dissolution of soluble minerals from the Rustler with attendant deformation and collapse, and deposition of sediments, first as the Gatuña Formation and later as debris from the Guadalupe Mountains forming an apron of sediment to the west of the site area. At least local dissolution of beds under the Gatuña resulted in deformation of the Gatuña, probably about 500,000 years ago. The Pécos River continued reworking alluvium and integrating the drainage from the Guadalupes.

The time bounds on dissolution in the site area are provided by the presence of the Gatuña Formation and carbonate-cemented conglomerates inferred to be the age of the Mescalero caliche or younger (570,000 years or less). West of, and near, the site, the Gatuña (including conglomerates) is apparently undisturbed, indicating locally that post-Gatuña dissolution is minimal. Within the landfill site, the Gatuña is considerably disturbed, showing that later dissolution and collapse has occurred. There is no evidence of active karst at the site.

The surface hydrology of the site area is broadly predictable from the geomorphology of the site and indicates it should not change significantly for geological periods of time. The near-surface hydrology is dominated by alluvium around the site, with ground water expected to move to the northeast and east. At the site, the Gatuña produces ground water in each of the six monitor wells drilled. Three of the monitor wells indicate ground water at about 50 ft below the surface; these monitor wells in the southeast part of the landfill are probably all showing the same ground water system. The other three boreholes, in the north and northwest part of the landfill site, are not yet known to have reached equilibrium and are not yet determined to belong to the same ground water system. The ground water elevations in these boreholes range from about 3060 ft (in monitor wells with apparently stabilized ground water levels) to about 3000 ft (in two wells with apparently rising ground water levels). Contours of ground water elevations at the site by Hendrickson and Jones (1952) are 3020 to 3040 ft (to the west). The observations at the site show ground water higher than projected by Hendrickson and Jones; the ground water flow direction is not yet established and may be more complex than estimated from contours provided in Hendrickson and Jones.

Each of the monitor wells drilled showed intervals of claystone or argillaceous rocks with little obvious porosity. The data from M-2, M-4, and probably M-6, of confined ground water, combined with impermeable beds, suggest there is little potential for vertical recharge at the landfill site.

CONCLUSIONS

The geology and hydrology of the Loving landfill site and immediate surroundings indicate this site should remain relatively stable or unalterred by natural processes for tens to hundreds of thousands of years. The major threat over that period of time will be further dissolution and the development of deeper surface drainage. Increased rainfall, as has occurred in the geological past, could accelerate these processes.

The hydrology of the Loving landfill site clearly reveals ground water at relatively shallow depths (about 50 ft below the surface), though three wells do not appear yet to have reached an equilibrium level. These wells will need to reach equilibrium for satisfactory demonstration of ground water levels and testing to determine probable direction of ground water flow. Fine-grained beds in each monitor well, and probable confined ground water in at least three wells, strongly suggest little, if any, vertical recharge of ground water at the landfill site.

RECOMMENDATIONS

Testing of hydraulic parameters and sampling for ground water chemistry/quality should be deferred until hydrological consultants have determined that ground water in the monitor wells has reached static or near-static levels. This will permit an initial estimate of gradients and whether the ground water sources are well-connected. Premature sampling in M-1, M-3, and M-5 may cause considerable delays in reaching static levels, given the slow rise in levels.

It is also recommended that the water in the monitor wells be tested for ground water quality and specific gravity in initial samples before any bailing. In southeastern New Mexico, local changes in specific gravity due to dissolution and modest mixing in relatively impermeable beds can be large and can significantly alter computed ground water gradients and flow directions.

A plan for monitoring ground water levels in the monitor wells should be implemented soon. It is recommended that levels should be measured at intervals of 1 to 2 months until static or apparent static water levels have been reached.

If the gradients finally established for this location are predominantly from east to west, as indicated by water levels which have so far been measured, an older landfill to the east of Higby Hole Road should be considered as a potential source of contaminants in eastern, upgradient wells. There is no known monitoring of this former landfill. Initial planning of water quality sampling as well as monitor locations should consider the possibility that upgradient (if to the east) water quality could be affected by this landfill.

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Appendix 1

Loving Landfill Closure

Monitor Well Descriptions and Graphics

Introduction and Explanation of Symbols

The monitor well graphic logs presented here were prepared from the field descriptions and logs. Several notes are provided below. The approximate locations for each borehole in section 32 (T.23S., R.28E.) are given relative to fence corners or fenced boundaries of the landfill site.

Explanation of Symbols

Gypsum or gypsiferous rock

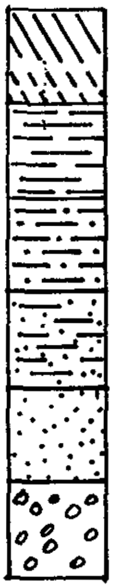
Claystone

Siltstone

Sandy siltstone

Sandstone

Conglomerate



Bioturbation (mainly rootcasts)

Ripple cross-bedding

Laminar bedding

Wavy bedding

Soft deformation

Fibrous gypsum in fracture

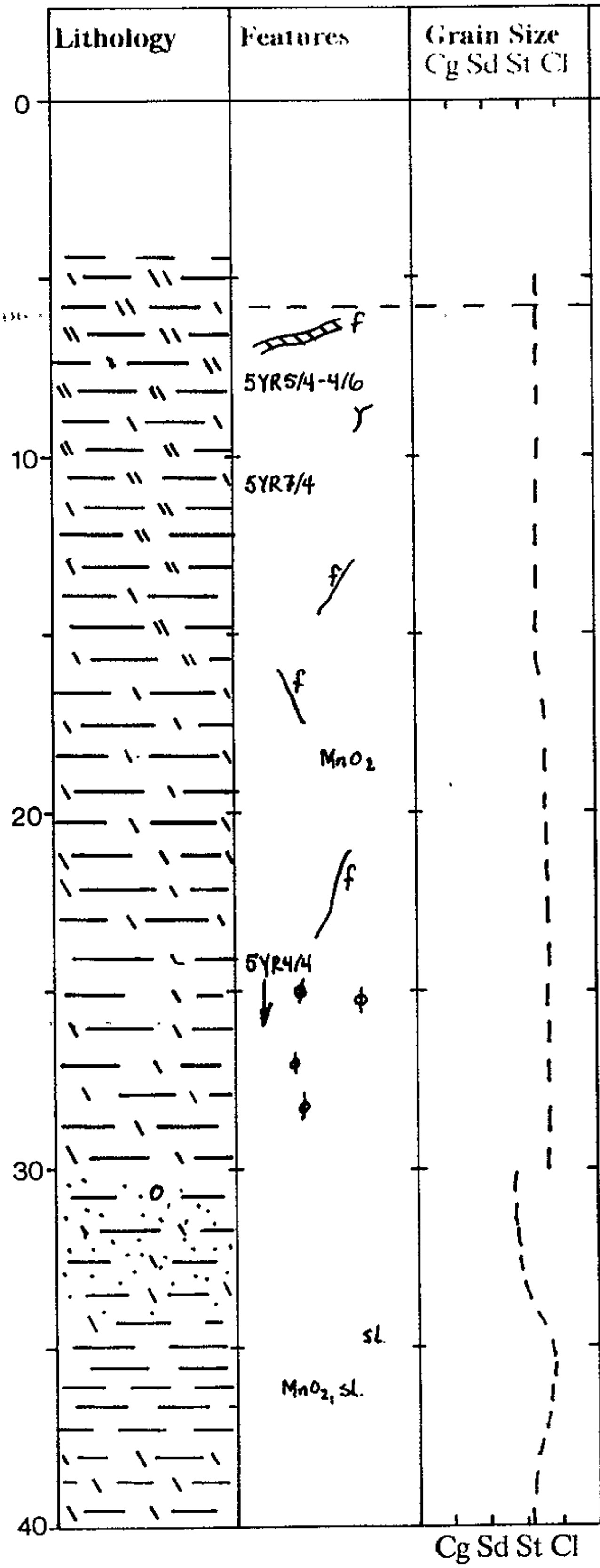
Abbreviations: f - fracture; MnO_2 - manganese oxide stain; sl - slickensides; calc - calcareous; 2.5YR 4/6 - numbers refer to colors based on Munsell Soil Color Chart.

The descriptions are based only on field study; estimates of the average grain size are not precision analyses of the rocks and have been given to show trends and relative sizes. Grain size estimates are included in some zones from cuttings where confidence in representative cuttings is better. Poor or no recovery is indicated by placing no graphic symbols. Graphic symbols may be arbitrarily placed in a coring interval where core loss occurs but cannot be exactly placed. Depths are in feet.

Line symbols for size estimates and unit contacts are continuous, dashed, or dotted; continuous lines indicate good sorting or sharp contacts while dots indicate poor sorting and gradational contacts.

MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

Drillhole No.: *LL M-1* *Location:* *30 fwl, 200 fnl* *Date:* *06/25/92*



Description

Possible disturbed fill to 6 ft.

Siltstone, argillaceous and white to clear crystalline gypsum.

Gatuña Formation

Gypsum in subvertical zones, some slight MnO_2; some root material of possible recent or modern origin.

No root zones apparent 10-20 ft. Some fractures about 60°, may be due to drilling.

Crystalline gypsum in apparent nodules as well as in subvertical to subhorizontal zones about 1/16 to 1/4 inch wide. Forms roughly continuous network on core surface.

Fracture has root casts, possible clay illuviation.

Carbonate nodules to about 1 inch diameter from about 24-28 ft.

Rare coarse sand particle of chert.

No gypsum, 34.5 to 36.5 ft. Slickensides, MnO_2.

Gypsum, very coarse, to about ½ inch; may be displacive.

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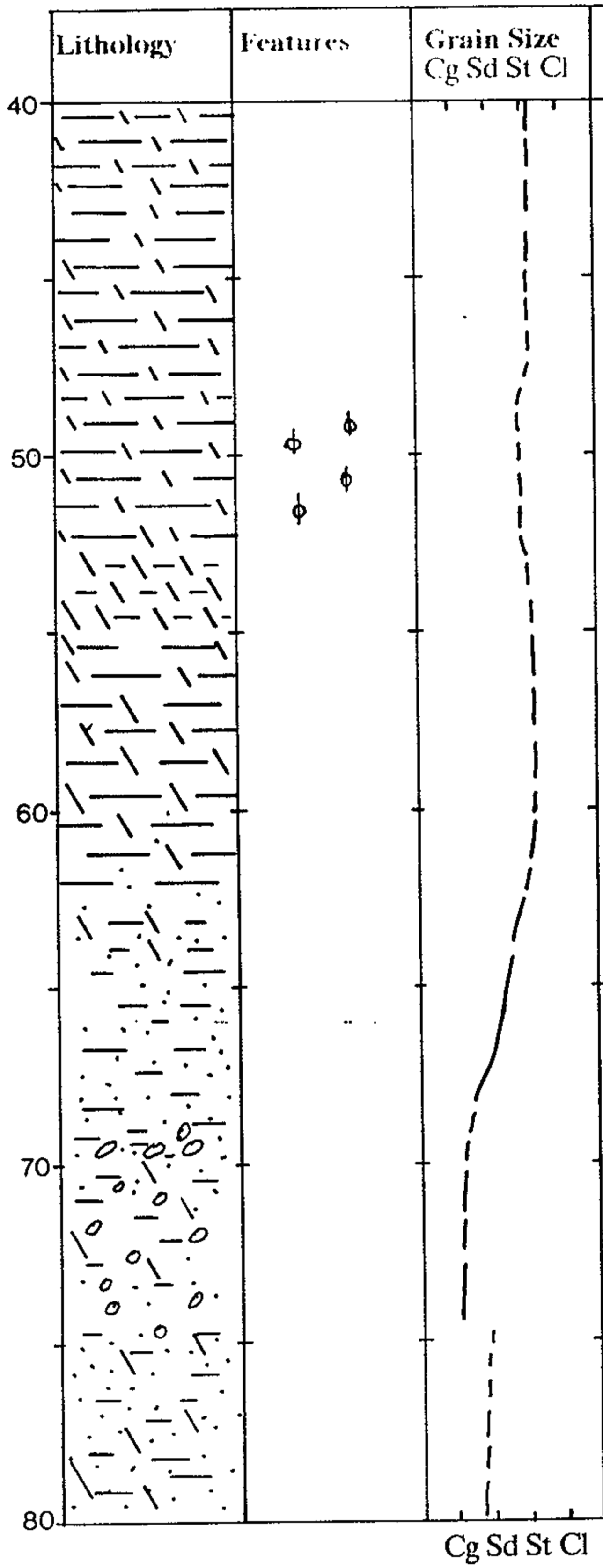
MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

Drillhole No.: *LL M-1* *Location:* *30 fwl, 200 fnl* *Date:* *06/25-26/92*



Description

40-69: Siltstone, argillaceous, with gypsum in pods, zones; gypsum from 40-45 generally < ¼ inch diameter, in continuous network along core.

