DETERMINATION OF SOURCE OF SEEPS AT BASE OF LEFT ABUTMENT OF SANFORD DAM, HUTCHINSON COUNTY, TEXAS

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AT BASE OF LEFT ABUTMENT OF
SANFORD DAM, HUTCHINSON
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PREFACE

The hydrogeology and water chemistry of the left abutment of Sanford Dam ("the Dam") in western Texas were evaluated in order to determine the source of certain seeps, which occur at the base of the abutment. The overall project was suggested by geologists with the Bureau of Reclamation ("USBR"), the federal agency which, along with the Canadian River Municipal Water Authority ("CRMWA"), oversees the operation of the Dam.

In the instant study, existing data were analyzed for the limited purpose of formulating an opinion that will assist the USBR and CRMWA in evaluating and identifying the source of the subject seeps. No opinion is expressed as to the resulting stability of the Dam or the possible effects of any of the conclusions contained herein.

I would like to express my thanks to Dr. Wayne Pettyjohn for serving as my major thesis advisor. His knowledge, advice and patience were greatly appreciated. I would also like to express my gratitude to Dr. Douglas Kent and Dr. Arthur Hounslow who made numerous suggestions and added significantly to this educational experience.

The assistance provided by Joe Jackson, Geologist, and Joe Prizio, P.E., Civil Engineer, with the USBR, and John Williams, P.E., General Manager of the CRMWA, was also appreciated. All of the data utilized herein were provided by these individuals who were always very courteous and cooperative. A special thank you is extended to Mr. Prizio who always made himself available to answer my questions and conduct data searches on my behalf.

Last but not least, special recognition and appreciation go to my wife, son, and daughter for their support, understanding and encouragement. Without their sacrifices, this study would not have been possible.

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CHAPTER I

INTRODUCTION

General Overview

Sanford Dam (the "Dam") is an earthfill structure that rises 200 feet above the bed of the Canadian River and is 6,390 feet in length. It was designed to store water to supplement the ground-water supplies for 11 West Texas cities, as well as to provide for flood control and recreational needs (Bock and Crane, 1963). The Dam is located approximately 38 miles north of Amarillo, Texas and 9 miles west of Borger, Texas (Figure 1). Lake Meredith, the reservoir created by the Dam, varies from 1 to 2 miles in width and extends for approximately 20 miles southwest of the Dam. The project area is located on the left (north) abutment of the Dam (Figure 2).

Objective

The objective of this study is to identify the source of water emerging at certain seeps on the left abutment near the base of the Dam. The study primarily concentrates on reviewing existing data in order to assist the Bureau of Reclamation ("USBR") and Canadian River Municipal Water Authority ("CRMWA") in resolving a question as to

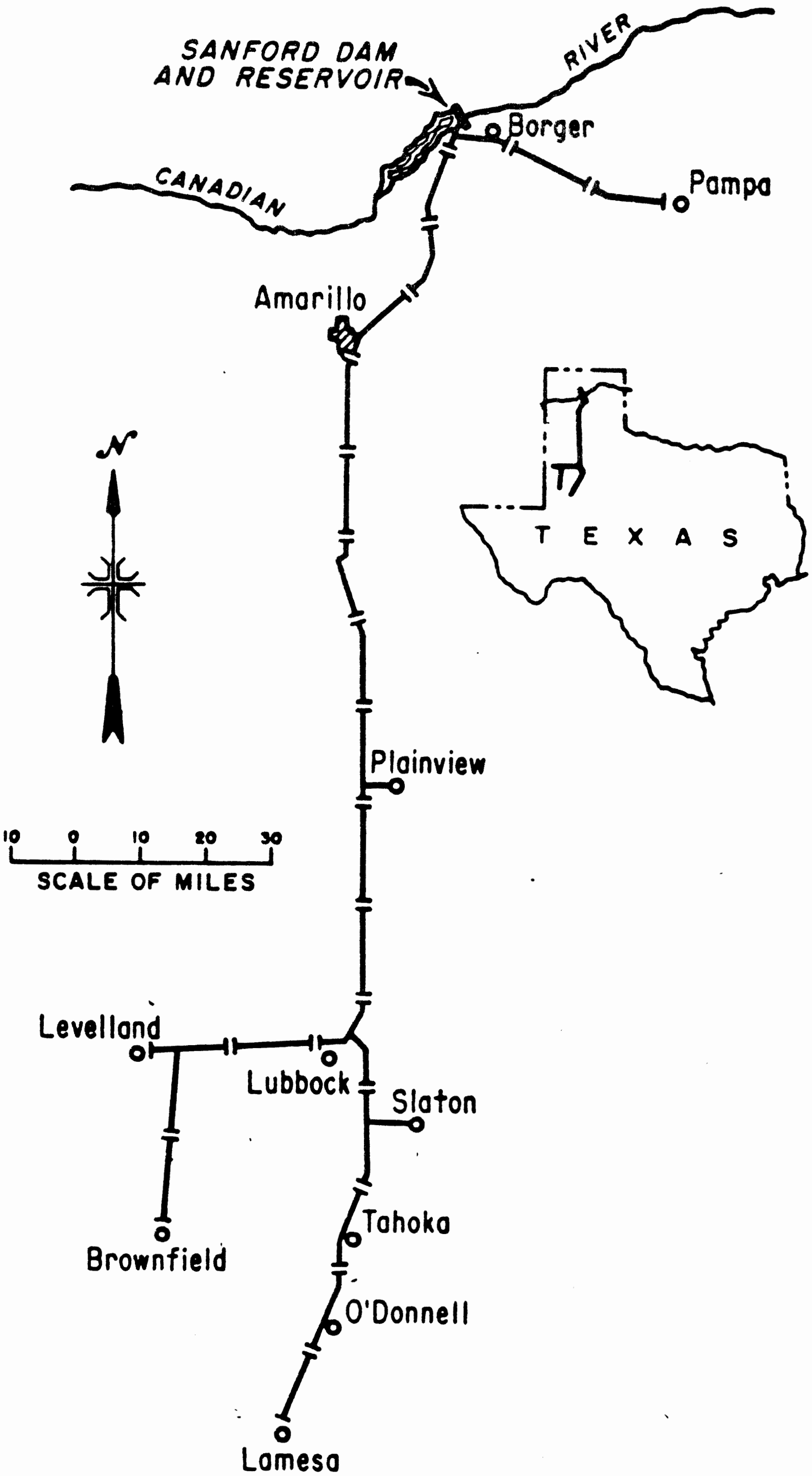


Figure 1. Location of Sanford Dam (Bock and Crane, 1963)

