# GEOHYDROLOGICAL DESCRIPTION

POST-CLOSURE PERMIT
HAZARDOUS WASTE LANDFILL
KERR-McGEE CHEMICAL CORPORATION
HENDERSON FACILITY
HENDERSON, NEVADA

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## LOCATION AND GENERAL SURFACE FEATURES

The Henderson Facility lies in the Basin and Range Physiographical Province (Fenneman, 1931). Features of this province consist of linear and semi-linear north-south trending mountain ranges separated by linear and semi-linear valleys. The Facility is located in portions of sections 12 and 13, Township 22 South, Range 62 East, about 1/2 mile west of Henderson, Nevada (Figure 1).

The Henderson Facility (Figure 2) is located within the Las Vegas Valley (southern edge), a valley that is about 40 miles long and up to 20 miles wide. The Valley trends south-southwest, and its floor ranges in altitude from 1500 to 3000 feet. This Valley is a tributary to the Colorado River. The Las Vegas Valley is bounded on the west by the Spring Mountains; on the east by Frenchman and Sunrise Mountains; on the north by the Desert, Sheep and Las Vegas Ranges; and on the south by the River Mountains and the McCullough Range.

The mountain ranges in the region are generally composed of exposed bedrock which have steep, often bare surfaces. They rise abruptly above the gently-sloping valley floor and are surrounded by flat-lying alluvial deposits extending to the central part of the Valley.

Las Vegas Wash is the major drainage in the area and represents the base level of Las Vegas Valley. The Wash is 3 miles north at its nearest approach to the Henderson Facility. Prior to 1920, Las Vegas Wash carried no continuous streams of surface water. However, an occasional flash flood flowed down the Wash. Just after World War I, artesian wells were drilled

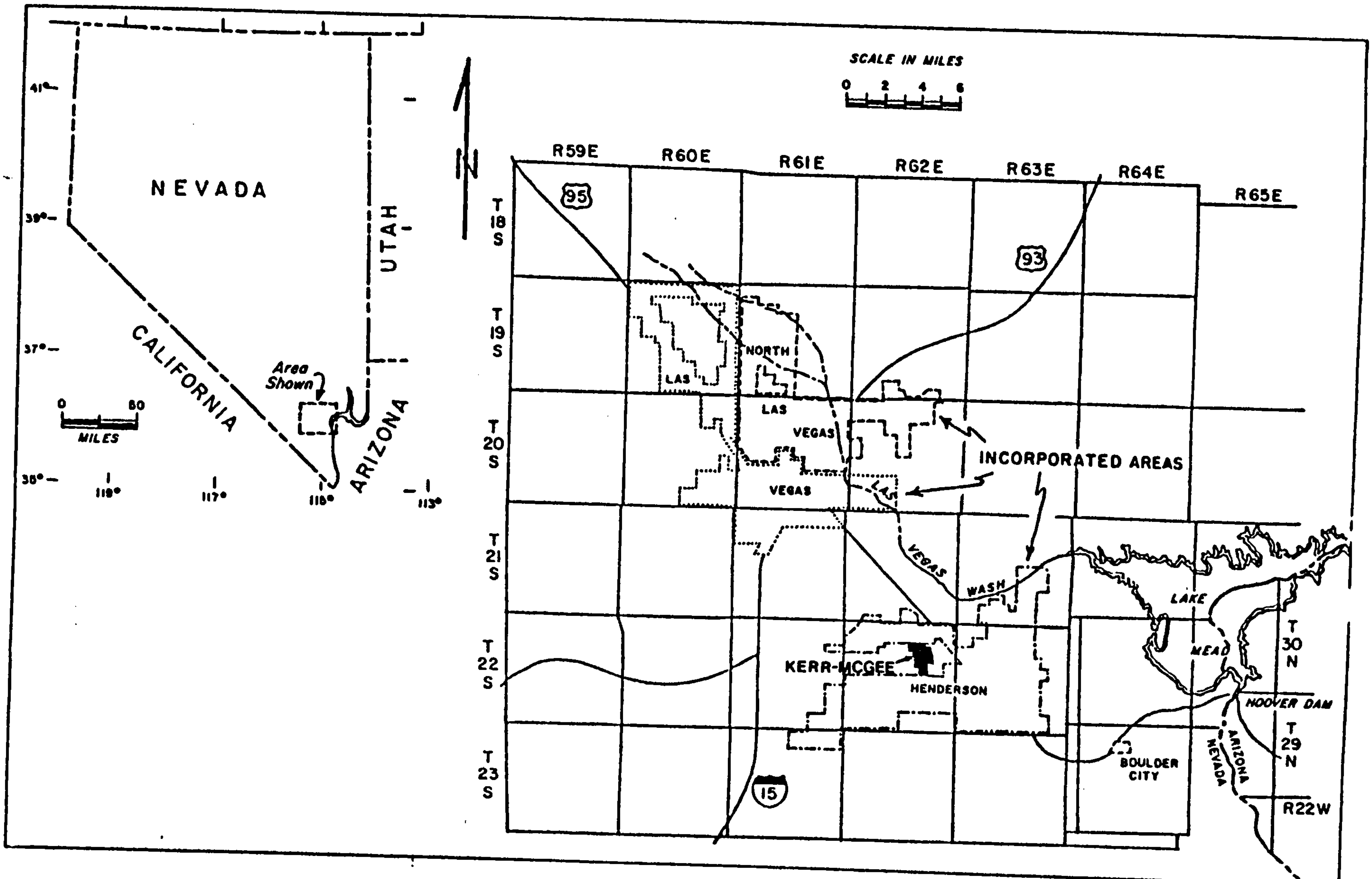


FIGURE 1. INDEX MAP OF THE REPORT AREA.

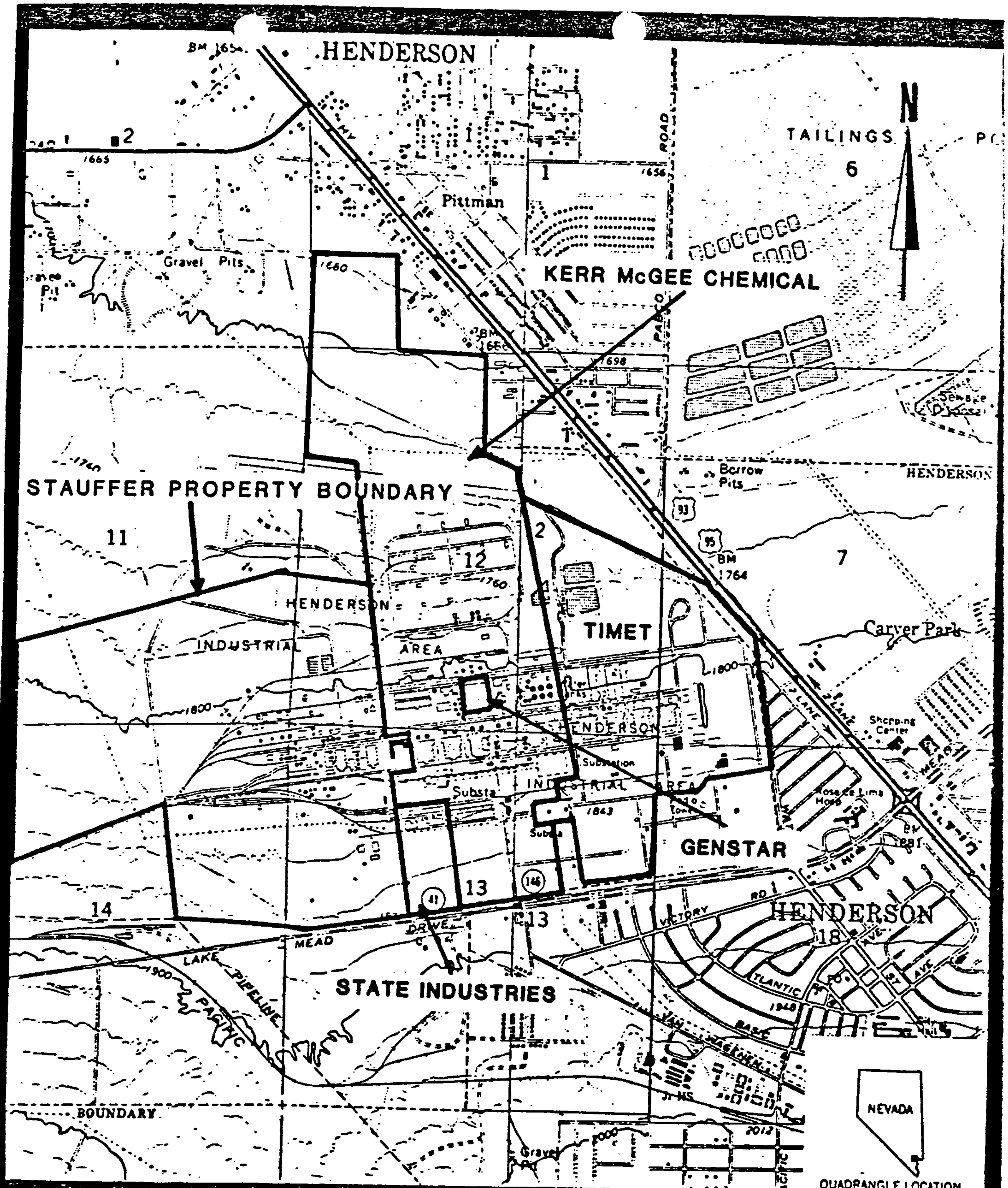


**FIGURE 2**

**KERR-McGEE CHEMICAL COMPANY SITE LOCATION**
**BMI COMPLEX**
**HENDERSON, NEVADA**

SOURCE:
USGS TOPOGRAPHIC MAPS, LAS VEGAS SE QUAD AND HENDERSON QUAD,
PR1973,PR1983 SCALE 1:24000

in the upper reaches of the Wash. Uncontrolled water from these wells seeped into the alluvial material and reappeared as springs farther down the Wash. Presently, several points of artificial discharge into Las Vegas Wash keep it flowing year round and discharging into Lake Mead (Colorado River). Several tributary drainages flow into Las Vegas Wash from the northeast, west, and southeast. All of these drainages are intermittent.

The Henderson Facility is located at the southern edge of the Las Vegas Valley and rests upon alluvial fan sediments from the Black Mountain of the McCullough Range. This alluvial fan forms a gradual northward sloping surface underlying the Facility. The topographic elevation at the Henderson Facility ranges from 1870 (southwest) to 1675 (northwest) feet above mean sea level (MSL). Topographic features for the Facility are presented in Figure 2.

Two small intermittent streams or ditches cross the Henderson Facility (Plate 1). The Beta Ditch crosses the Facility just north of the AP ponds and leaves the property northeast of the C-1 pond. This ditch is tributary to the Las Vegas Wash. The second unnamed ditch crosses the northern portion of the Facility and eventually flows into an abandoned gravel pit. This conducts storm water only.

The principal city in the area is Henderson, Nevada, with a population of 24,363 in 1980. Las Vegas, Nevada is 7.5 miles northwest of the Facility.