Slight whitish mottling from carbonate at 47 ft to nodules at about 52 ft.

Mainly crystalline gypsum with argillaceous siltstone from 53-55 ft.

61-65: unit becomes more sandy, less gypsum.

Gravel, siltstone, mudstone at base of recovered core.

69-85: Sandstone, with silt and rare small pebbles (generally < ½ inch) from 69 to 75 ft or granules and some gypsum. Poorly consolidated, soft. No bedding observed.

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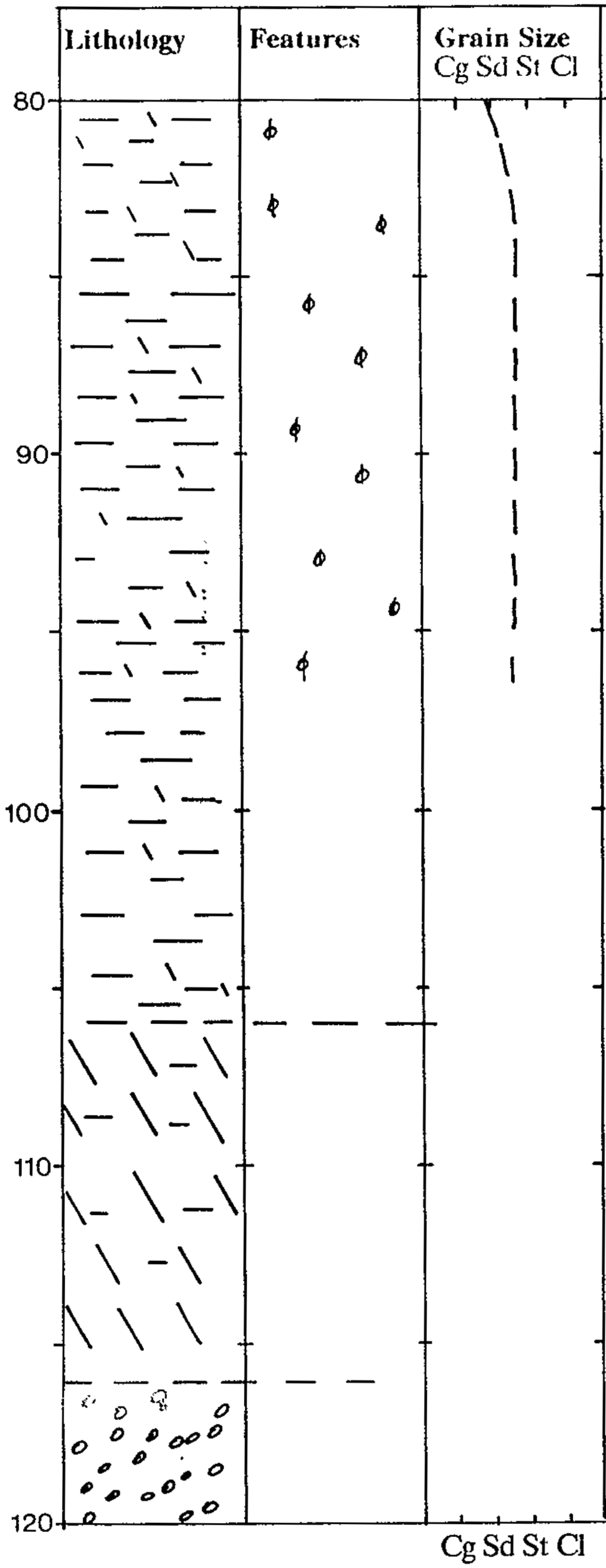
MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

Drillhole No.: *LL M-1* *Location:* *30 fwl, 200 fnl* *Date:* *06/26/92*



Description

Poorly developed calcareous nodules to about ¼ inch and displacive gypsum to about ½ inch from 80-85 ft.

85-97: Siltstone, sandy, argillaceous, with displacive and some fibrous gypsum. Calcareous nodules, poorly developed.

97 ft. End coring, begin rotary drilling. Graphics and notes based on cuttings recovered. Depths based on depth of bit at time of recovery.

106-116: White gypsum powder.

116-126: Pebbles, gravels of rounded to broken light brown to gray limestones.

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MONITOR WELL GEOLOGICAL LOG
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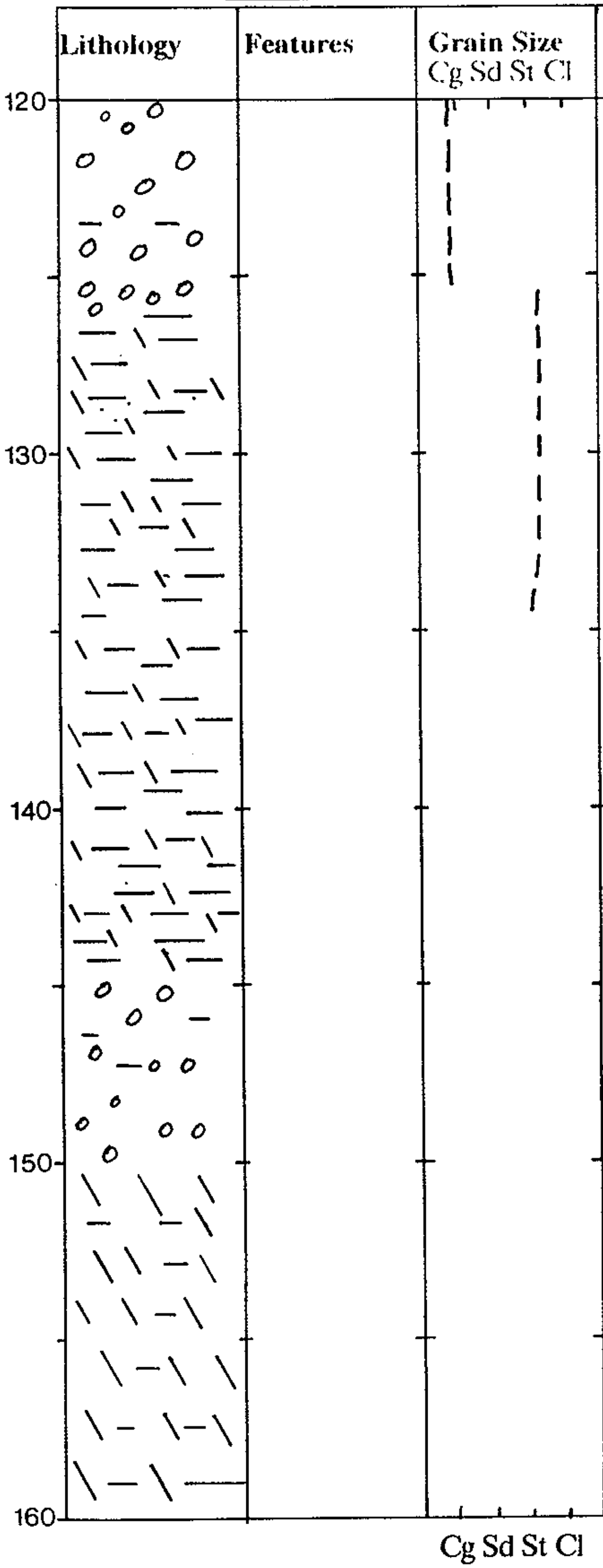
Drillhole No.: *LL M-1* *Location:* *30 fwl, 200 fnl* *Date:* *06/26/92*



Description

126: Siltstone, brown, with gypsum.

145-150: Gravels and pebbles.

150: Gypsum with siltstone.

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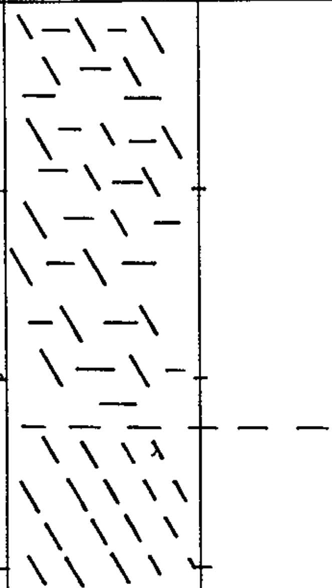
MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

Drillhole No.: *LL M-1* *Location:* *30 fwl, 200 fnl* *Date:* *06/26/92*

Lithology	Features	Grain Size Cg Sd St Cl	Description
160			
180			
200			160-205: Gypsum and very dark brown sticky mud, with rare clasts or fragments of rounded chert and limestone.
			205-220: Mainly gypsum, some yellowish mud.
220			**End drilling. T.D. 220 ft.**



Cg Sd St Cl

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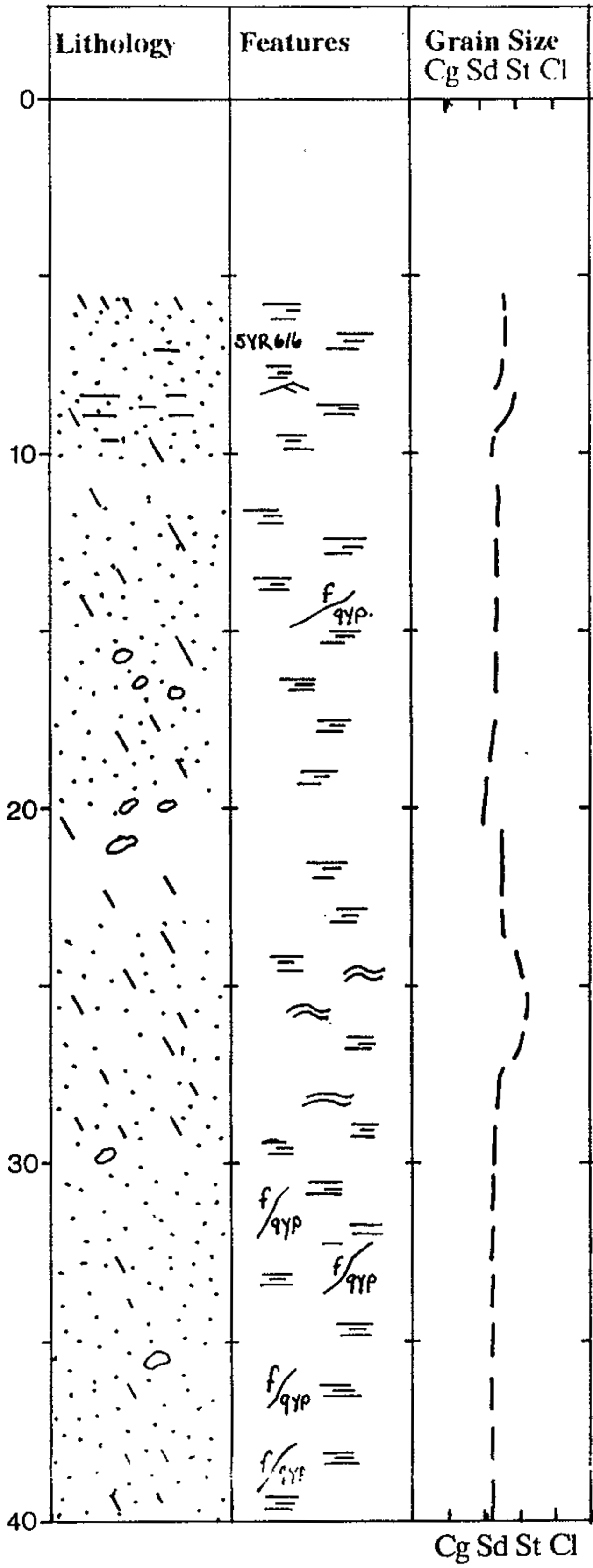
MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

Drillhole No.:LL M-2 *Location: 100 fn, 50 fe of SE corner* *Date: 06/27/92*



Description

Gatuña Formation.