## SITE DESCRIPTION

The Kerr-McGee Henderson Facility is located in the Henderson Industrial Complex which was the site of the Basic Magnesium Incorporated (BMI) plant operated by the U.S. Government during World War II. The Henderson Facility is involved in the manufacture of industrial chemicals which are: sodium chlorate, ammonium perchlorate, manganese dioxide, boron trichlorate, boron tribromide, elemental boron, and sodium perchlorate. A site map is presented in Plate 1.

## CLIMATE

The climate in the Henderson, Nevada area is typical of the arid southwest with precipitation falling in two clearly defined rainy seasons. During the winter, frontal storms produce low intensity rainfall over large areas. Some frontal storms also occur during the summer, but most rainfall during this season results from thundershowers occurring during periods of influx of warm, moist tropical air. Over one-third of the four inches of annual average rainfall at Las Vegas McCarran Airport (2162 feet elevation) falls as short term, high intensity rainfall during these thunderstorms, which can be quite severe and result in flash floods. Most documented floods in Las Vegas occurr during July and August.

The mean daily maximum temperature at Las Vegas McCarron Airport ranges from 13.0°C (Celsius) in January to 40.5°C in July; the mean daily minimum temperature for the same months ranges from 0.5°C to 24.5°C.

The potential annual evaporation from lake and reservoir surfaces ranges from 60 to 82 inches, or roughly 15 to 20 times the annual precipitation.

## GEOLOGIC SETTING

### Regional Stratigraphy

The Henderson Facility is located at the southern edge of the Las Vegas Valley. Las Vegas Valley lies along a boundary separating areas of strikingly different geology. The mountain ranges bounding the east, north, and west sides of the Valley consist primarily of Paleozoic and Mesozoic sedimentary rocks (limestones, sandstones, siltstones, and fanglomerates). The mountains on the south and southeast consist primarily of Tertiary volcanic rocks (basalts, rhyolites, and andesites) that lie directly on Precambrian metamorphic and granitic rocks.

The Las Vegas Valley occupies a deep structural basin that has been filled with a thick sequence of sediments. Beginning in Miocene time, a thick sequence of alluvial and lacustrine sediments began accumulating in the Basin. In the Las Vegas area, the earliest of these deposits are the Thumb and Horse Springs formations of Miocene-age. These formations outcrop in the Frenchman Mountain area, where they consist primarily of limestone, sandstone, siltstone, and conglomerate. These formations occur at depths of at least from 3000 to 3700 feet in the Las Vegas area.

Overlying the Thumb and Horse Springs formations is the Muddy Creek formation. The Muddy Creek formation is a multi-colored, poorly to well-consolidated siltstone, clay, and sand with minor intercalated fanglomeratic horizons. The fine-grained facies is most common in the Las

Vegas area, but near the mountains the coarse-grained facies becomes prominent. The Muddy Creek formation reaches thicknesses of 3000 feet and occurs at depths from 0 to 3000 feet in the Las Vegas area. The Muddy Creek formation is typically flat lying to gently tilted and has been cut by many small faults. The surface configuration of the Muddy Creek formation is often characterized by erosional features which give considerable relief to its surface in some areas.

The Muddy Creek formation is unconformably overlain by Plio-Pleistocene basin fill sediments. These sediments represent semi-continuous sedimentary filling of the Basin that was probably periodically interrupted, either by nondeposition or erosion. Distinct subsurface beds are generally thin, discontinuous, and laterally variable making Basin wide correlation difficult. Three depositional facies are recognized in the Plio-Pleistocene depositional period. These are: 1) coarse-grained piedmont alluvium, 2) fine-grained fluvial and lacustrine basin fill, and 3) "blue" lacustrine clay.

The coarse-grained piedmont alluvium consists of coalescing sequences of alluvial fans (as in the Henderson area) and sediments flanking the mountain ranges of the Valley. These deposits adjacent to the McCullough Range contain almost all volcanic fragments and thin toward the mountain range.

The fine-grained fluvial and lacustrine basin fill crops out along the axis of the Basin and is not present in the Henderson area.

The third facies noted above is the "blue" clay. The "blue" clay is laterally extensive in the center of the Basin, where it is encountered at depths of 480-600 feet.

Figure 3 presents the generalized regional stratigraphic column for the Las Vegas Basin. Figure 4 is a generalized geologic map of the Basin.

Site Stratigraphy

This section describes only the geological units of greatest significance to the Henderson Facility site hydrogeology. The geological units include the upper 200 feet of the Muddy Creek formation and overlying alluvial fan sediments, each of which is discussed below. A detailed site stratigraphic column is presented in Figure 5.

Muddy Creek Formation

The Muddy Creek formation of Pliocene age underlies the Henderson Facility in the subsurface. This formation consists of brown- to reddish-brown silty clay and clayey silt. Thin, discontinuous lenses of fine sand and silt may be present locally.

The upper 200 feet of the Muddy Creek formation at the Henderson Industrial Complex were extensively investigated by neighboring Stauffer Chemical Company. Five wells were drilled to depths of 230 feet. All of these wells are within 2000 feet of the Kerr-McGee Henderson Facility. Similar geological conditions exist over the entire Henderson Industrial Complex and the logs of these wells are representative for the Henderson Facility. The lithology encountered when drilling these wells indicated that no

| Geologic unit in Las Vegas area | Epoch | Period | Era | Age before present (millions of years) |
|---|---|---|---|---|
| Recent alluvium | Holocene | Quaternary | Cenozoic | |
| Plio-Pleistocene Basin Fill | Pleistocene | | | 0.01 |
| Muddy Creek Fm | Pliocene | Tertiary | | 1.8 |
| Horse Spring Fm<br>Thumb Fm | Miocene | | | 5.2 |
| Intrusive (igeneous), extrusive (volcanic), and sedimentary (continental limestone, sandstone, shale) rocks | pre-Miocene | | | 22.5 |
| Sedimentary rocks (marine); dominantly sandstones and limestones | | | Mesozoic | 65 |
| Sedimentary rocks (marine); dominantly carbonate rocks with sandstones | | | Paleozoic | 225 |
| Igneous and metamorphic "basement" rocks | | | Precambrian | 570 |

FIGURE 3. REGIONAL STRATIGRAPHIC COLUMN FOR THE LAS VEGAS, NEVADA AREA (After Bell, 1981 ).

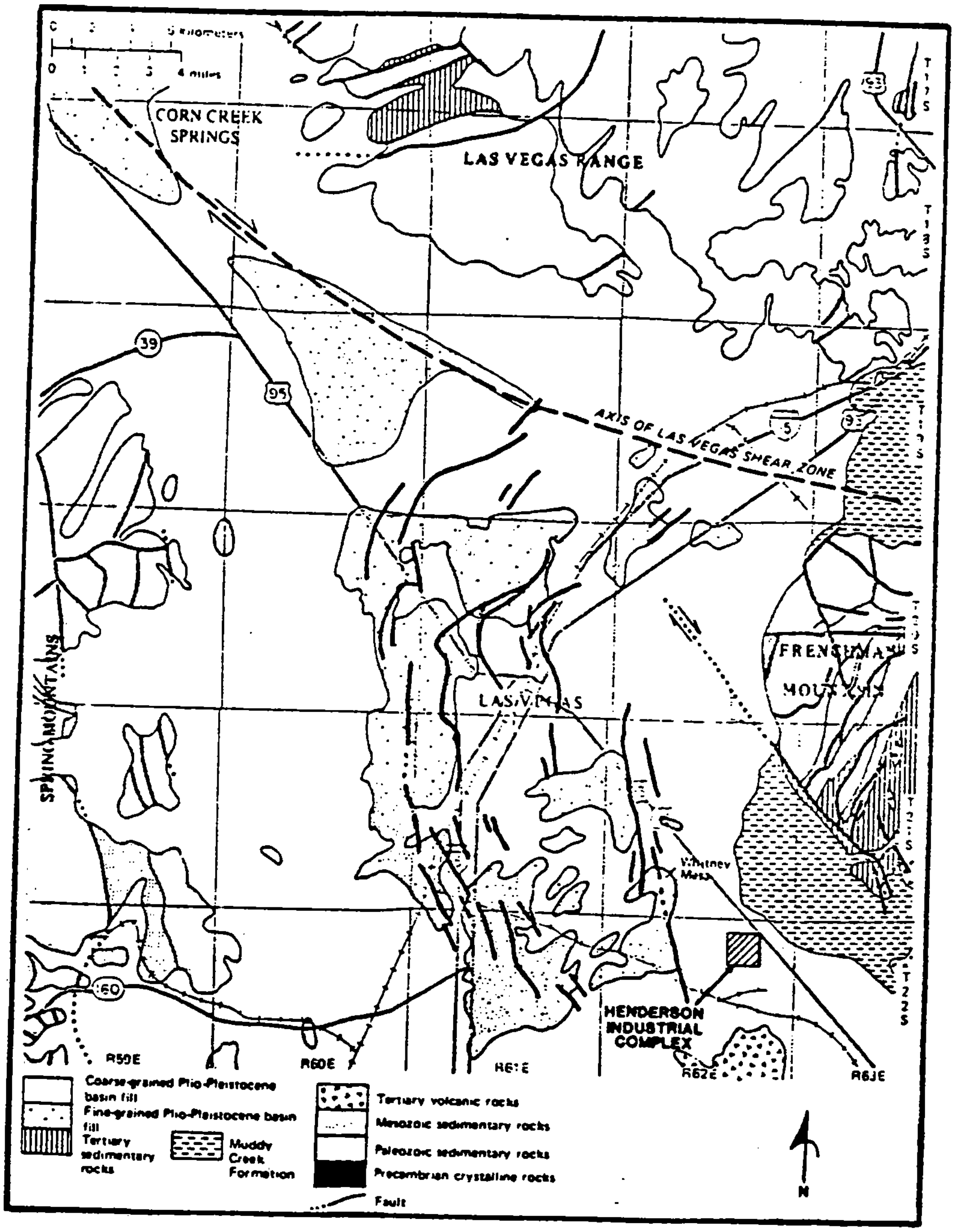


FIGURE 4. GENERALIZED GEOLOGICAL MAP OF THE LAS VEGAS VALLEY AREA (After Bell, 1981).

| GEOLOGIC AGE | GEOLOGIC FORMATION | APPROXIMATE THICKNESS, FT | LITHOLOGIC DESCRIPTION |
|---|---|---|---|
| PLEISTOCENE | ALLUVIAL FAN DEPOSITS | 19.5 - 61.5 | Heterogeneous, poorly sorted, unconsolidated deposits of silty sandy gravels and silty gravelly sands consisting primarily of reworked volcanics and meta-volcanics. Sands and gravels typically multi-colored with reddish-brown the dominant color. Gravels may be locally cemented or slightly cemented by calcium carbonate. Small lenses of a white clayey silt common near the base of this deposit. Boulder and large cobbles are common throughout. |
| PLIOCENE | MUDDY CREEK FORMATION | 500? - 3000 | NOTE: This description for upper 200 feet of Muddy Creek.<br><br>The Muddy Creek is typically a moderately consolidated sandy-silty clay to a clayey silt. The upper 2 feet of the formation is typically a brown clayey silt grading into a brown silty clay. Small discontinuous silt and fine sand lenses may be present locally. |

FIGURE 5. SITE SPECIFIC STRATIGRAPHIC COLUMN FOR THE KERR-McGEE HENDERSON FACILITY.

recognizable sand or gravel (permeable) horizons were encountered in three of the wells and silty clay was the predominant lithology encountered in these wells. Two wells encountered thin sand zones at 127 and 220 feet.