0-30: Sandstone, with argillaceous siltstone and gypsum in thin laminae along bedding. Sand is very fine to medium, subangular to subround, < 1% dark grains. Thin laminae and ripple-scale cross-beds abundant.

More gypsiferous 10-20 ft.

22: Clay clasts, purplish and yellow.

29: Dip 5-10°.

30-40: Thin laminae of sandstone, sandstone and siltstone, some thin clay interlaminae. Gypsum is along bedding, as probable cement, also as thin (2-4 mm) fracture fillings at 10-45° opposite dip. Clay clasts at 30 and 36 ft.

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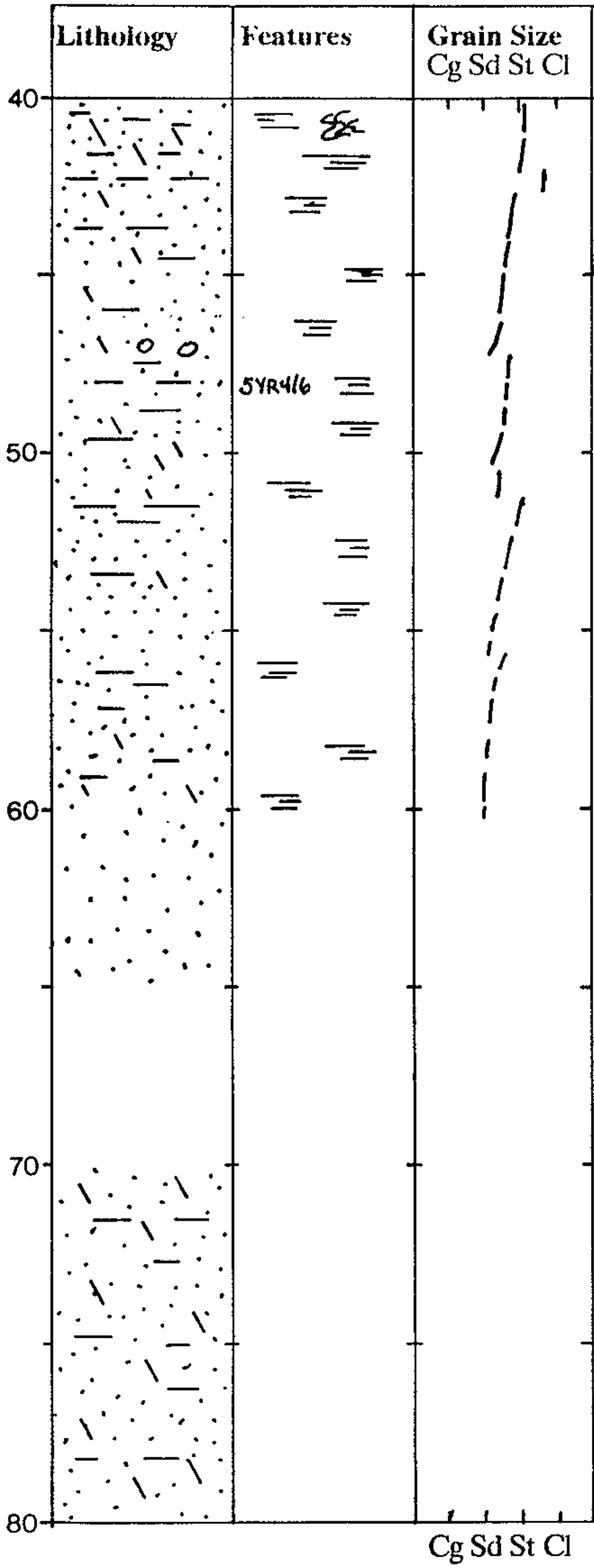
MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

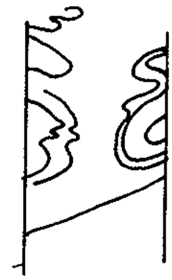
Drillhole No.: *LL M-2* *Location:* *100 fn, 50 fe of SE corner* *Date:* *06/27/92*



Description

40-60: similar to above. More argillaceous zones from 40-50, rare MnO_2 along bedding. Crinkled bedding at 40-42 ft as well as dips on planar beds. Clay clasts at 47 ft.

Detail at 41 ft →



60-T.D.: sticking at 60 ft; rotary with 5 inch bit with air from surface. Graphics and discussion reflect cuttings.

70: Sandstone, fine, siltstone with argillaceous zones, gypsiferous.

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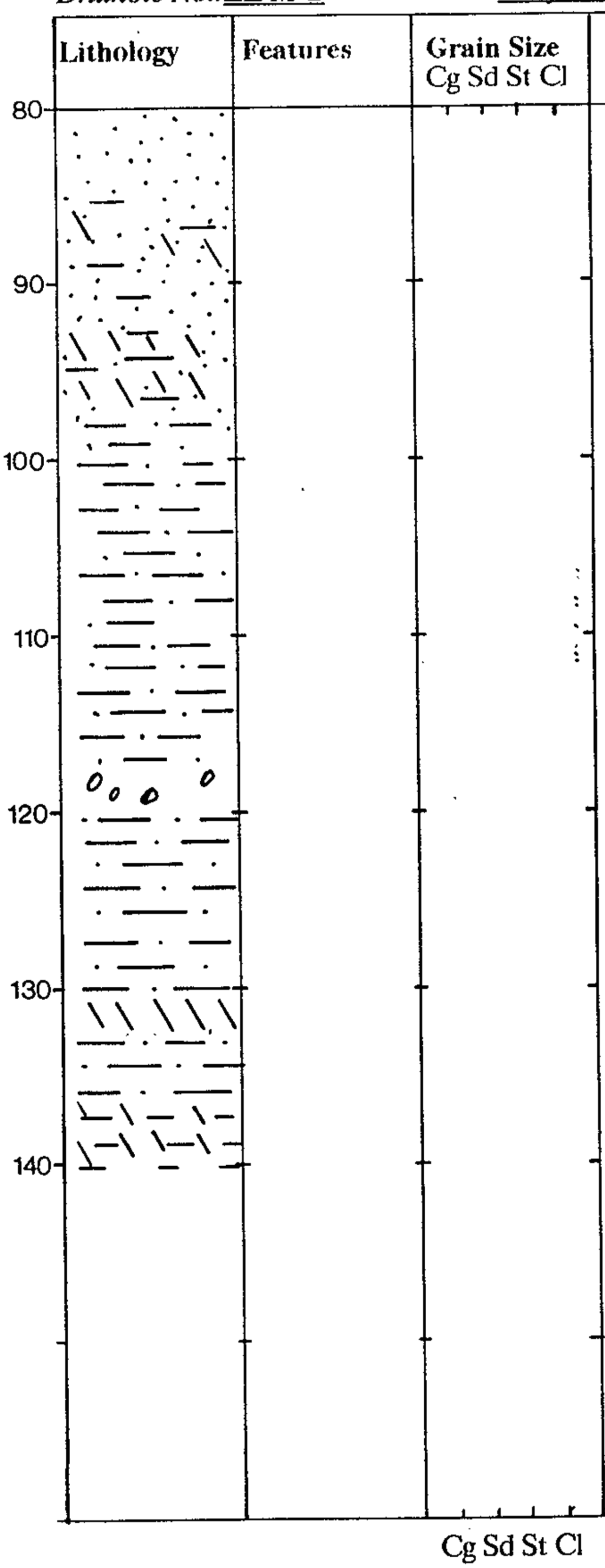
MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

Drillhole No.: *LL M-2* *Location:* *100 ft. 50 fe of SE corner* *Date:* *06/27/92*



Description

80-92: Siltstone, sandy, and claystone, gypsiferous, soft.

92-97: as above, harder, more grayish brown.

97-120: similar to 80-92 ft. Some gravel, pebble fragments at 118 ft. Water returned to surface while drilling at 118 ft.

120-128: Siltstone, argillaceous, soft, dark brown.

128-130: Siltstone, gypsiferous, harder than above, grayish brown.
130-132: Gypsum.
132-135: Siltstone and claystone, soft, brown.

135-140: Siltstone, hard, grayish brown, gypsum cemented. Similar to 92-97 ft.

End drilling. T.D. 140 ft.

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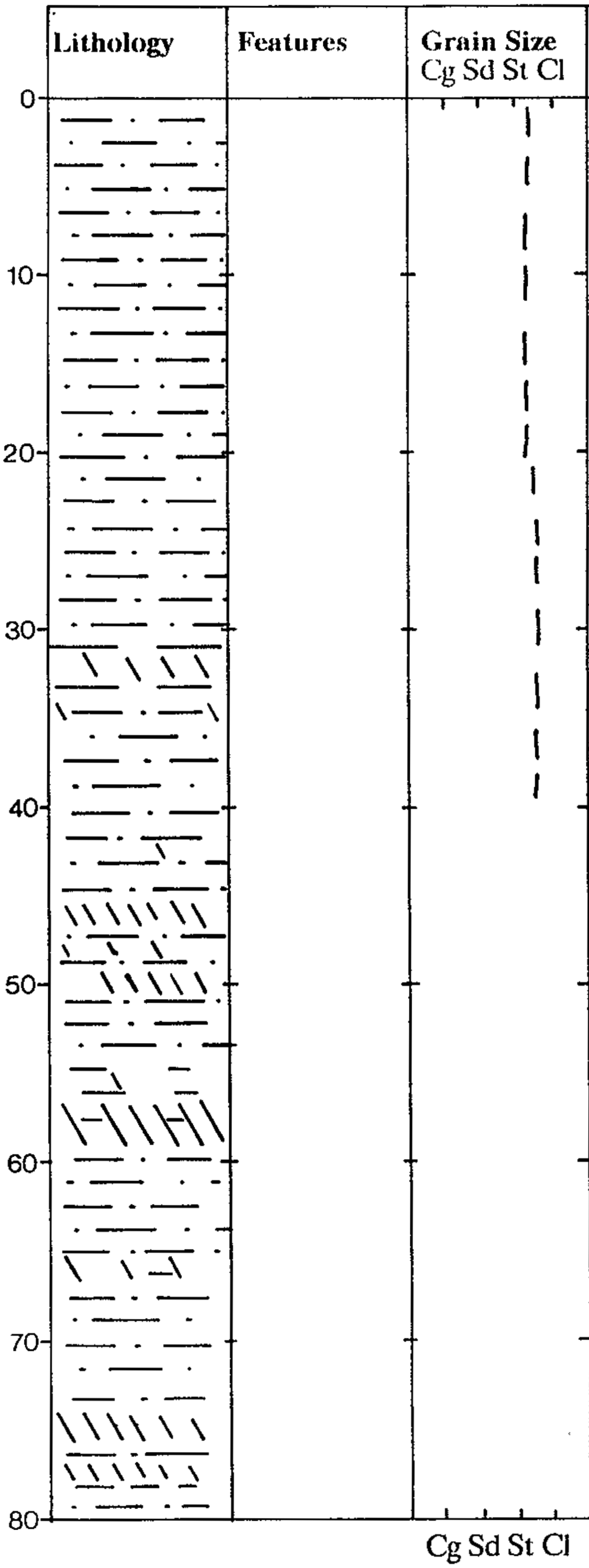
MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

Drillhole No.: *LL M-3* *Location:* *100 fs, 50 fe of NE corner* *Date:* *06/27/92*



Description

Gatuña Formation.
Rotary drilling with air. Graphics and descriptions from cuttings.

0-31: Siltstone, sandy, gypsiferous, light brown to medium brown. Includes slightly more argillaceous zones, including 22-31.

31-33: Gypsum.

Similar to zone above gypsum.

Reddish-brown siltstone and claystone with gypsum.

69-70: Claystone/siltstone, dark grayish brown.

Siltstone, claystone, reddish-brown.

80: no moisture in tubing after 35 minute shutdown.