However, Geraghty and Miller (1980), indicate that these sands have limited areal extent because they were not encountered in neighboring wells that penetrated this formation to at least 230 feet. Also, wells completed within these sand horizons indicated that a positive groundwater head differential exists over the groundwater levels noted in the "Near-Surface" aquifer. This pressure differential prevents downward leakage of shallow groundwater to these deeper permeable strata (Geraghty and Miller, 1980).

Over 100 monitoring wells and test borings have been drilled on the Henderson property. Most of these wells penetrate the upper 5 to 20 feet of the Muddy Creek formation. Logs prepared from these wells indicate that the upper 2 feet of the Muddy Creek formation typically consists of a brown clayey silt followed by brown silty clay. Thin, discontinuous fine sand and silt lenses may be locally present. The fine-grained nature of this formation (silty clay) is of utmost importance since it effectively inhibits extensive vertical migration of any contaminant at the site.

The upper surface of the Muddy Creek formation has been modified through erosion. An erosional surface is evident on the top of the Muddy Creek formation and was caused by an ancient drainage system. Referring to Plate 2, the configuration of the top of the Muddy Creek formation is shown beneath the Henderson Facility. The predominant feature of this map is the northward sloping surface of this formation. The surface slopes at gradients that range from 0.80% (42 feet/mile) to 5.4% (285 feet/mile) with an average of 2.5% (132 feet/mile). Five major erosional features are evident upon examination of this map. A buried erosional channel appears to start near pond AP-5 and strikes north along a line to well M-23. An interfluve area is suggested to exist east of this channel and strike northward. A second interfluve area exists west of this channel and also strikes northward (from wells H-38 to to MC-20). A major buried channel exists (along a line from wells H-23 to MC-56 to MC-50 to H-51) in the northwest corner of the Henderson Facility. Stauffer Chemical Corporation is currently operating a groundwater interception system over the width of this channel. This buried channel trends northeast. A third interfluve area occurs due west and bounds the western side of the channel. Definition of where these buried channels and adjacent interfluves occur is of utmost importance because they greatly control the occurrence and movement of groundwater beneath the Henderson Facility. Typically, the erosional channels contain greater thicknesses of more permeable sands and gravels than the interfluve areas adjacent to these channels. The role of these channels in groundwater occurrence and movement beneath the site is discussed more fully in the section titled Site Hydrogeology.

A map showing depth-to-top of the Muddy Creek formation is presented in Plate 3. The depth-to-top of the Muddy Creek formation varies from 19.5 to 55 feet over the site. Examination of this map shows the presence of interfluve areas (near wells MC-59, M-18, and MC-60) with the intervening buried channel systems (near well M-27, and wells MC-80 to H-51).

The configuration of the Muddy Creek formation is shown more clearly in the geologic cross sections presented in Figures 6, 7, and 8 (Line of section shown on Plate 7). The cross sections in Figure 6 shows very little Muddy

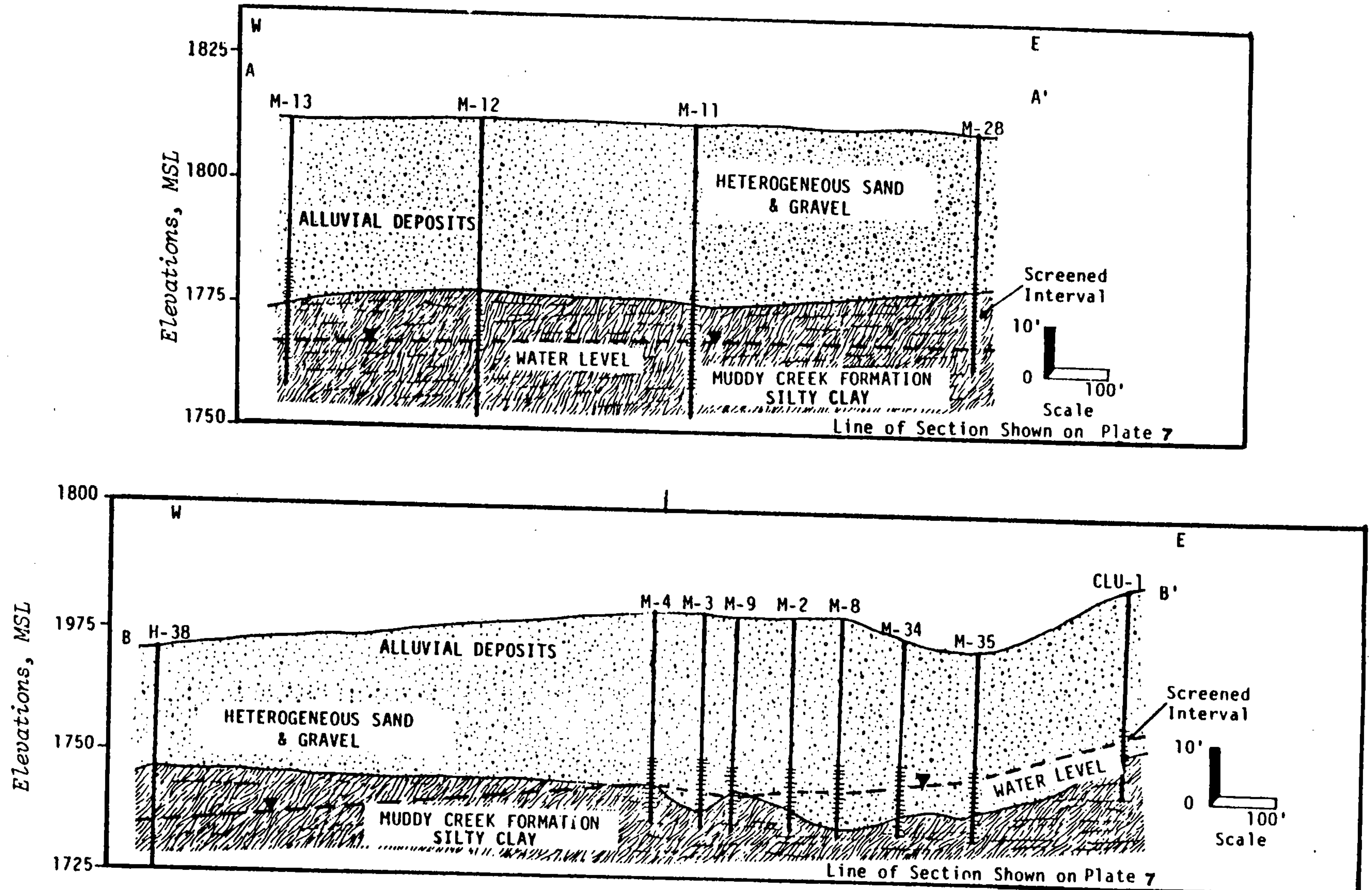


FIGURE 6. EAST-WEST GEOLOGICAL CROSS SECTIONS FOR AREAS DOWNGRADIENT OF THE P- AND S-SERIES IMPOUNDMENTS (B-B') AND UNITS 4, 5, AND 6 (A-A') AT THE HENDERSON FACILITY.

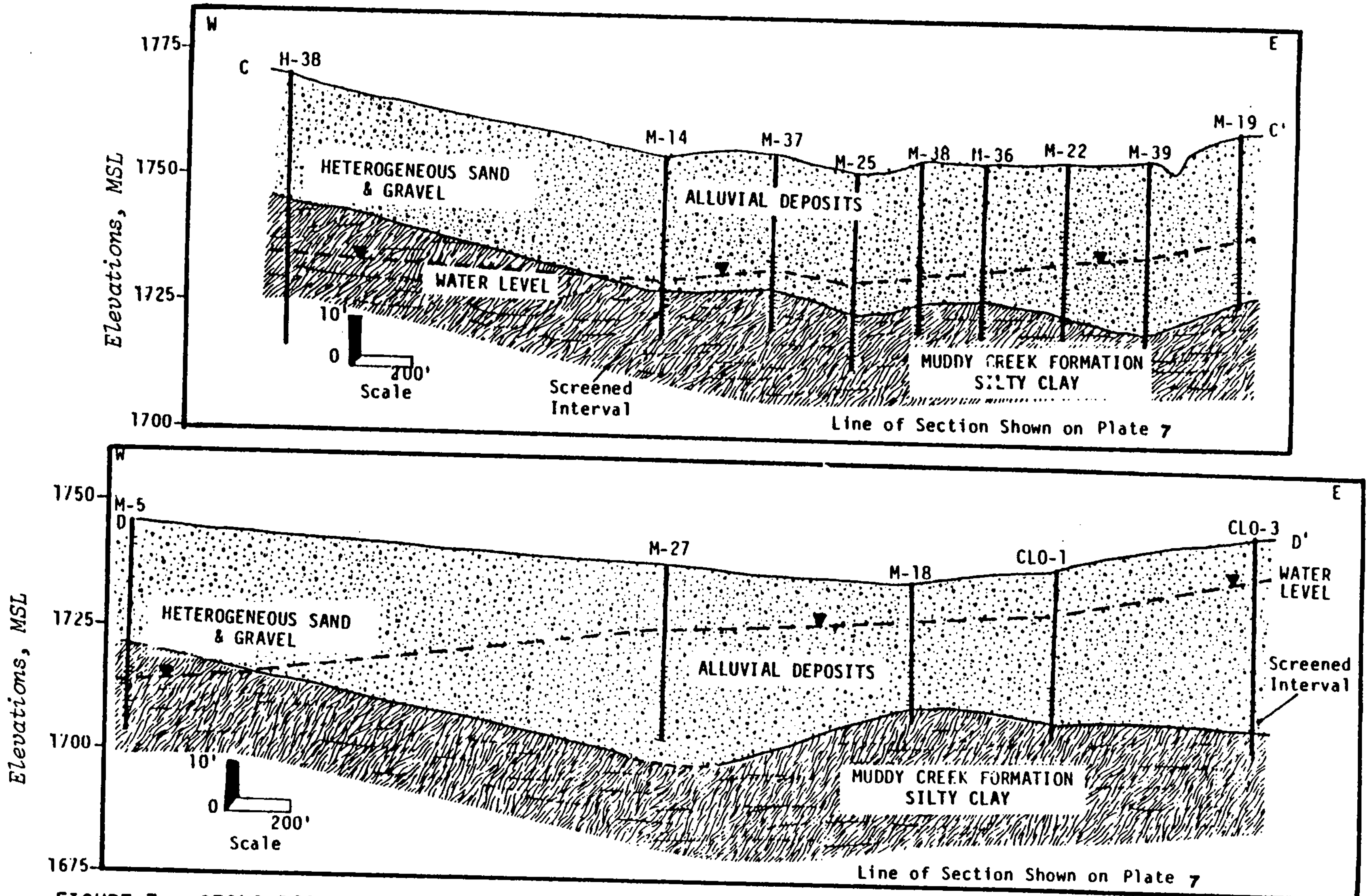


FIGURE 7. GEOLOGICAL CROSS SECTIONS (EAST-WEST) NORTH OF THE AP IMPOUNDMENT AREA, HENDERSON FACILITY.

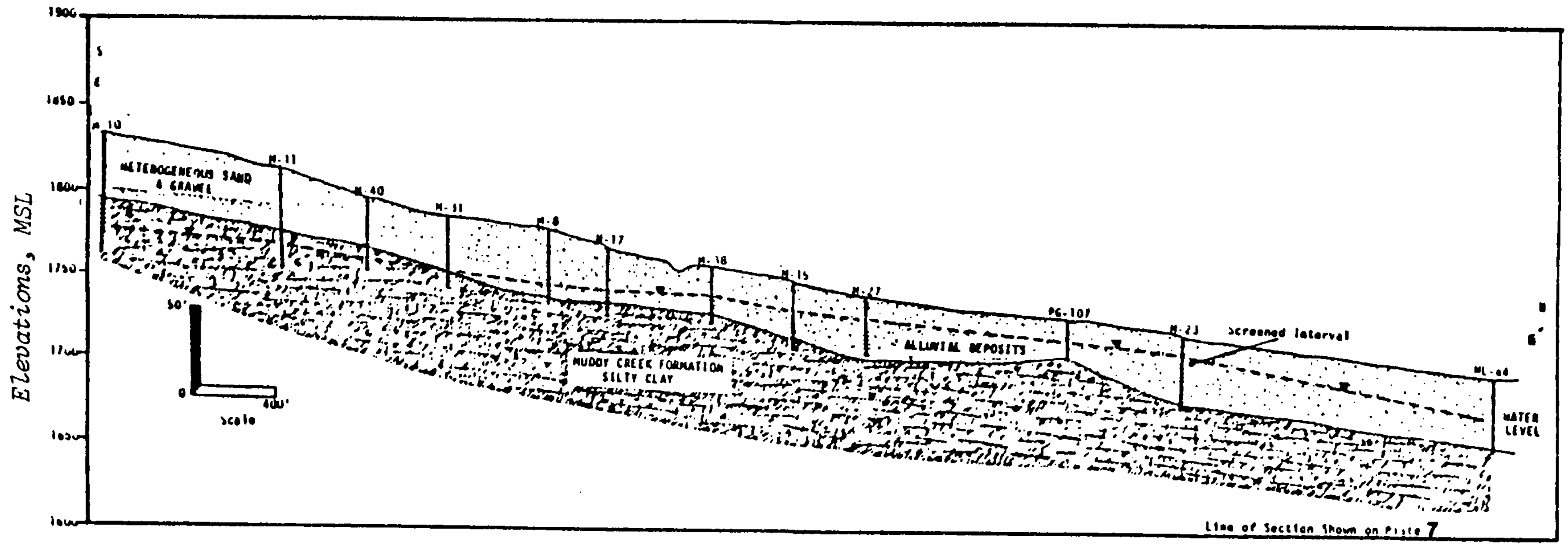


FIGURE 8. GEOLOGICAL CROSS SECTION (NORTH-SOUTH) THROUGH THE HENDERSON FACILITY.

Creek relief along section A-A' near Units 4, 5, and 6. Section B-B' shows the existence of an erosional channel from wells M-4 to CLU-1, north of the steam plant. The geological cross sections presented in Figure 7, shows the presence of a small channel system along section C-C'. A major channel system is indicated along section D-D'. The cross section (E-E') in Figure 8 shows the general configuration of the Muddy Creek formation in a north-south direction. It is evident from examination of these sections that the buried channel systems in the area trend in a northerly direction, are narrow, and become more entrenched into the Muddy Creek formation in this direction.

## Plio-Pleistocene Alluvial Fan Deposits

The Kerr-McGee Henderson Facility is situated over alluvial sediments derived from erosion of the McCullough Range (1 mile south of Kerr-McGee) that form northwest-sloping coalescing alluvial fans. These alluvial fans were deposited during the infrequent flood runoff periods and were deposited on the older erosional surface of the Muddy Creek formation. The thickness of these deposits varies locally depending upon the erosional configuration of the Muddy Creek surface. Generally, these alluvial deposits thicken from south to north beneath the Henderson Facility. Plate 3, shows the thickness of the alluvial fan deposits which is also the depth to the top of the Muddy Creek formation. These sediments are thickest over the erosional channels and thinnest over intervening interfluve areas. Thickness of these sediments range from 19.5 to 61.5 feet beneath the Henderson Facility.

The lithology of these deposits consists primarily of a reddish-brown, heterogeneous, poorly sorted mixture of sand and gravel (volcanics) with lesser amounts of silt and clay. Boulders and cobbles are common. Due to their mode of deposition, no distinct beds or units are continuous over the Henderson Facility. Distinct layers are only present in the form of gravel beds cemented with caliche (calcium carbonate), present only in the northwest corner of the site. Since caliche is not found elsewhere on the site it will not be discussed further.

A major feature of these alluvial deposits is the stream deposited sands and gravels that were deposited within the old channels developed on the Muddy Creek formation. These deposits conform to the old channel boundaries which were characteristically linear and narrow in configuration. These "channel fill" deposits are typically more uniform sands and gravels (few fines) and show higher permeability than the adjacent poorly-sorted alluvial deposits. Once the old erosional channels were filled with the "channel fill" deposits they were encased by the poorly-sorted alluvial fan deposits. The importance of these "channel fill" deposits is that they greatly affect and control the occurrence and movement of the groundwater.

Often times a distinct formation change between the Muddy Creek formation and alluvial sediments does not exist. Normally, a 5-foot transitional zone occurs above the Muddy Creek formation where small white clayey silt lenses are interbedded with sand and gravel.

The geologic cross sections presented in Figure 6, 7, and 8 shows the thickness and distribution of the alluvial deposits. Typically deposits found in the erosional channels are "clean" sands and gravels (with few fines) as compared to other alluvial fan deposits.

Structural Geology

The structural features of those strata pertinent to this investigation (Muddy Creek Formation and overlying basin-fill alluvial fan deposits) are discussed below.

The Muddy Creek formation is generally flat lying to gently tilted in surface exposures. It has been cut by many small faults and has locally been severely disrupted. This formation is sheared and tilted in the Las Vegas Wash area, and it is in sharp fault contact with the Frenchman Mountain Block.

The structure within the Plio-Pleistocene basin fill is characterized by a series of generally north-south trending faults. These faults are thought to result from natural consolidation of basin-fill sediments and are referred to as "compaction faults" by Bell (1981). These faults are typically marked by escarpments exhibiting heights up to 100 feet or more. These escarpments have also been considerably modified by erosion in many areas and are shown on Figure 4.

There are no recognizable structural features present in the Muddy Creek formation or overlying alluvial fan Plio-Pleistocene basin-fill deposits that underlie the Kerr-McGee Henderson Facility.

## Geological History

The geologic history of the Henderson region is characterized by repeated periods of deposition, uplift, igneous activity, and erosion. Thick sequences of marine sedimentary deposits accumulated throughout Paleozoic and Mesozoic time, with periodic interruption by orogenic (crustal deformation) activity. Continental-type sedimentary deposition and widespread volcanic and fault activity continued through Cenozoic time. Thick deposits of volcanics were extruded over broad areas and accompanied by strike-slip faulting during mid- to late-Tertiary time. The volcanic and tectonic activity peaked during the Miocene epoch. Following this volcanic and tectonic activity in Miocene time, and continuing through Pliocene time, a thick sequence of alluvial and lacustrine sediments were deposited in a deep structural basin. These deposits included the Horse Springs and Muddy Creek formations. Following deposition of the Muddy Creek formation, a period of erosion occurred. The erosional period was followed by periodic deposition of Pleistocene coarse-grained alluvial deposits consisting of coalescing sequences of alluvial fans flanking the mountain ranges.

# HYDROGEOLOGY

## Regional Hydrogeology

Nearly all of the groundwater supply in Las Vegas Valley comes from what Harill (1976) has termed the "Valley-Fill Groundwater Reservoir." This reservoir consists of the Muddy Creek formation and the overlying Plio-Pleistocene basin-fill sediments.

The aquifer system was originally subdivided into two major components by Maxey and Jameson (1948): 1) The Near Surface Water and 2) the Confined Water. The Confined Water was further divided into three zones - shallow, middle, and deep. The Confined Water aquifer, as defined by Maxey and Jameson, is recognizable only in the central part of the Basin and does not allow for correlation to other parts of the Basin. Harrill therefore, prefers to use the terms: 1)"Near Surface" Reservoir and 2) "Principal Aquifers", where the "Principal Aquifers" includes the original subdivisions by Maxey and Jameson as well as other recognized zones.

The shallow and middle zones of the Confined Water aquifer are the major sources of pumped water in Las Vegas Valley. These zones occur in the thickest sequences of Plio-Pleistocene valley fill deposits. These two zones are not present in subsurface in the Henderson area (including the Henderson Facility) due to the thin deposits of these sediments. The deep zone of the Confined Water system is believed to exist in the Muddy Creek formation. The shallow, middle, and deep Confined Water zones tapped by wells in the central part of the Las Vegas Valley occur at depths of about 200-450, 500, and 700 feet respectively.

Recharge to the "Principal Aquifers" is from runoff from precipitation occurring in the surrounding mountains which infiltrate the alluvium along the valley margins. Recharge also occurs through upward flow between aquifer systems. Discharge is principally through evapotranspiration, pumping from wells, and recharge to the "Near-Surface" aquifer system.

The "Near-Surface" aquifer is found at the top of the Muddy Creek formation usually in the overlying alluvial sand and gravel deposits. The "Near-Surface" aquifer may also occur in the upper portions of the Muddy Creek formation. All aquifers in Las Vegas Valley are separated by thick sequences of low-permeability, fine-grained sediments. Interconnection between all aquifers in the Valley only occurs through upward leakage along fault zones and through semi-confining layers. This upward leakage recharges the "Near-Surface" aquifer which is augmented by artificial recharge from irrigation and other forms of artificial water application to the land surface. The upward leakage between aquifers prevents the downward movement of groundwater from the "Near-Surface" aquifer. Little recharge occurs in the Valley itself from precipitation which is largely consumed by evapotranspiration.

Site Hydrogeology

The geological units which are important to this investigation are the upper portions of the Muddy Creek formation and the overlying alluvial fan sediments. This aquifer is termed the "Near Surface" aquifer as described above. The deeper "Principal Aquifer" will not be discussed since it is several hundreds of feet deep and is separated from the "Near Surface" aquifer by low-permeability fine-grained sediments. Since groundwater at the Henderson Facility is contained within both the alluvial fan sediments and the upper portions of the Muddy Creek formation, a discussion of each hydrogeologic environment will be presented.

## Muddy Creek Formation

Groundwater occurs in the upper portions of the Muddy Creek formation beneath the Henderson Facility. Typically, groundwater is found within the Muddy Creek silts and clay over the southern and west-central portions of the Facility. Referring to Plate 4, the areas where the "Near-Surface" groundwater is contained within the Muddy Creek formation is indicated by zero or negative lines of saturated thickness. All groundwater in areas south of the zero boundary line lies within the Muddy Creek formation while groundwater found north and east of this line lies within the alluvial deposits. As shown in Plate 4, the groundwater may occur at depths as much as 17 feet below the top of the Muddy Creek formation.