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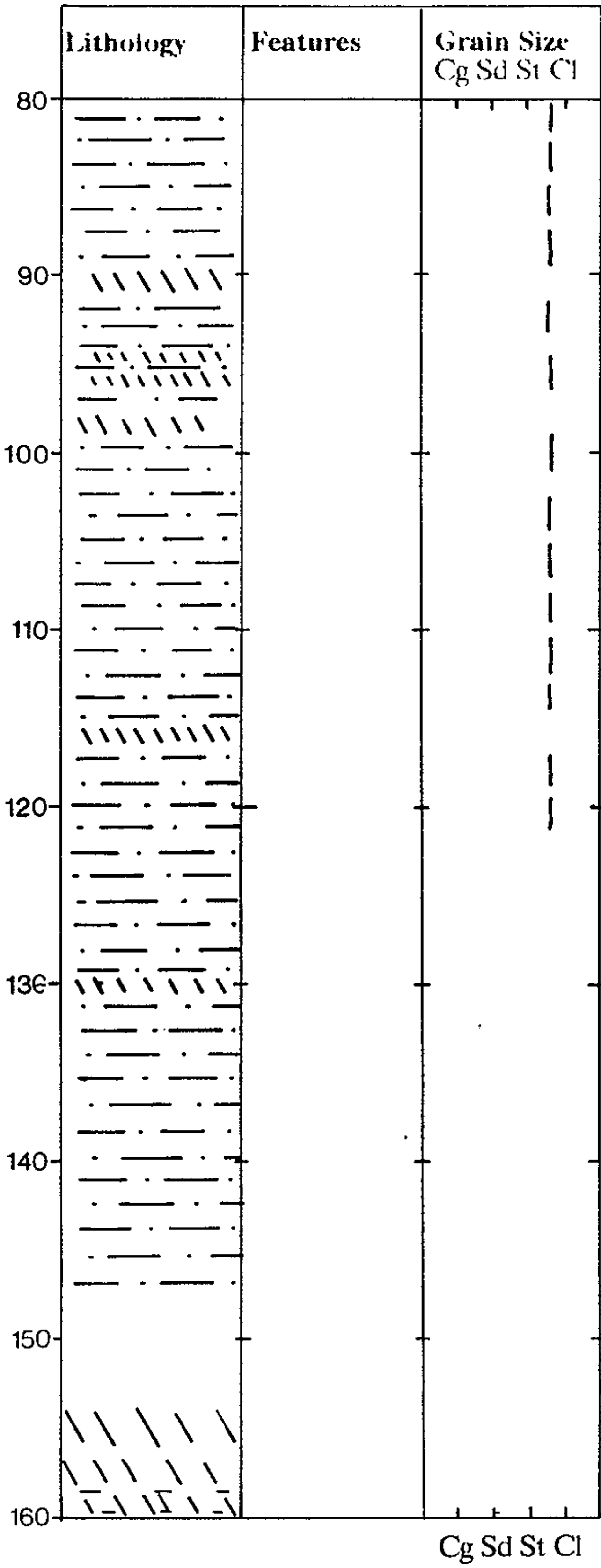
LOVING LANDFILL SITE

Drillhole No.: *LL M-3* *Location:* *100 fs, 50 fe of NE corner* *Date:* *06/27/92*



Description

80-153: Siltstone/claystone, gray, with gypsum stringers or between between 90-100 ft; gypsum interbeds and some gypsiferous zones 100-153 ft. Some zones slightly more grayish brown, brownish gray below 100 ft.

153-158: Mostly gypsum.

158-161: Gypsum with siltstone.

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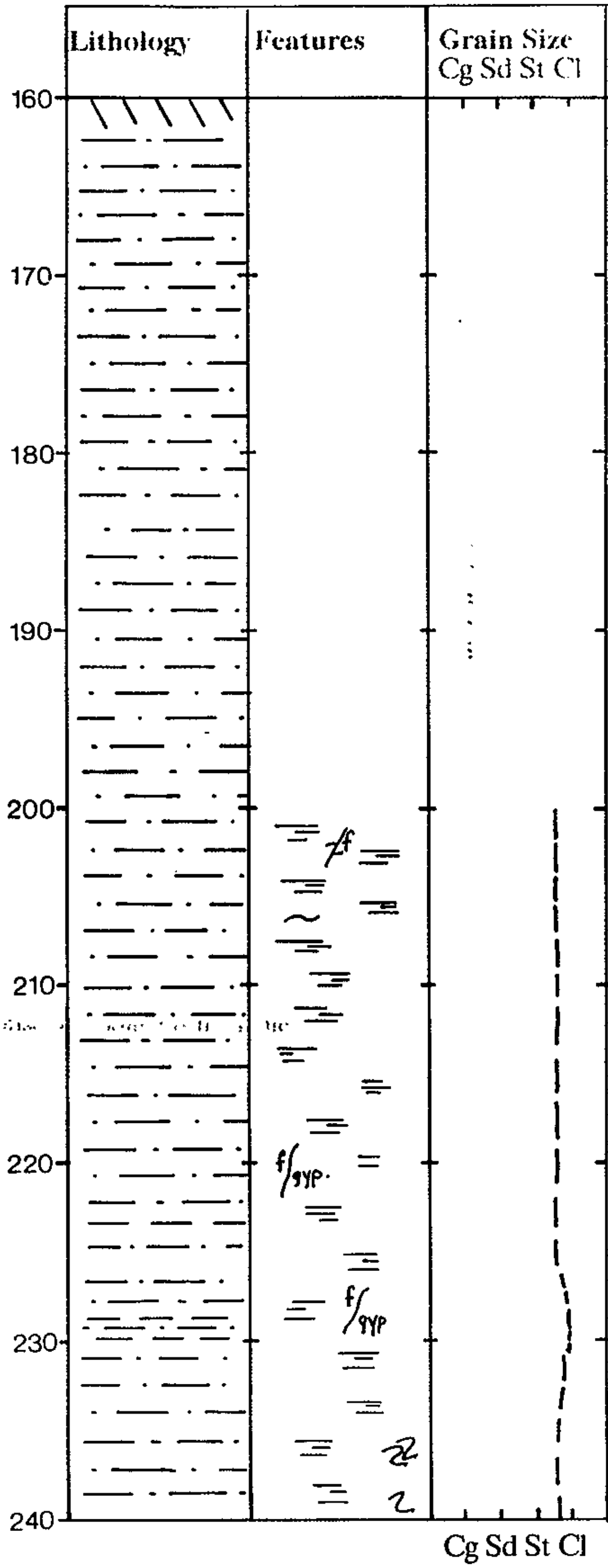
MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

Drillhole No.: *LL M-3* *Location:* *100 fs, 50 fe of NE corner* *Date:* *06/28/92*



Description

161-200: Siltstone/claystone, grayish brown, with gypsum throughout. Zone may be slightly more moist at about 174 ft. Becomes very sticky at 198-200 ft. No apparent fluid production during 30 minute observation period.

Begin coring.

200-248: Siltstone, sandy, to claystone, silty, dark brownish gray with gypsum veins and cement. Some white gypsum and gypsiferous zones. Well laminated. Fractures, some with gypsum or fibrous gypsum growth, slight offset at about 201 ft. Some wavy bedding. Dips 10-20° at about 208, 20°+ at 235 ft, some contorted bedded 235-240 ft.

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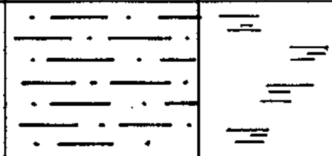
MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

Drillhole No.: *LL M-3*   *Location:* *100 fs, 50 fe of NE corner*   *Date:* *06/28/92*

Lithology	Features	Grain Size Cg Sd St Cl	Description
240 			**End drilling. T.D. at 248 ft.**
250			
		Cg Sd St Cl	

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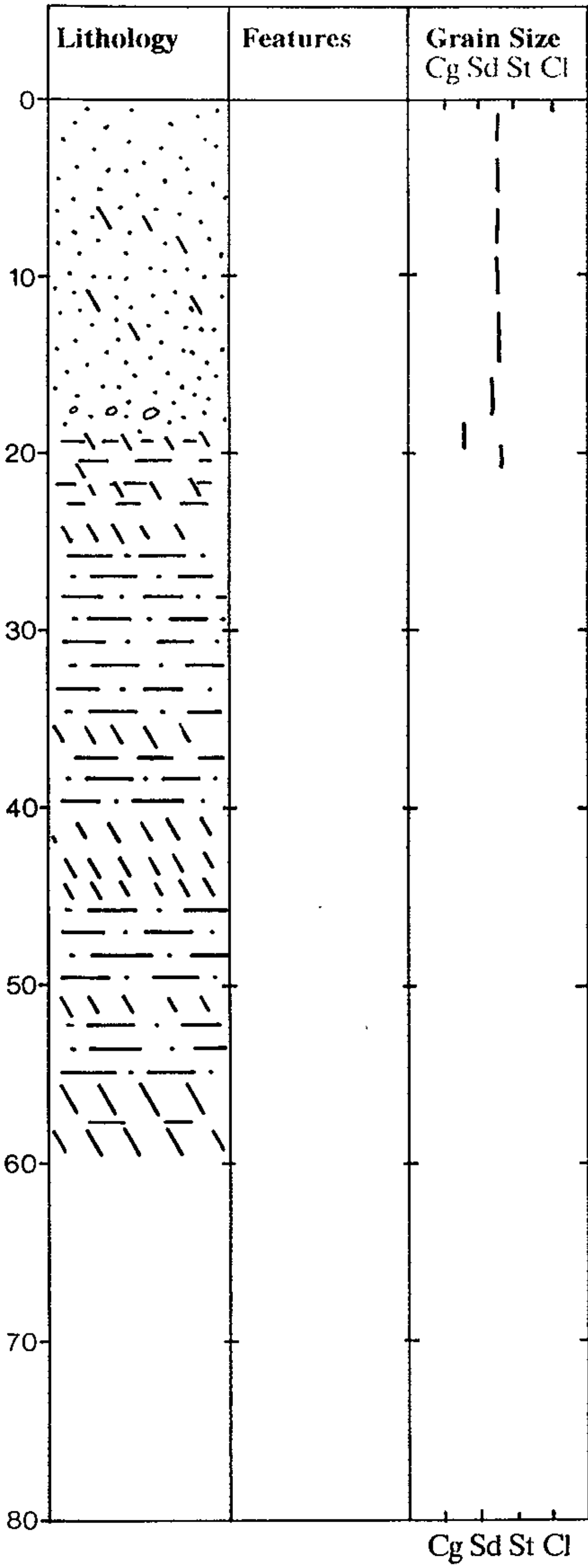
MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

Drillhole No.:LL M-4 *Location: 250 fe, 50 fs of SW corner* *Date: 06/28/92*



Description

Rotary drilling with air; cuttings used for graphics and description.

Gatuña Formation

0-18: Sandstone with gypsum, upper part is disturbed by landfill activities.

18-19: Gravel, sand, somewhat moist.

19-38: Sandstone and gypsum with siltstone.

38-40: Claystone and siltstone, soft, reddish brown.

40-60: Interbedded gypsum and siltstone.

No return of cuttings at 50 ft.

Water return to surface.

End drilling. T.D. 60 ft.