Groundwater found within the Muddy Creek formation downgradient from past contaminant source areas show chromium levels above background. Results of laboratory vertical permeability tests on undisturbed samples from the Muddy Creek formation at neighboring Stauffer Chemical Company (<2000' west of Kerr-McGee) indicate that the upper 10 feet of the Muddy Creek formation has a vertical permeability of between $1.2 \times 10^{-7}$ cm/sec ($2.5 \times 10^{-3}$ gpd/ft$^2$) to $2.0 \times 10^{-6}$ cm/sec ($4.2 \times 10^{-2}$ gpd/ft$^2$) with an average of $5.85 \times 10^{-7}$ cm/sec ($1.2 \times 10^{-2}$ gpd/ft$^2$), (Geraghty and Miller, 1980). Kerr-McGee performed field permeability tests at four wells the Henderson Facility (M-9, M-11, M-12, and M-13) completed in the Muddy Creek formation. These tests indicate that the Muddy Creek formation has a horizontal permeability or hydraulic conductivity ranging from 6.5 gpd/ft$^2$ ($3.1 \times 10^{-4}$ cm/sec) to 54.5 gpd/ft$^2$ ($2.6 \times 10^{-3}$ cm/sec) with an average of 29.1 gpd/ft$^2$ ($1.4 \times 10^{-3}$ cm/sec). The average hydraulic gradient over areas where the groundwater occurs within the Muddy Creek formation at the

Henderson Facility was measured to be an average of $\frac{\Delta h}{l} = .027$. Transmissivity values varied from 45.2 to 180 gpd/ft and averaged 89.1 gpd/ft. The storage coefficient was taken from aquifer test data developed from Stauffer Chemical (Hall, 1983). The average storage coefficient was .053.

Using Darcy's flow equation and an effective porosity of 0.20 for the thin sand and silt stringers, an average flow velocity of 0.53 feet/day was calculated for groundwater flowing through the Muddy Creek formation. Because this velocity seems somewhat high for flow through clays, small sand and silt stringers and lenses within the upper part of the Muddy Creek formation may account for most of its permeability, and groundwater flow is principally occurring through these small zones. These small lenses appear to be in communication with the overlying alluvial aquifer.

Groundwater moves in a northwesterly direction through the Muddy Creek formation and over most of the site as shown in Plate 5. The groundwater gradient is uniform over most of the site except near the pumping depressions caused by Stauffer Chemical's interceptor well field in the northwest portion of the Henderson Facility. The gradient varies from 1.2% to 2.7% (excluding Stauffer's recovery area) and averages 1.5%.

Water-level data collected from June, 1983 to June, 1985, from Muddy Creek monitoring wells M-11, M-12, and M-13 show small groundwater fluctuations of 1.3, 1.68, and 1.2 feet respectively, over this period and appear to be a result of seasonal climatic changes. The groundwater is typically at its lowest levels during the spring months and at its highest levels during early to late fall.

## Alluvial Fan Deposits

Alluvial fan deposits outcrop over the entire Henderson Facility and overlie the Muddy Creek formation. Over the southern and west-central half of the Facility the alluvial fan deposits are unsaturated. Referring to Plate 4 and Figure 8, the unconfined alluvial fan deposits become saturated (contain groundwater) north and east of the zero saturated thickness line. South and west of this line the unconfined groundwater lies within the Muddy Creek formation. The saturated thickness map (Plate 4) for the alluvial fan deposits indicate that these deposits range from 0 to greater than 27.7 feet in saturated thickness. Generally the larger zones of saturation occur over the buried "channel fill" deposited in stream channels developed on top of the Muddy Creek formation. The smallest zones of saturation occur over the interfluve areas that separate these old channel systems. An examination of the saturated thickness map (Plate 4) indicates there is a buried stream channel trending north-northeast from pond AP-5 as evidenced by the large saturated thickness of the alluvial deposits in this area. A second channel system is indicated in the northwest corner of the map and in fact was previously defined by Stauffer Chemical (Hall, 1983).

The greatest depositional thicknesses of alluvial fan sediments occur within the old stream channel system developed on the Muddy Creek surface. Referring to Plate 3, the thickness of the alluvial fan deposits vary from 19.5 feet at well MC-59 to 61.5 feet at geological boring MC-17.

The depth-to-groundwater map presented in Plate 6 indicates that the depth-to-groundwater varies from over 55 feet at the southern portion of the Facility to 5 feet in the northeast corner near well PG-103. The depth-to-groundwater decreases in a northeasterly direction until it reaches the vicinity of the AP impoundments. From the AP impoundments to the north property boundary the depth-to-groundwater decreases rapidly east to northeast. The reason for the rapid decrease in the depth-to-groundwater toward the east-northeast (near well PG-103) is believed to be influenced by the erosional configuration of the Muddy Creek formation or related to structural features that may be present in the subsurface, such as a fault.

Because of the variability in alluvial fan deposition and saturated thickness of the alluvial deposits, no specific or average permeability or transmissivity value have been used to describe the groundwater flow velocity in these deposits. Typically the "channel fill" deposits which are found in the old buried stream channels developed on top of the Muddy Creek formation are much more permeable than the deposits in the interfluve areas that separate the buried channel systems. The higher permeability and transmissivity noted for the "channel fill" deposits probably is a result of reworking of these sediments by stream action and lesser amounts of fine materials present.

The groundwater velocity was calculated for the alluvial deposits using Darcy's equation, assuming an effective porosity of 0.20 and using an average gradient of 0.015, varied from 0.5 to 16 feet/day. The greatest groundwater velocity of 16 feet/day occurred within the "channel fill" deposits near well M-27. The lowest groundwater velocity of 0.5 feet/day was from an interfluve area north of pond P-3 (well M-4) where poorly sorted alluvial fan deposits occur. Intermediate values of permeability, transmissivity, and flow velocity probably occur between the crests of the interfluve areas to the center of the "channel fill" deposits.

The transmissivity of the alluvial deposits ranged from 231 gpd/ft at well M-4 (interfluve area) to 23,786 gpd/ft at well M-27 "channel fill" deposits.)

The hydraulic conductivity varied from 50.2 gpd/ft$^2$ (well M-4) to 1496 gpd/ft$^2$ at well M-27. The storage coefficient, as determined by Stauffer Chemical Corporation from numerous pumping tests, averages 0.053 (Hall, 1983). A summary of Kerr-McGee aquifer tests is presented in Table 1.

Water table fluctuations are noted in several wells completed within the alluvial deposits at the Facility. Figure 9 shows water-level fluctuations for wells north of the P- and S-series impoundments from June, 1983, to June, 1985. Maximum water-level fluctuations in any one well varied from 1.54 to 2.55 feet and averaged 2.07 feet. Water-level fluctuations (Figure 10) in the areas north of the AP impoundments show maximum fluctuations for the period of record (June, 1983 to June, 1985) between 1.72 to 3.08 feet and averaged 2.25 feet. These groundwater fluctuations are the result of seasonal climatic changes with groundwater at its lowest level during the spring months and at its highest level during the fall.

TABLE 1. SUMMARY OF AQUIFER TEST RESULTS CONDUCTED BY KERR-McGEE ON SELECTED WELLS AT THE HENDERSON FACILITY.

| WELL | TRANSMISSIVITY gpd/ft | | HYDRAULIC CONDUCTIVITY gpd/ft | |
|---|---|---|---|---|
| | SLUG METHOD Bouwer and Rice, 1976 | JACOB SEMI-LOG Drawdown | SLUG METHOD | JACOB SEMI-LOG Drawdown |
| M-2 | 1219 | --- | 313 | --- |
| M-2 | --- | 1764 | --- | 453 |
| M-3 | 2379 | --- | 983 | --- |
| M-4 | 231 | --- | 50.2 | --- |
| M-8 | 3628 | --- | 834 | --- |
| M-9* | 180 | --- | 54.5 | --- |
| M-11* | --- | 79.2 | --- | 8.5 |
| M-11* | 61.2 | --- | 6.5 | --- |
| M-12* | 45.2 | --- | 19.2 | --- |
| M-13* | 70.1 | --- | 36.1 | --- |
| M-15 | 4717 | --- | 306 | --- |
| M-17 | 1445 | --- | 182 | --- |
| M-27[1] | 23,786 | --- | 1496 | --- |

Note: *Aquifer test conducted on Muddy Creek clays
[1]Aquifer test in "Channel Fill" Alluvial Deposit
All other aquifer tests were conducted on Alluvial fan deposits

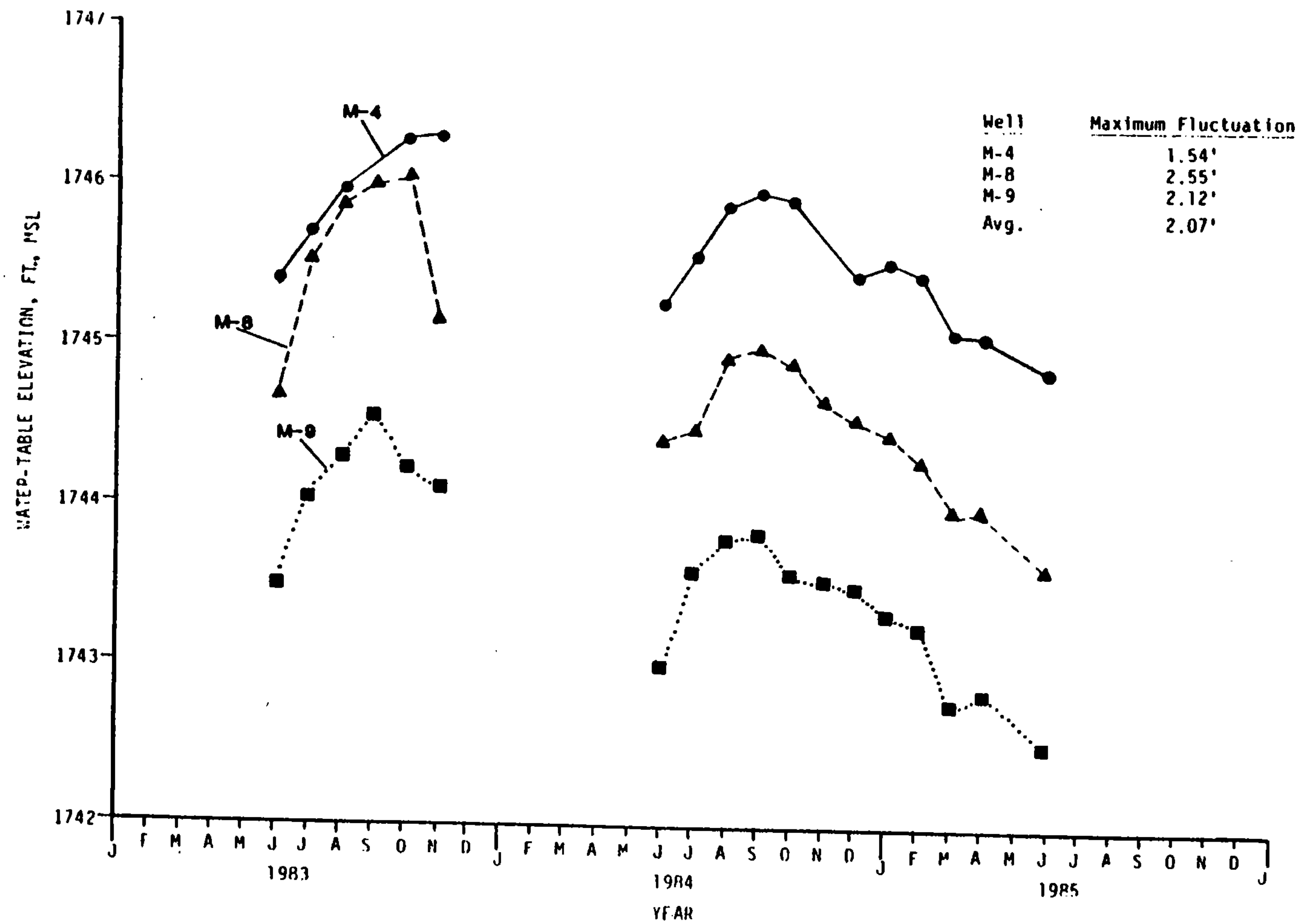


FIGURE 9. HYDROGRAPHS SHOWING WATER-LEVEL FLUCTUATIONS IN SELECTED WELLS DOWNGRADIENT FROM THE P- AND S-SERIES IMPOUNDMENTS AT THE HENDERSON FACILITY.

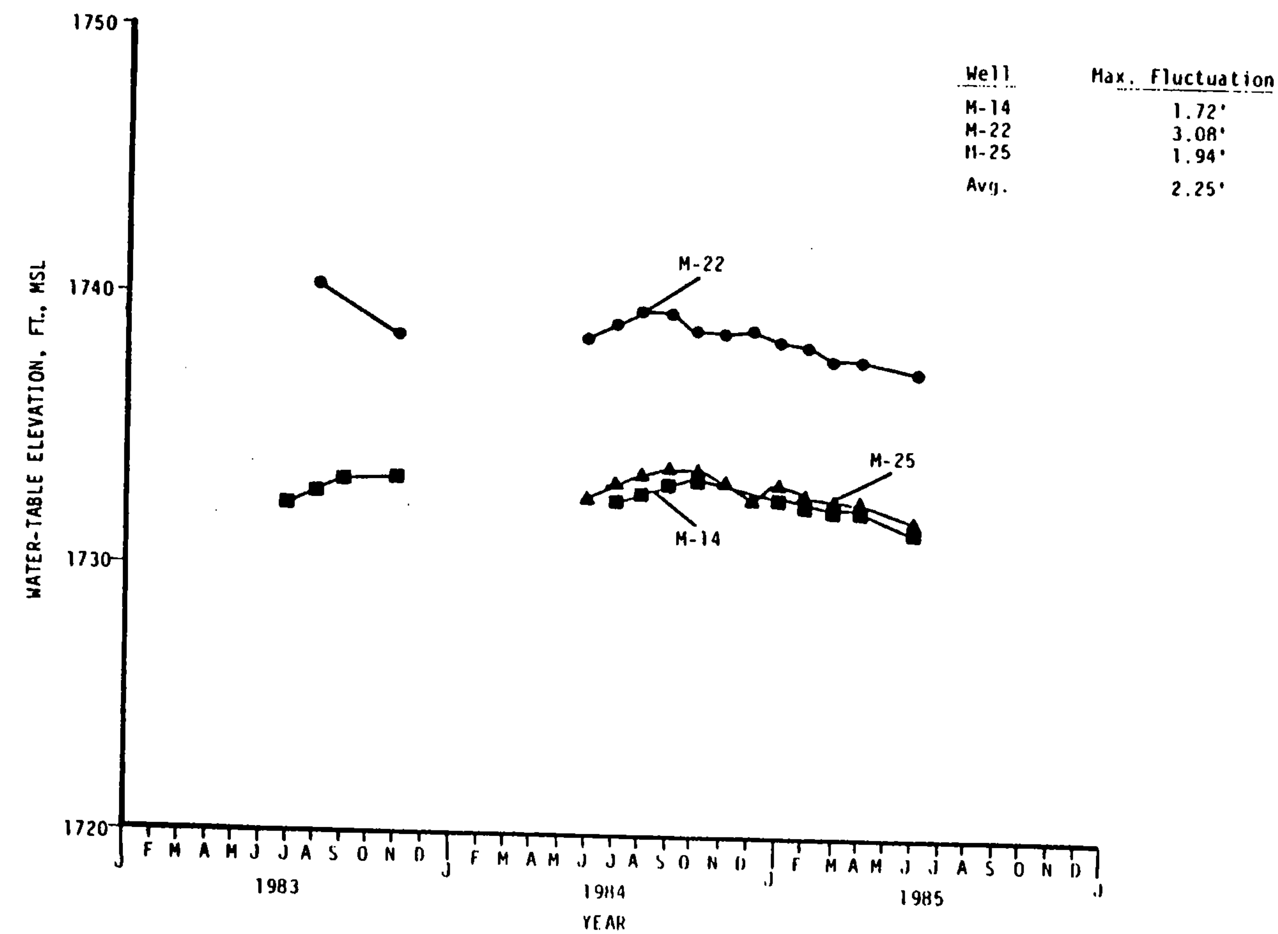


FIGURE 10. HYDROGRAPHS SHOWING WATER-LEVEL FLUCTUATIONS FROM SELECTED WELLS NORTH OF THE AP IMPOUNDMENT AREA, HENDERSON FACILITY.

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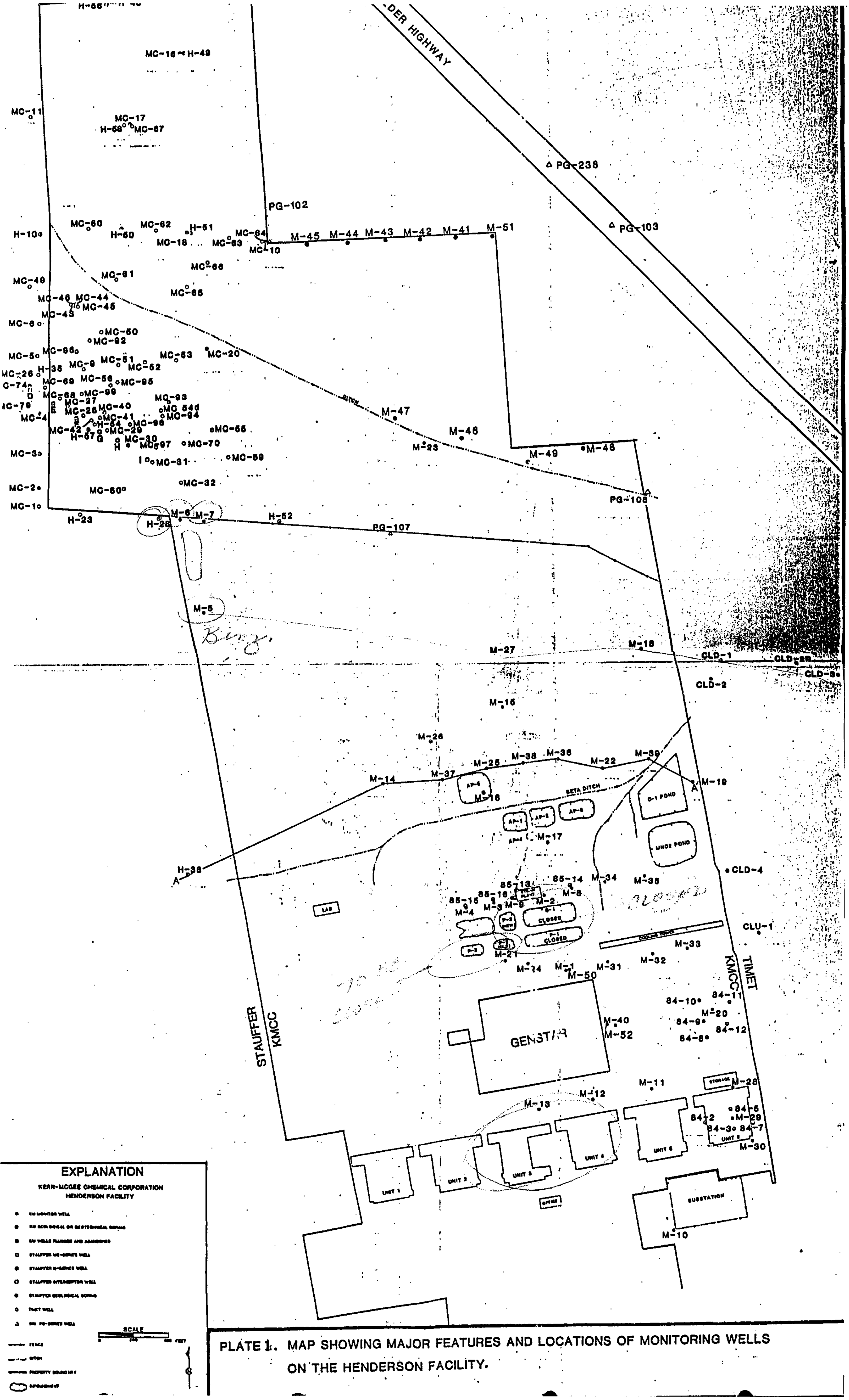


PLATE 1. MAP SHOWING MAJOR FEATURES AND LOCATIONS OF MONITORING WELLS ON THE HENDERSON FACILITY.