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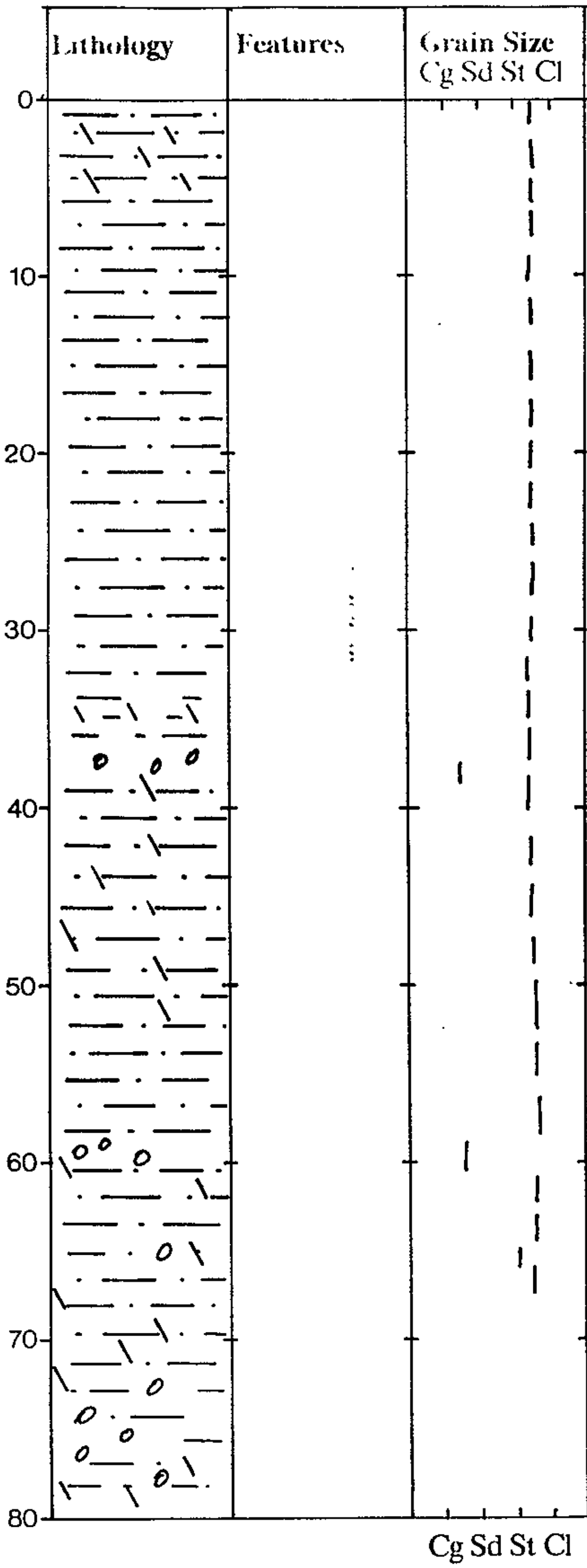
MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

Drillhole No.:LL M-5   *Location: 200 fe, 50 fs of NW corner*   *Date: 06/29/92*



Description

Rotary drilling with air; cuttings used for graphics and description.

Gatuña Formation

0-34: Claystone and siltstone, reddish brown, with zones or blocks of gypsum. Soft, cuttings molded during drilling.

30: Sticky zone.

34-37: Gypsiferous claystone and siltstone.

37-38: Conglomerate, limestone clasts.

38-58: Gypsiferous siltstone and claystone.

58-60: Gravel, limestone clasts.

60-74: Gypsiferous siltstone and claystone, grayish brown.

74-78: Gravelly zone.

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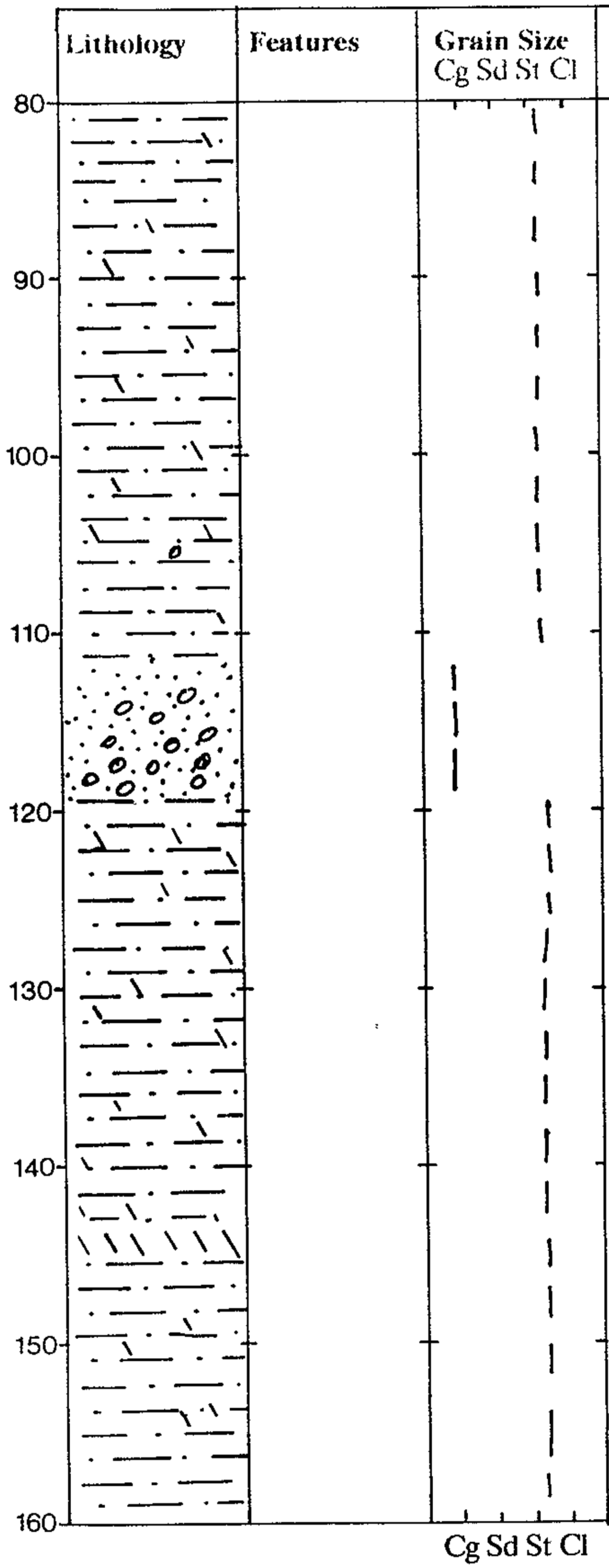
MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

Drillhole No.: LL M-5 *Location:* 200 fe, 50 fs of NW corner *Date:* 06/29/92



Description

78-112: Siltstone and claystone, reddish brown, with gypsum or gypsiferous zones and beds. Becomes more grayish brown in color below 87 ft.

112-119: Sand, gravel, gypsum, yellowish.

119-160: Siltstone/claystone, reddish brown, with gypsum. Soft, moist. Coarse gypsum in cuttings from about 142-145 ft with intermittent returns of cuttings.

160: Claystone, gray, soft.

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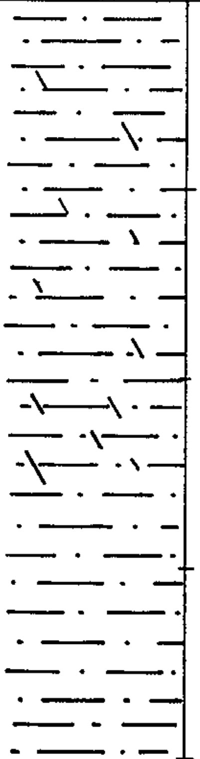
MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

Drillhole No.: *LL M-5* *Location:* *200 fe, 50 fs of NW corner* *Date:* *06/29/92*

Depth	Lithology	Features	Grain Size Cg Sd St Cl	Description
160				
170				
180				
190				160-200: Claystone and siltstone, grayish brown, soft, with zones/beds of gypsum. Unit generally more gypsiferous from 181-185.
200				**End drilling. T.D. 200 ft.**

Cg Sd St Cl

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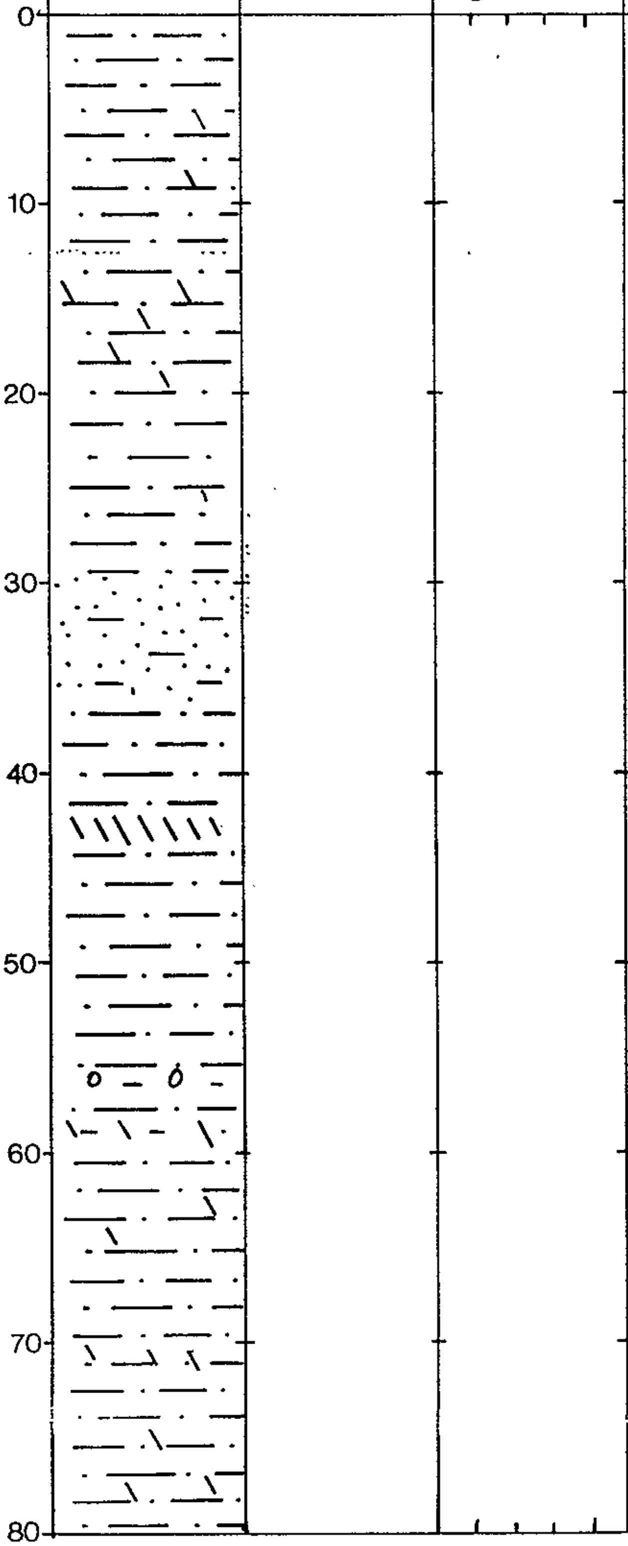
MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

Drillhole No.:LL M-6   *Location: 100 fw, 150 fn of SE corner*   *Date: 06/29/92*

Lithology	Features	Grain Size Cg Sd St Cl	Description



Rotary drilling with air; cuttings used for graphics and description.

Gatuña Formation

0-75: Siltstone and claystone, reddish brown, soft, with fibrous gypsum and gypsiferous zones. Sandy zone from about 28-38 ft. Gypsum zone at 43 ft. Clasts at 57 ft.

75-79: Claystone, greenish gray, with brown claystone and siltstone.

79-80: Coarse gypsum fragments.

Cg Sd St Cl

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MONITOR WELL GEOLOGICAL LOG
LOVING LANDFILL SITE

Drillhole No.: *LL M-6* *Location:* *100 fw, 150 fn of SE corner* *Date:* *06/29/92*

Depth	Lithology	Features	Grain Size (Cg Sd St Cl)	Description
80				
90				80-100: Siltstone/claystone, gray and brown. Blew water from borehole at about 95 ft.
100				
110				
120				**End drilling. T.D. 120 ft.**

Cg Sd St Cl

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Appendix 2
Loving Landfill Closure
Monitor Hole Histories

General

The hole histories for the drilling of monitor wells for closure of the Loving landfill site are compiled from field notes by Dennis Powers and Marvin Magee. The borehole histories are a chronological record of the daily events in drilling and completion of each borehole. Where minor differences in records existed, they have been reconciled based on the best apparent record; these generally reflect minor variations in data about times of events or exact depths. The main report includes generalized illustrations of the features of each borehole as completed.

The drilling contractor was Stewart Brothers, Inc., Grants, NM; a four man crew utilized a Chicago Pneumatic 650, top head drive, rotary drilling rig. The crew and rig arrived on site June 25, 1992; the last well was completed on July 1 and surface shrouds were finished July 2, 1992.

The program for the Loving landfill was implemented to establish wells for monitoring ground water levels and quality following closure of the landfill. Drillholes were cored through various intervals to establish the fundamental geology. Drilling was conducted with air when possible; some conditions required use of foam or water. The wells were established as piezometers to monitor initial ground water level recover, provide for sampling, and enable bailing or other testing of hydrologic parameters, if necessary.

Drillhole LL M-1

LL M-1 was located about 20 ft inside the western fenceline of the landfill, approximately at the middle of the boundary line. The surface elevation of LL M-1 is about 3112 ft.

June 25

1500-1545	Moved rig onto landfill site and set up to drill M-1.
1545-1830	Drilling and coring with air, using 94 mm wireline system, from ground surface to 70 ft with good but variable recovery of Gatuña Formation.

June 26

0700-0705	Checked borehole with water detector; borehole dry.
0705-0740	Cored to 76 ft, using air; drilling difficult from 74-76 ft.
0740-0900	Reamed hole to 5" diameter with tricone bit to 76 ft. Rerigged for coring.
0900-1030	Cored using air to 97 ft with variable recovery. Put 5 gal water into drillhole from surface while drilling at 95 ft. Coring difficult; changed to rotary drilling with examination of cuttings.
1030-1745	Rotary drilling in Gatuña Formation from 97 to 220 ft. Foam was used in drilling from about 160 ft to TD. No detectable fluid in borehole. Removed drilling string from borehole and shut down rig. Major electrical storm north and south threatening site.

June 27

0700-0940	Checked for water in M-1; possible fluid level at 215-216 ft below surface and bottom of borehole at 225 ft. Bailed hole "dry", waited 20 minutes, bailed again; estimated 15 gal of soapy water and muck (mainly mud clasts and gypsum). Decided to move to another location and allow borehole to stand.

July 1

	Set 2 inch schedule 40 FJ PVC tubing as follows: screen from 200 to 170 ft, riser from 170 ft to surface. Completed monitor well with sand pack (10-20 size) from 240 (TD) to 160 ft, benseal from 160 to 122 ft, and cemented from 122 ft to surface with 15 lb neat cement. Set well shroud.

Drillhole LL M-2

LL M-2 was located about 50 ft east and 100 ft north of the [illegible] corner of the landfill. The surface elevation of LL M-2 is about 3109 ft.

June 27

0940-1010	Moved to location for LL M-2 and set up to core.

1010-1155	Core with air with good recovery from ground surface to 60 ft. Probable condensation in core barrel and sticking from 50-60 ft.
1155-1445	Standby and rotary drilling with 5" tricone bit from 60 to 118 ft, using air. Recover cuttings of Gatuña Formation. At 118 ft, cuttings stopped returning, pressure in drill string rose, and then water began blowing from air return.
1445-1515	Continued drilling hole to 140 ft TD with rotary tricone bit (5") to provide sump for tubing.
1515-1530	Rig down to move to M-3 location.

June 30

Set 2 inch schedule 40 FJ PVC tubing as follows: blank tubing from 140-130 ft, screen from 130 to 110 ft, riser from 110 ft to surface. Completed monitor well with sand pack (10-20 size) from 140 (TD) to 94 ft, benseal from 94 to 78 ft, and cemented from 78 ft to surface with 15 lb neat cement.

July 2

Set shroud.

Drillhole LL M-3

LL M-3 was located about 50 ft east and 100 ft south of the northeastern fence corner of the landfill. The surface elevation of LL M-3 is about 3111 ft.

June 27

1530-1615	Moved to M-3 location and set up to drill.
1615-1845	Rotary drilled with air using 5" tricone bit from surface to 140 ft depth. Cuttings from Gatuña Formation primarily finer-grained siltstone/claystone with variable gypsum content. Checked water level in M-2 (57.2 ft below surface).

June 28

0700	Checked water levels in M-2 (48 ft below surface) and M-3 (no fluid detected) at 140 ft.
0700-0900	Rotary drilled with air to 200 ft; sticky clay and difficult drilling from 198-200 ft.
0900-0915	Halted drilling and removed drill string for observation of any fluid entry.
0915-0945	Monitored borehole with water detector at 200 ft; no fluid entry detected.
0945-1350	Re-entered borehole with wireline coring system and bit. Cored slowly with to TD at 248 ft with excellent recovery.
1350-1445	Observed borehole for fluid entry; no water detected.
1445	Rig down for move to M-4.

June 30

Set 1¼ inch tubing as follows: screen from 240 to 220 ft, riser from 220 ft to surface. Completed monitor well with sand pack (10-20 size) from 245 (TD) to 175 ft, benseal from 175 to 157 ft, and cemented from 157 ft to surface with 15 lb neat cement.

July 2

Set shroud.

Drillhole LL M-4

LL M-4 was located about 250 ft east of southwest fence corner and 50 ft south of the south fence line of the landfill. The surface elevation of LL M-4 is about 3108 ft.

June 28

1445-1515 Rig down and move from M-3 to M-4. Set up and prepare for rotary drilling with 5" tricone bit.

1515-1615 Rotary drill to 60 ft. No cuttings returned from about 50 ft, damp to wet cuttings from 51 ft, moisture blowing from hole from 53 ft (1555 hours). Cuttings from gypsum at 60 ft.

1615-1745 Shut down drilling, observed fluid level rise from about 53.6 (1620 hours) to 51.6 ft (1655 hours) (levels measured from top of drill pipe, about 3 ft above ground level). Bailed about 30 gal to 1730 hours. Measured about 10" recovery in water level from 1733 to 1745 hours.

1745-1800 Pulled rig off hole and shut down operations.

June 29

0710-0805 Checked water levels at M-1,2,3, and 4.

June 30

Set 2 inch schedule 40 FJ PVC tubing as follows: screen from 60 to 40 ft, riser from 40 ft to surface. Completed monitor well with sand pack (10-20 size) from 60 (TD) to 35 ft, benseal from 35 to 20 ft, and cemented from 20 ft to surface with 15 lb neat cement.

July 2

Set shroud.

Drillhole LL M-5

LL M-5 was located about 25 ft south of approximate midpoint of north fence line of the landfill. The surface elevation of LL M-5 is about 3112 ft.

June 29

0805-1155 Rotary drilled with air using 5" tricone bit from surface to 200 ft. Gatuña Formation indicated by cuttings to TD. No fluid or moist zones identified.

1155-1235 Rig down, move to M-6 location and set up for drilling.

1630-1745 Move rig back to M-5 to install tubing for monitor well. Set 1¼ inch tubing as follows: screen from 193 (TD) to 183 ft, riser from 183 ft to surface. Placed sand pack (10-20 size) from 193 to 174 ft, benseal from 174-156 ft, and cemented from 156 ft to surface with 15 lb neat cement.

July 1

Set well shroud.

Drillhole LL M-6

LL M-6 was located about 150 north and 100 ft west of the southeast fence corner of the landfill. The surface elevation of LL M-6 is about 3113 ft.

June 29

1235-1630 Rotary drilled with air, using 5" tricone bit, from surface to 120 ft in Gatuña Formation. Possible fluid entry at 90 ft, probable fluid production from fracture at 115 ft. Pressure increase within drillstring in M-6 coincided with fluid level rise in M-2. Lowered pressure in M-6 and fluid production coincided with lowering of fluid level in M-2. Blew fluid from borehole. Monitored fluid level rise briefly; rigged down for rig move.

June 30

Set 2 inch schedule 40 FJ PVC tubing as follows: screen from 120 to 90 ft, riser from 90 ft to surface. Completed monitor well with sand pack (10-20 size) from 120 (TD) to 84.8 ft, benseal from 84.8 to 72 ft, and cemented from 72 ft to surface with 15 lb neat cement.

July 1

Set well shroud.

Table 2-1
Well Reference and
Early Ground Water Elevations,
Loving Landfill Monitor Wells

		Ground Water Elevation (Depth)	
	Date:	*July 2*	*August 6*
Monitor Well	**Well Shroud Elevation**		
LL M-1	3113.9	2979.1 (134.75)	2997.3
LL M-2	3110.7	3060.2 (49.9)	3060.8
LL M-3	3113.1	2890.1 (223.0)	3026.3
LL M-4	3110.5	3070.8 (39.7)	3060.6
LL M-5	3113.1	< 2917.1 (dry to 196)	2984.3
LL M-6	3114.2	3060.9 (53.3)	3060.9

Note: All measurements provided by Marvin Magee (JOAB, Inc.).

Table 2-2

Loving Landfill Hydrological Data

Obtained During Drilling Program

Date	Time	Depth (fluid or hole)	Reference Point	Comment
LL M-1				
June 26	0700	70'	drill pipe	Dry to TD @ 70'
June 27	1530	190?	surface	Questionable fluid level or mud; TD 220'.
June 28	0700	215-216'	surface	Possible water; bottom @ 225'
	0910	193?	surface	Possible fluid level
June 29	about 0715	170.3	surface	Fluid level; bottom 216'
LL M-2				
June 27	1445	118'	drill pipe	Blow water from hole while drilling
June 27	1555	84'	surface	Fluid level; TD 120'.
	1723	63.5'	surface	" "
	1744	61.5'	surface	" "
	1849	57.2'	surface	" "
June 28	0703	48.0'	surface	" "
	0900	48	surface	" "
	1700-1730			No change during bailing of M-4
June 29	about 0725	47.0	surface	Fluid level
	about 1500			Fluid level rise to <42' with pressure buildup in M-6; level drop with pressure release in M-6
LL M-3				
June 27	1750	80	Drill pipe	No fluid after 35 min; TD 80'
June 28	0945	200	Drill floor	No fluid after 30 min; TD 200'
	1445	248	Drill floor	No fluid detected at TD 248'
June 29	about 0735	190'	Surface	Damp mud?
LL M-4				
June 28	1600	53'	Drill pipe	Blow water from borehole while drilling
	1620	53.63'	Drill pipe	Drill pipe about 3' above surface
	1625	52.54	Drill pipe	as above
	1630	52.17	Drill pipe	as above
	1635	52.0	Drill pipe	as above
	1640	51.90	Drill pipe	as above
	1645	51.79	Drill pipe	as above

Table 2-2, cont.
Loving Landfill Hydrological Data
Obtained During Drilling Program

Date	Time	Depth (fluid or hole)	Reference Point	Comment
LL M-4, cont.				
June 28	1650	51.71	Drill pipe	as above
	1655	51.63	Drill pipe	as above
	1700-1730			bailed about 30 gal
	1733	54.33	Drill pipe	see above
	1735	54.08	Drill pipe	see above
	1740	53.71	Drill pipe	see above
	1745	53.48	Drill pipe	see above
June 29	about 0745	47.90	Surface	surface about 3' lower than drill pipe
June 29	about 1500			No change in level with pressure buildup and release in M-6
LL M-5				
June 29	1200	200'	Drill pipe	Dry to TD @ 200'
LL M-6				
June 29	1412	95'	Drill pipe	Blew water from borehole; TD @ 120'. Pressure buildup in M-6 produced fluid level rise in M-2; pressure release resulted in M-2 drop. M-4 showed no effects.