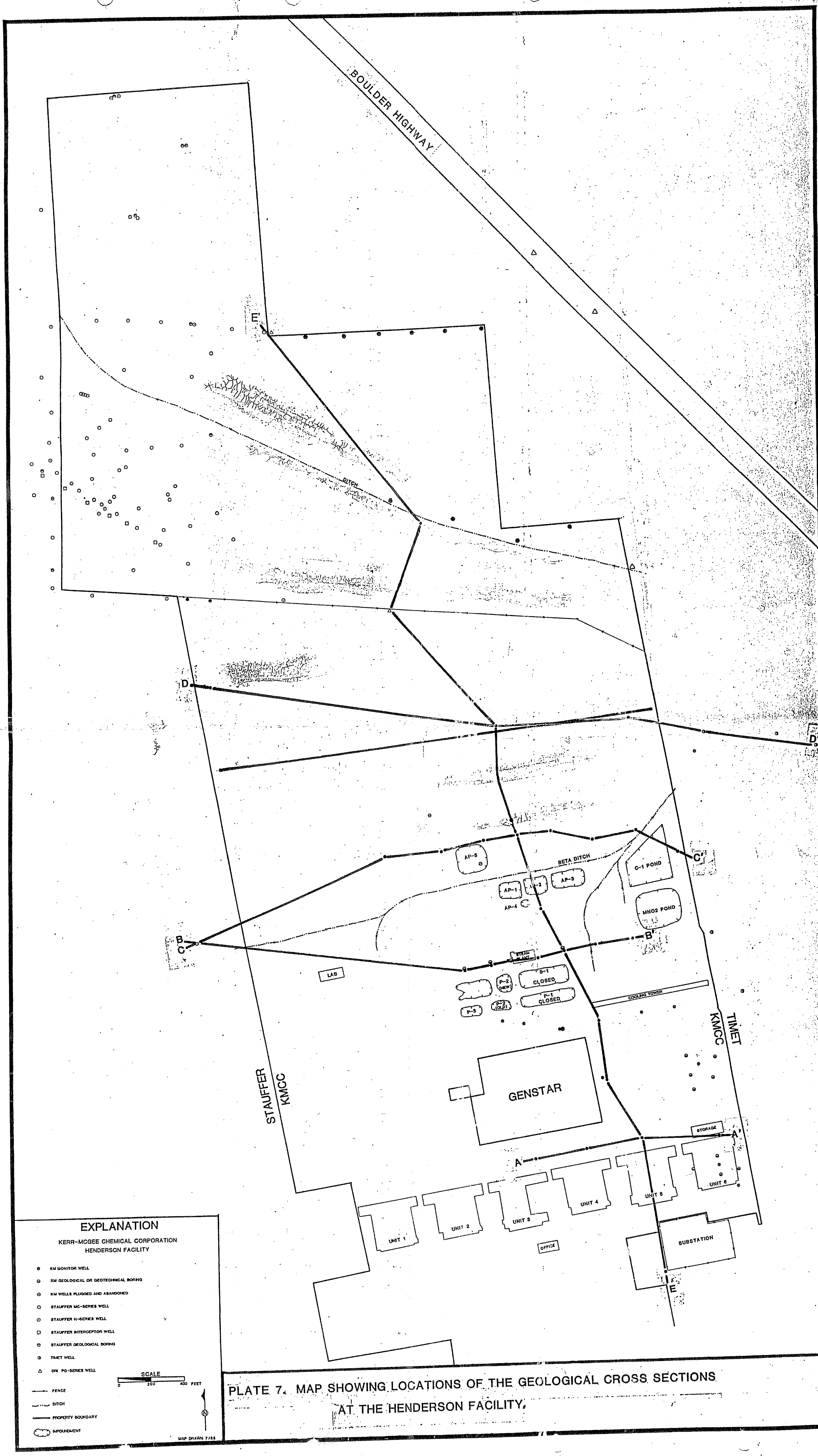


PLATE 7. MAP SHOWING LOCATIONS OF THE GEOLOGICAL CROSS SECTIONS AT THE HENDERSON FACILITY.

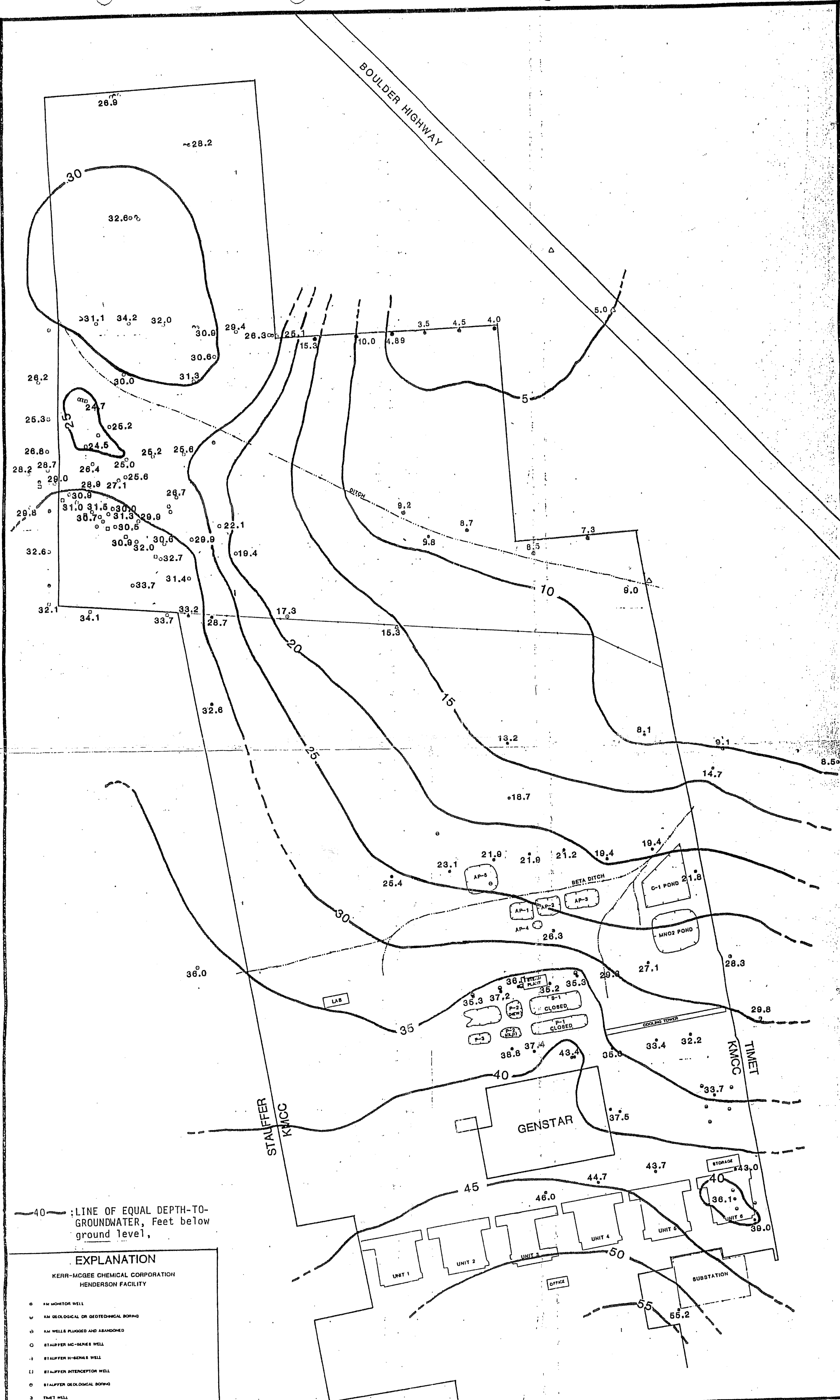


PLATE 6, MAP SHOWING DEPTH-TO-GROUNDWATER IN JUNE/JULY, 1985 AT THE HENDERSON FACILITY.

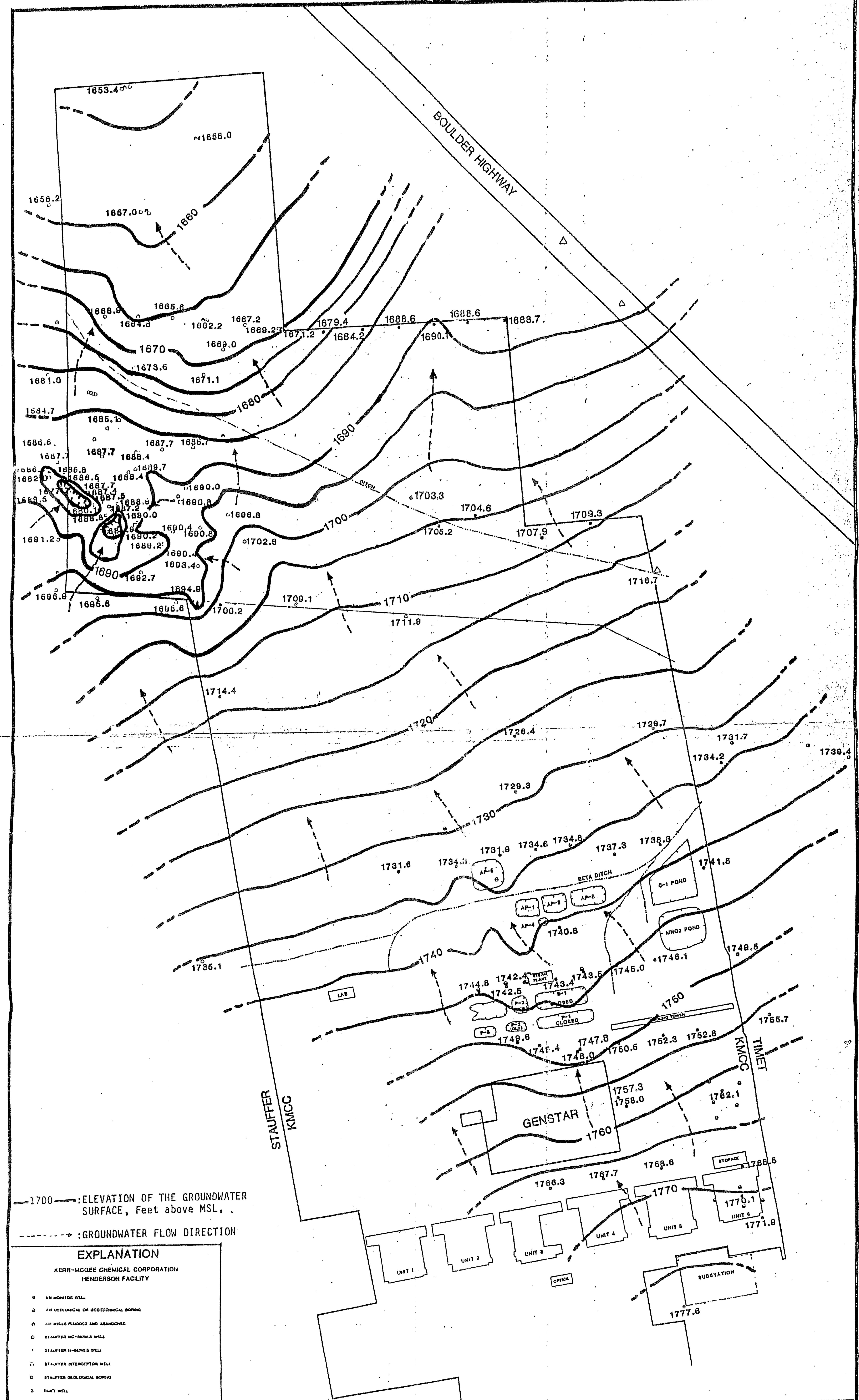


PLATE 5. POTENTIOMETRIC MAP FOR THE NEAR SURFACE AQUIFER IN JUNE-JULY, 1985 AT THE HENDERSON FACILITY.