Figure 2-1

As-Built Configuration of LL M-1

Well I.D.: *LL M-1*
Location: *Loving Landfill*

Type: *Piezometer*
Elevation*: *3113.91 ft*
*Top of well shroud without locking cap

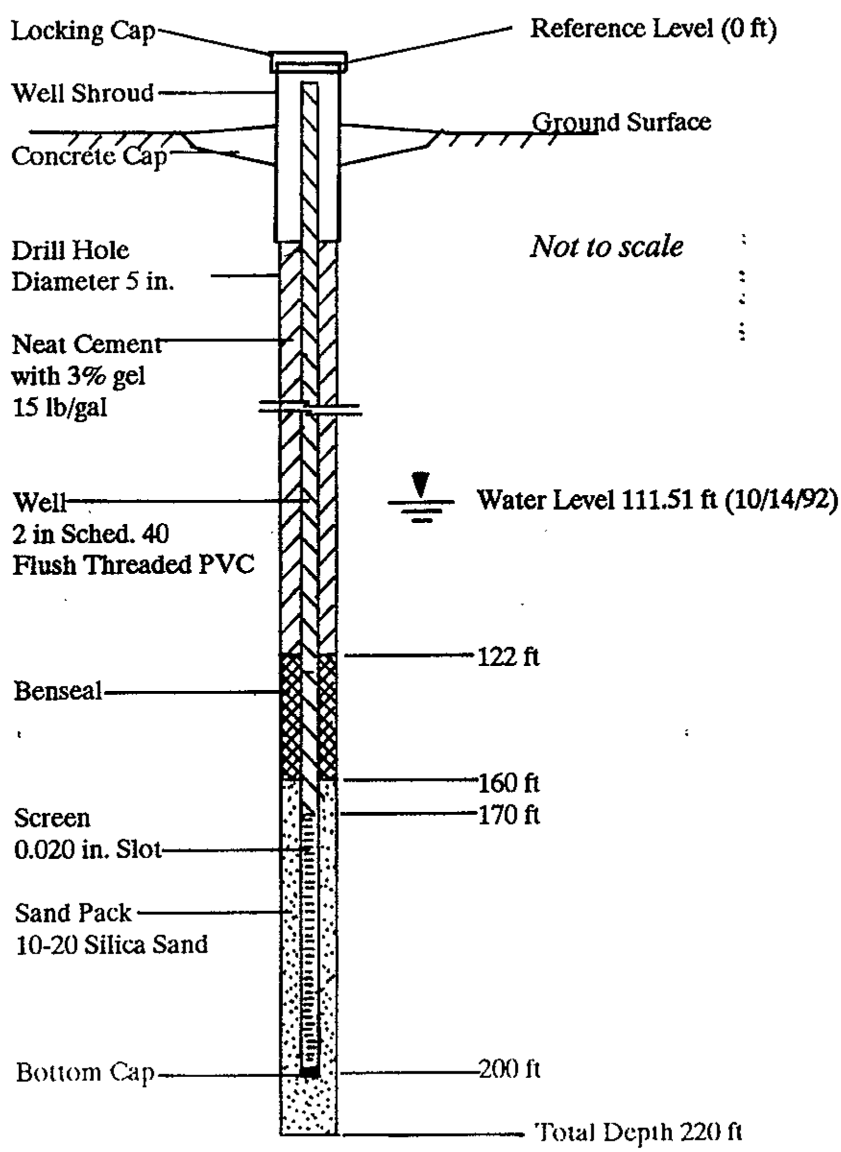

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Figure 2-2

As-Built Configuration of LL M-2

Well I.D.: *LL M-2*
Location: *Loving Landfill*
Type: *Piezometer*
Elevation*: *3110.73*
**Top of well shroud without locking cap*

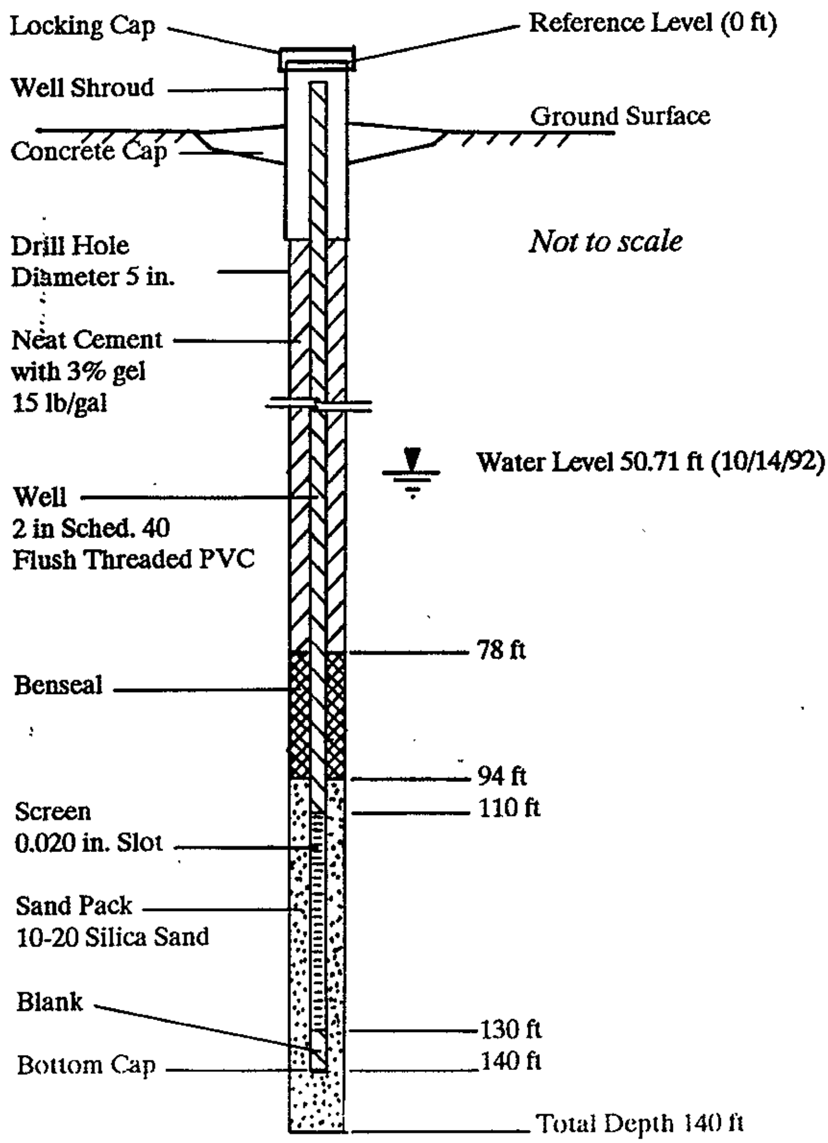

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Figure 2-3

As-Built Configuration of LL M-3

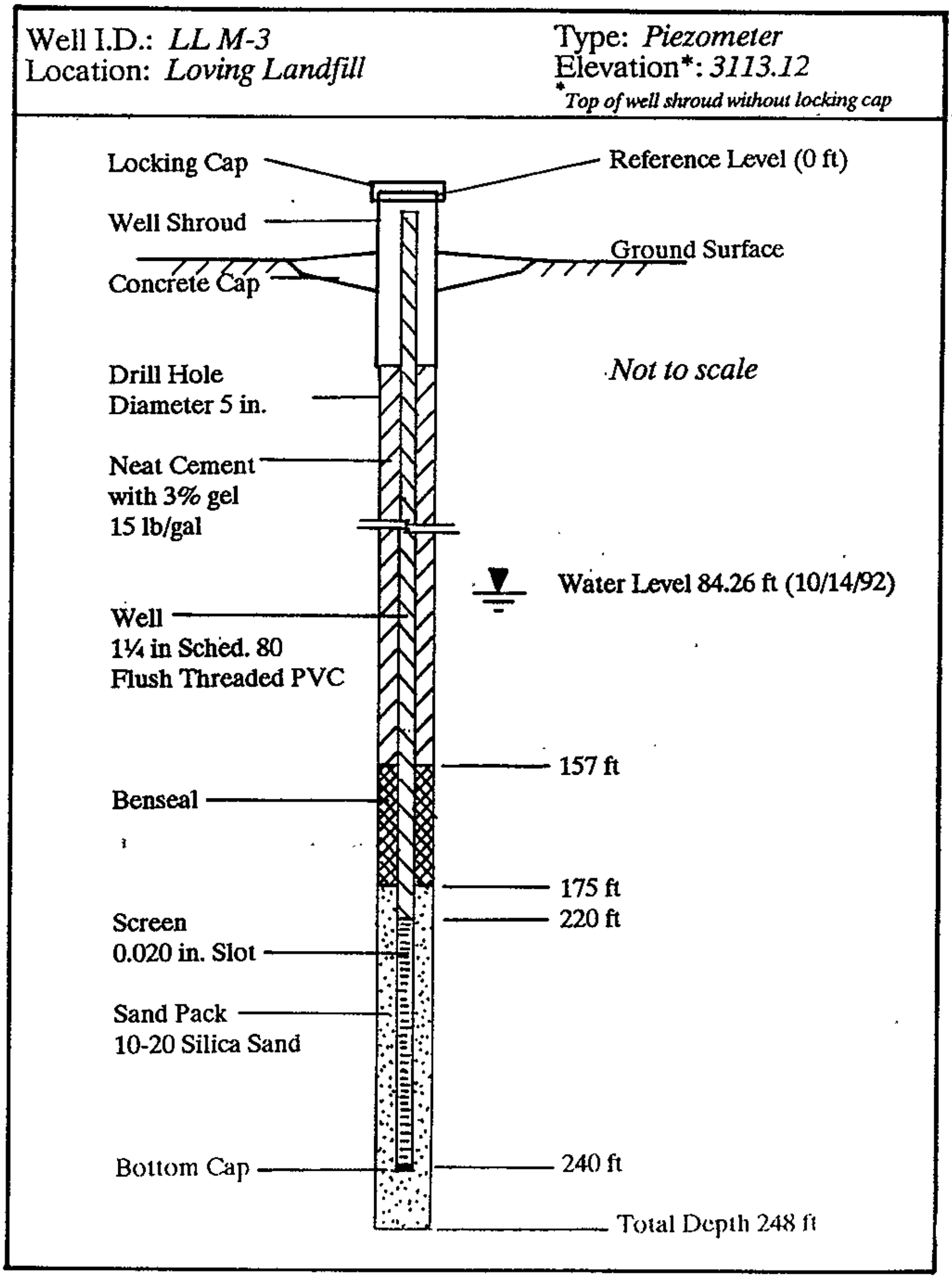

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Figure 2-4

As-Built Configuration of LL M-4

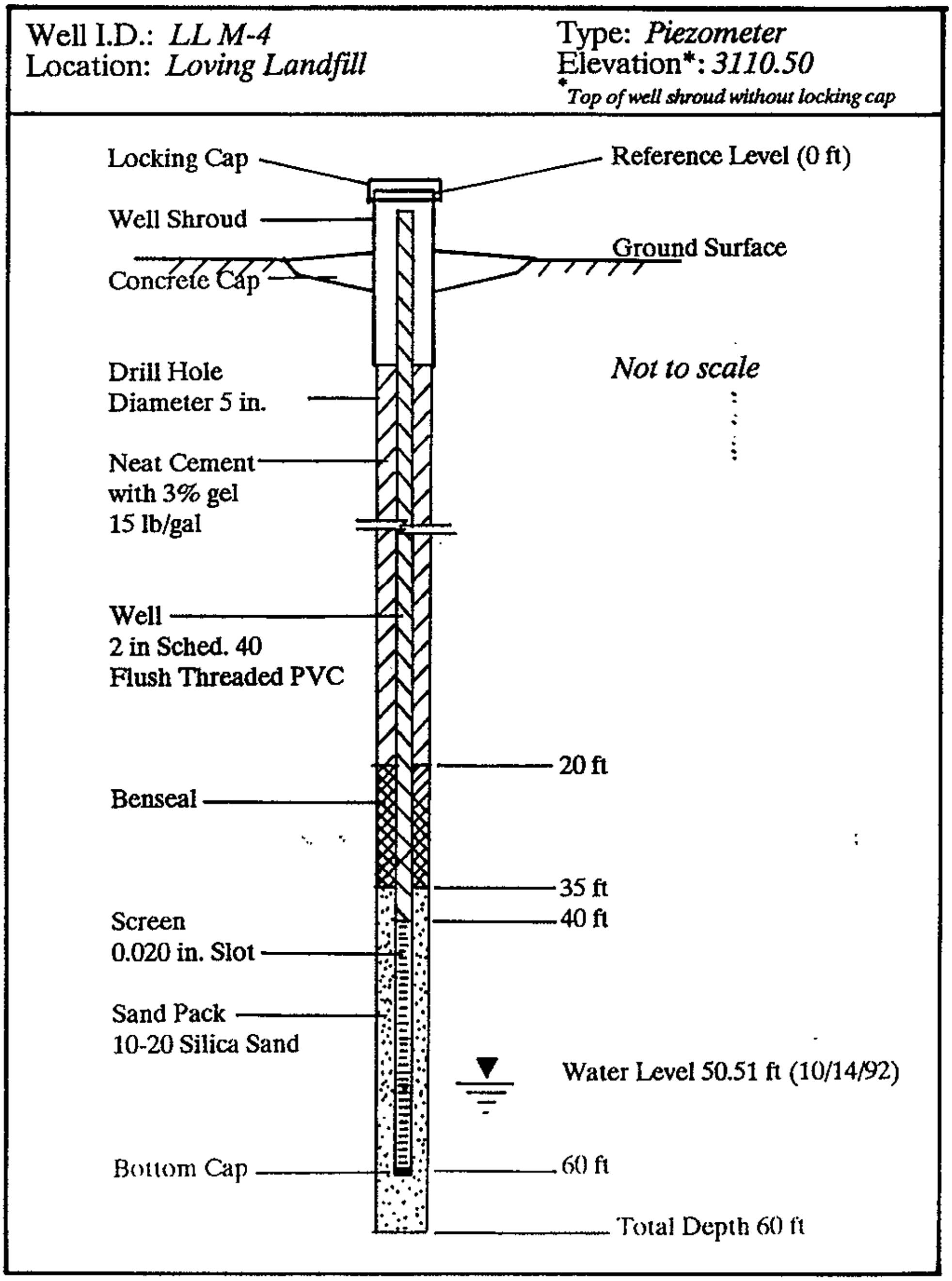

Figure 2-5

As-Built Configuration of LL M-5

Well I.D.: *LL M-5*	Type: *Piezometer*
Location: *Loving Landfill*	Elevation*: *3113.11*
	Top of well shroud without locking cap

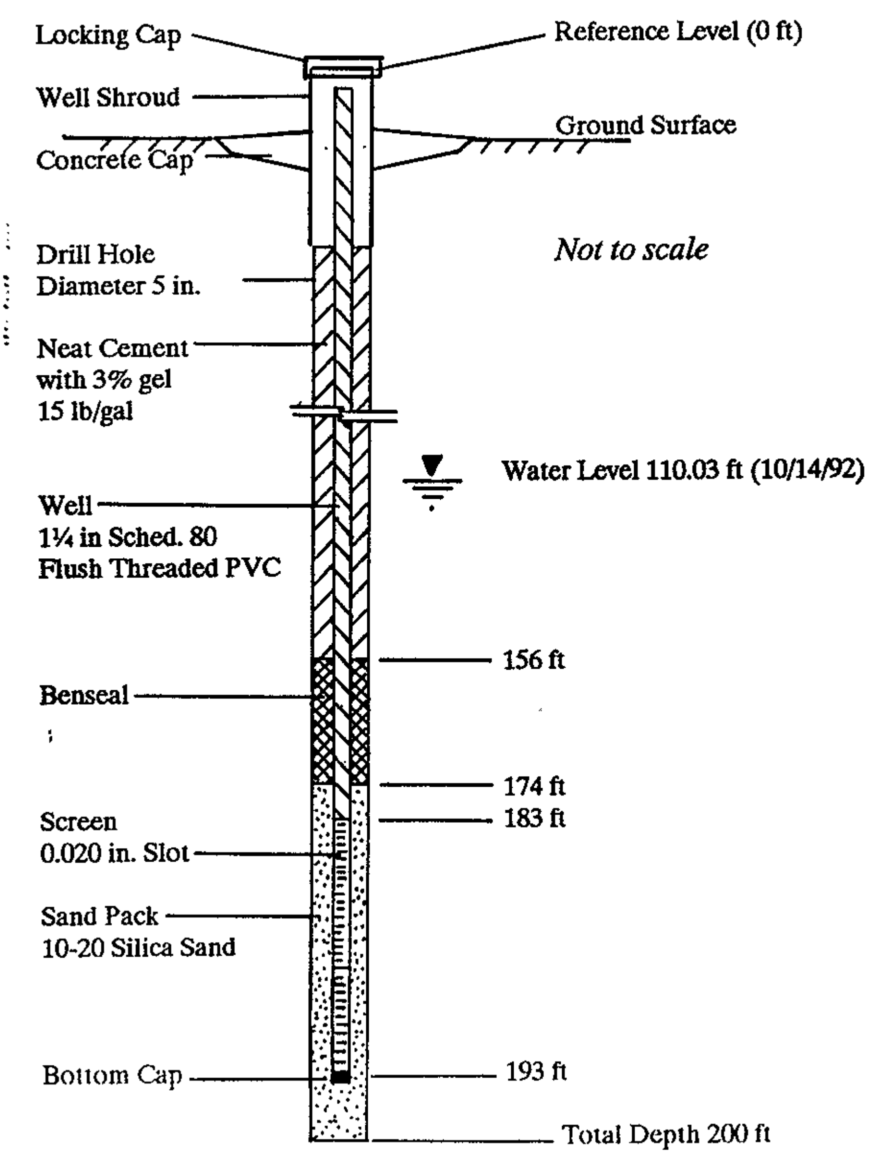

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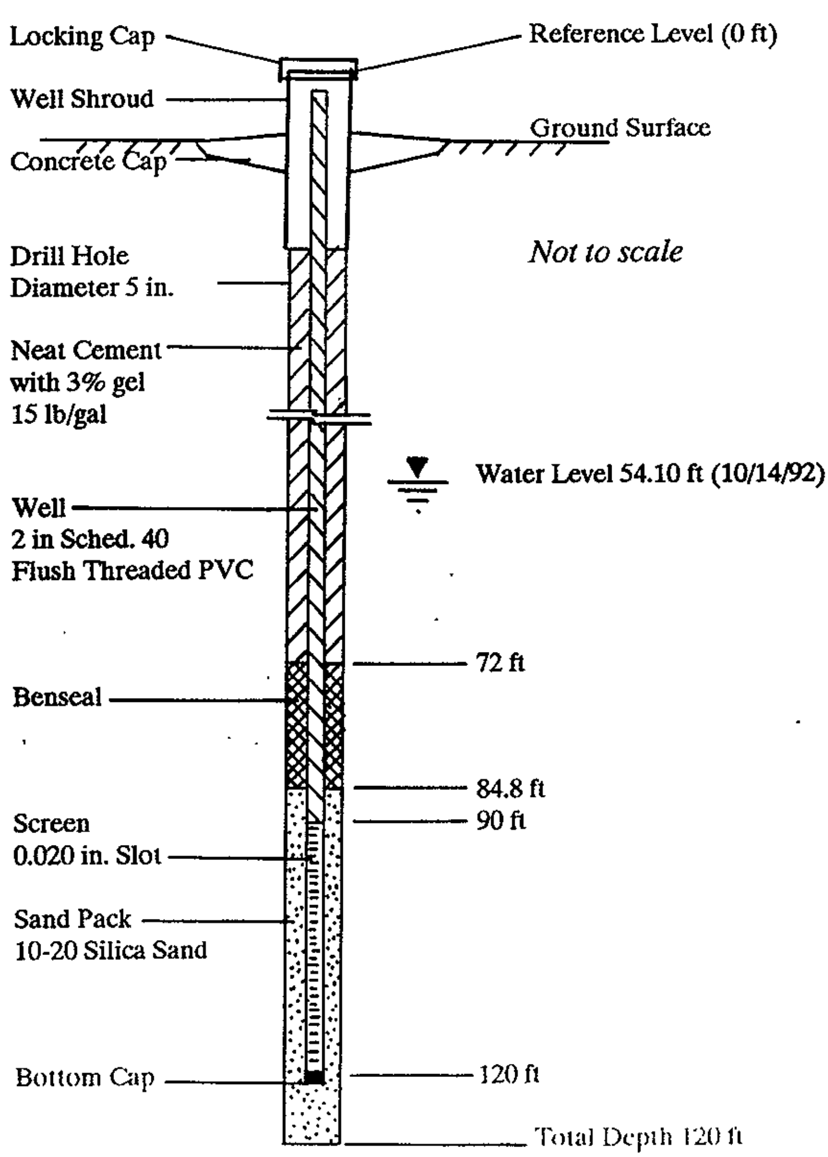
Figure 2-6

As-Built Configuration of LL M-6

Well I.D.: *LL M-6*
Location: *Loving Landfill*

Type: *Piezometer*
Elevation*: *3114.22*
Top of well shroud without locking cap



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Appendix 3
Loving Landfill Closure

Monitor Well Plan
Loving Landfill Site

06/22/92

by

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Evaporite Geology
Frontier Sulfur

06/22/1992

Monitor Well Plan
Loving Landfill Site

This plan is provided as a guideline to drilling and establishing ground water monitoring wells following closure of the Loving landfill site. This plan is for conceptual purposes and does not attempt to establish all of the field operational details or variables which may develop as the monitor wells are established. These will be reported following completion of the monitor wells.

Objective: Three or more locations will be drilled at the Loving landfill site to serve for long-term monitoring of ground water in the general upgradient and downgradient positions.

Background Hydrology: No wells in the immediate vicinity of the landfill site are known to encounter the saturated zone. A shallow drillhole (< 50 ft depth) east of the landfill boundary and immediately south of the transfer point has not indicated any standing fluid in repeated testing with an electric ground water tester.

On a larger scale, the Pecos valley and floodplain has numerous wells for domestic and irrigation purposes. Data reported by Jones and Hendrickson (1952) from the vicinity show that ground water, generally exceeding limits for human consumption but suitable for irrigation, is at depths < 100 ft and show ground water depth contours at the landfill site between 75 and 100 ft. From the information available, we anticipate a generally easterly flow direction for ground water under the landfill site. There is uncertainty about the flow direction because there are no data points at the site, and the surface topography could be influencing the local ground water depth. Somewhat more southerly or northerly flow directions are possible.

Background Landfill Conditions: The information available about the landfill indicates the following conditions:

dead animal pits along the northern half of the western boundary and around the northeastern corner of the site, and

several north-south (lengthwise) trenches filled with other waste.

In addition, the western boundary abuts property not owned by Eddy County, while the property immediately south and east of the landfill proper is owned by the County.

Basic Plan to Establish Monitor Wells: In view of some uncertainty about the ground water gradient at the landfill, the drilling and completion plan considers options to minimize expenses if initial locations are not adequate to monitor up- or downgradient ground water flow. In addition, the landfill site is small, and monitor well locations will only be separated by distances of about 500 ft or less. The gradient may be so slight that it can only be determined with confidence after a period of monitoring. If the gradient is very slight, the initial well sites may not be adequate monitoring points, even though located on the basis of the available information from initial drilling. The agencies involved need to recognize that additional monitor wells may need to be established in the future to adequately test up- and/or downgradient flow. It may also be necessary to delay periodic sampling if static water levels in any monitor well are recovering too slowly, due to low productivity, to securely establish gradients between sampling intervals.

The following steps are the basic plan for establishing monitor wells:

1. Drill the first three locations (see figure) without completing as monitor wells if the boreholes will stay open. Establish preliminary ground water levels, using temporary tubing if appropriate. Drilling will be without fluids, if possible, and initial bailing will be minimized to provide least disturbed conditions to the static water level.

2. If the locations are appropriate as up- and downgradient monitor wells or if the gradient is too slight to be certain, complete last drilled location as a monitor well. Relocate over other two monitor locations successively and complete as monitor wells.

2a. If any or all of the original locations can be determined to be inappropriate for up- and/or downgradient monitoring, cement these boreholes to the surface. Drill and complete monitor wells in alternate locations.

3. Obtain final survey of reference elevation points.

4. Develop well as necessary and take initial samples for analysis.

5. If the gradients can only be determined after extensive monitoring and prove the ground water flow is not adequately sampled by the well locations, additional monitor holes will have to be drilled and completed.

Initial Locations: Based on the general evidence of west to east ground water flow, three initial locations have been chosen (see attached figure). The upgradient monitor well (LL M-1) is located inside the landfill site within 30 ft of the western boundary at about the north-south midpoint (coordinates about 20E, 275N on attached figure). The M-1 locations is south of the dead animal disposal pit near the northwestern corner of the site. The second monitor well (LL M-2), in a downgradient position, will be located outside the fenced eastern boundary (coordinates about 350N, 500E). The third monitor well (LL M-3) is also located in the downgradient position (coordinates about 100N, 500E).

Procedures: Monitor wells will be drilled in accordance with procedures in the regulations. The drillrig, pipe, and tools will be cleaned prior to drilling. Operations will avoid, as much as possible, use of use of drilling fluids, hydrocarbons or other materials which may be tested for in ground water samples as evidence of waste transport.

The surface completion will include a small cement pad, protective casing, and padlocks to prevent surface inflow or tampering.

The first borehole will be cored as possible. The second borehole (in the downgradient direction) will be rotary drilled with regular examination of cuttings. Coring will be optional. The third borehole will be cored if variability in the second borehole warrants it; it is probable that geological information will be adequate to characterize the rocks based on rotary drilling of the last two boreholes. Cores will be described, photographed, and maintained in coreboxes for a period of at least one year, until monitoring baselines have been established.

Reference Cited

Hendrickson, G.E., and Jones, R.S., 1952, Geology and ground-water resources of Eddy County, New Mexico: Ground-water Report 3, New Mexico Bureau of Mines & Mineral Resources, Socorro, NM.