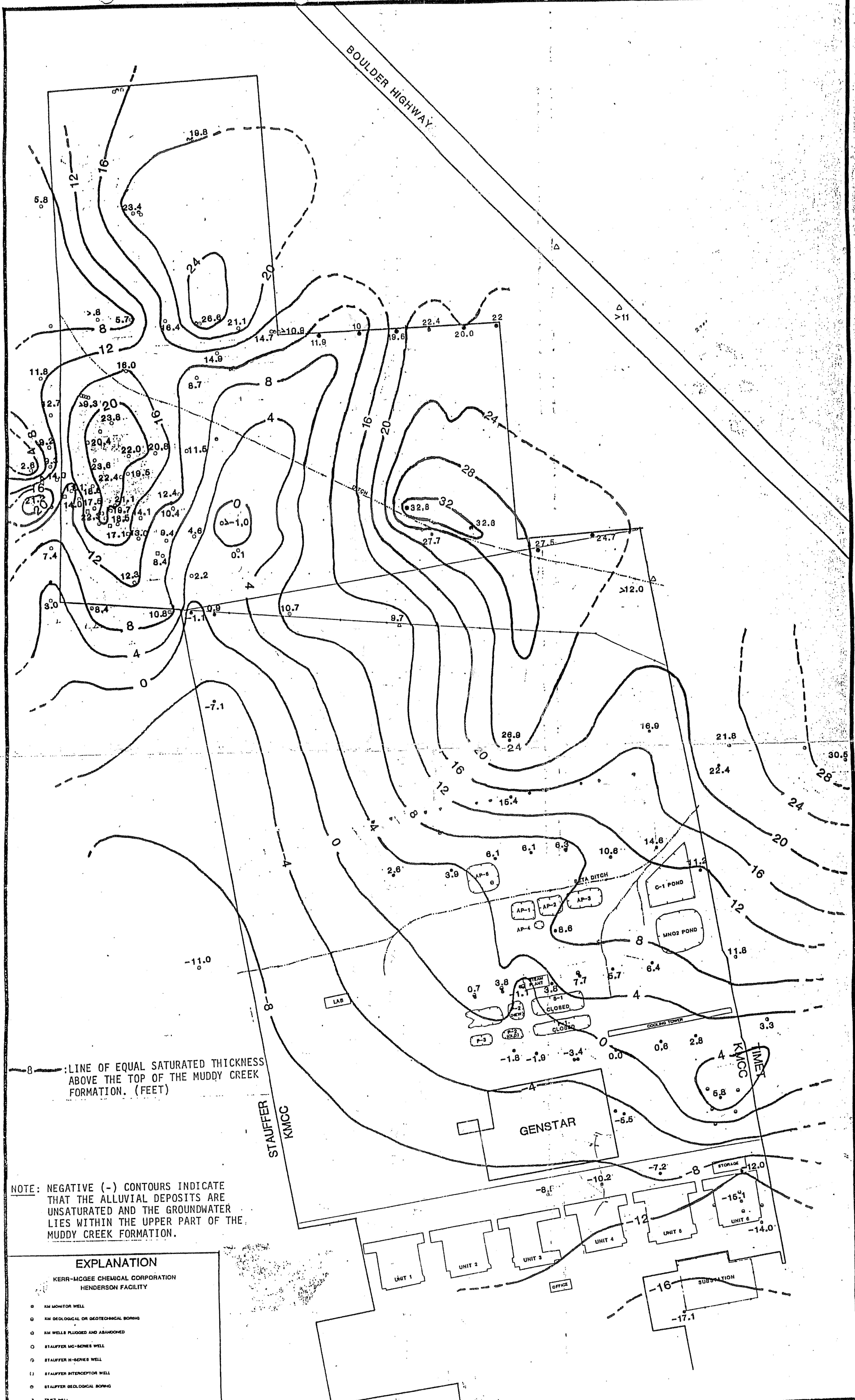


PLATE 4. MAP SHOWING SATURATED AQUIFER THICKNESS FOR THE ALLUVIAL DEPOSITS IN JUNE/JULY, 1985 AT THE HENDERSON FACILITY.

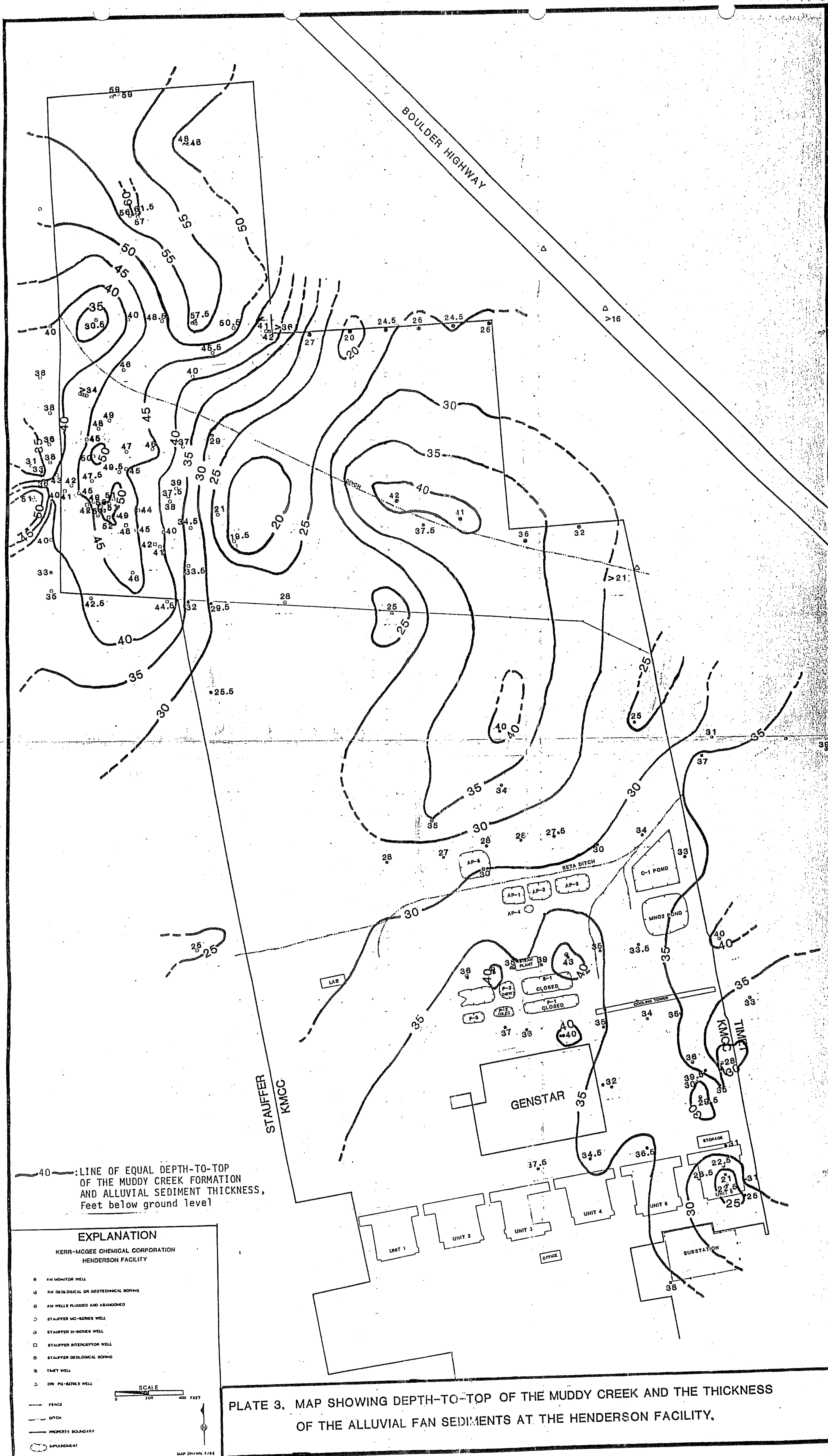


PLATE 3. MAP SHOWING DEPTH-TO-TOP OF THE MUDDY CREEK AND THE THICKNESS OF THE ALLUVIAL FAN SEDIMENTS AT THE HENDERSON FACILITY.

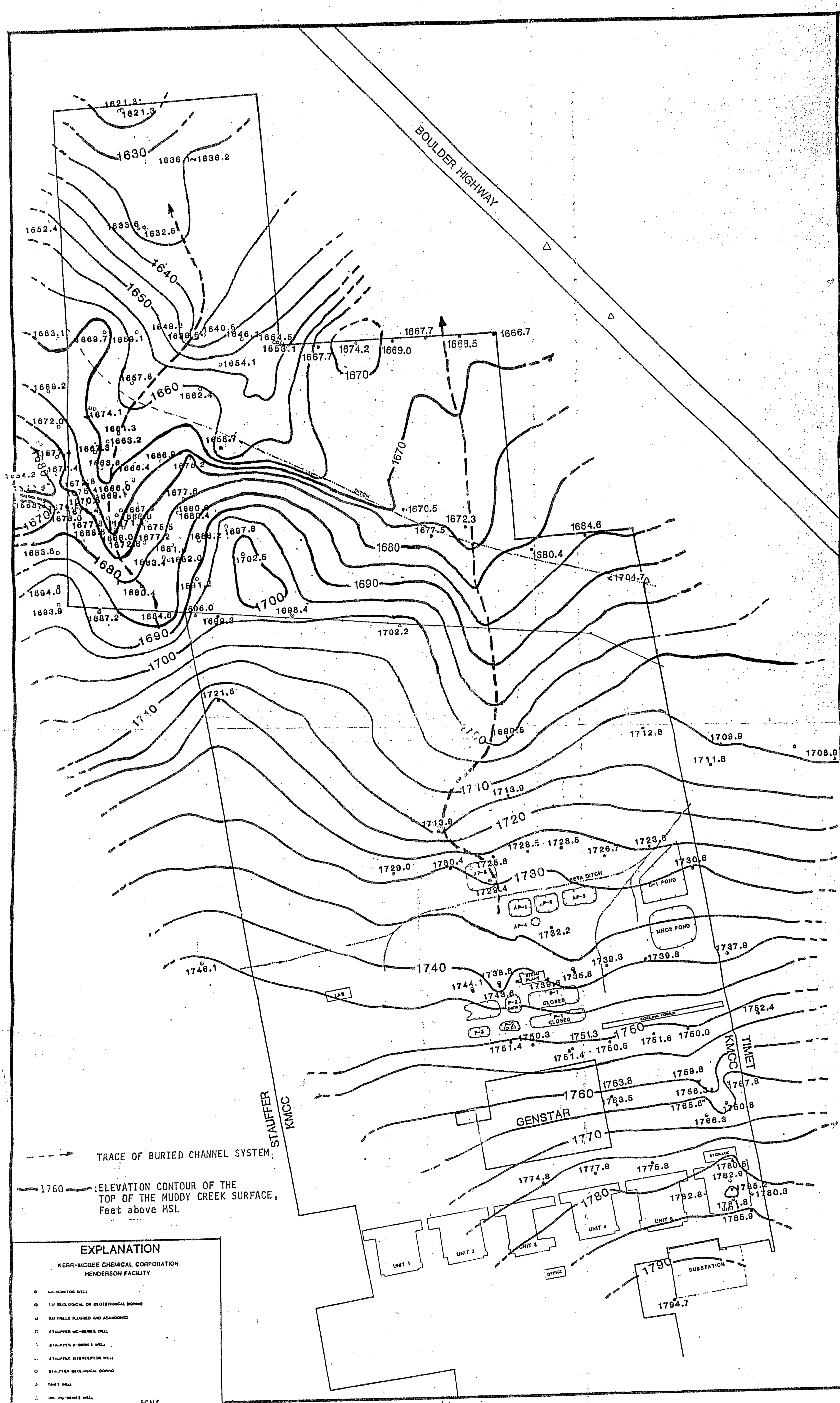


PLATE 2. MAP SHOWING THE ELEVATION OF THE TOP OF THE MUDDY CREEK FORMATION A THE HENDERSON FACILITY.