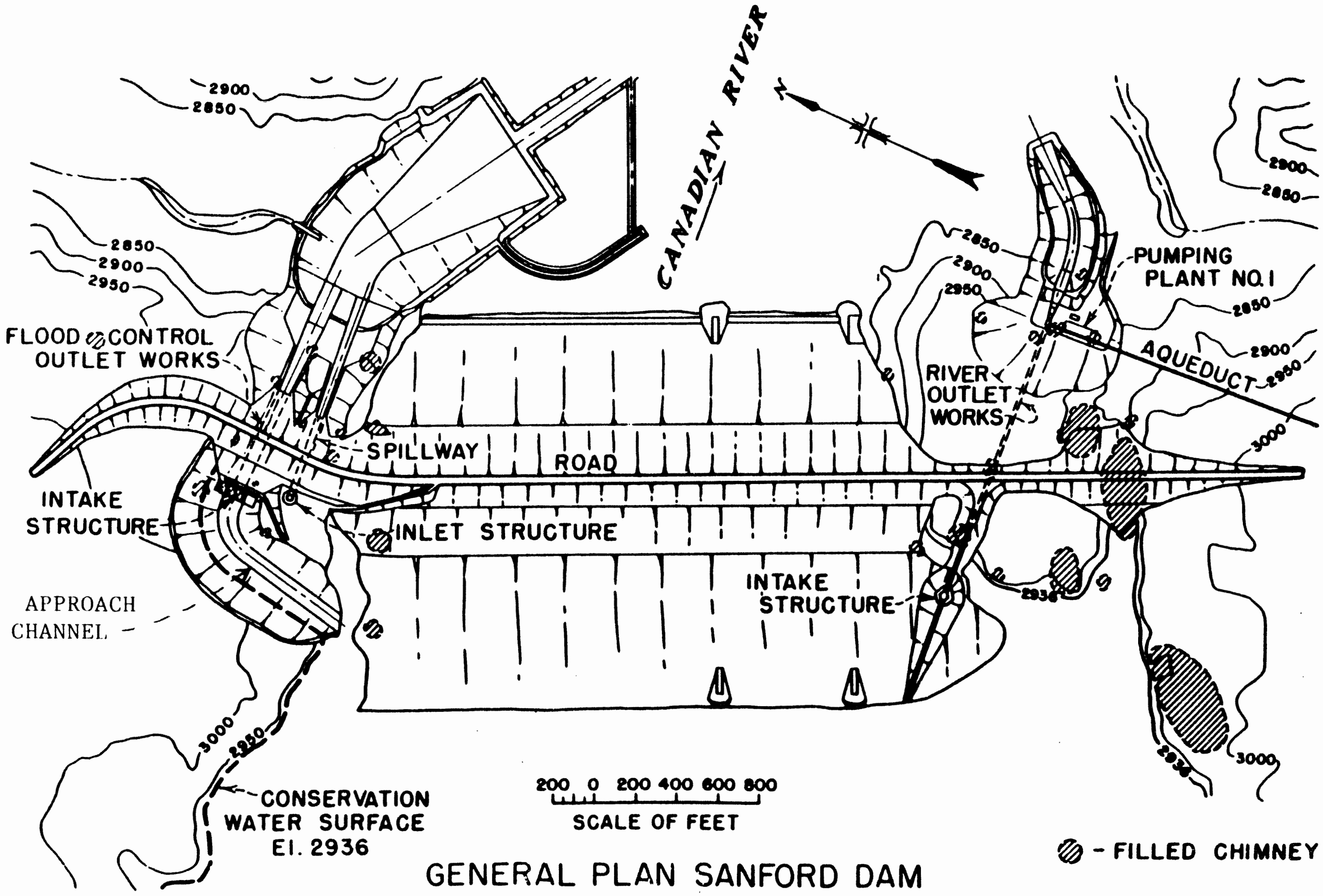


Figure 2. Map of Sanford Dam (Bock and Crane, 1963)

whether the seeps are the result of the movement of reservoir water through the left abutment, or if they are simply manifestations of the pre-existing natural ground-water system in the local area. The conclusion is intended to be used to supplement other studies presently being conducted by the USBR.

Methods of Investigation

This investigation was based on data provided by the USBR and the CRMWA. The geological data consist of sample logs of investigatory holes drilled in 1952, 1953, and 1961, and monitoring wells drilled in 1967 and 1988. Also, water level and seep-discharge measurements were recorded at various times over the last 20 years. The data were utilized in the preparation of structural and potentiometric maps and cross-sections, and graphical comparisons of reservoir levels versus water levels in monitoring wells and the discharge rate of the principal seep. The maps, cross-sections, and graphs were used to show the geologic and hydrologic connection between the reservoir and the seeps.

Chemical data consist of various water sample analyses performed in 1969, 1970, 1986, and 1990, and an analysis of a precipitate taken from the seep area in 1992. The majority of the samples were taken from the reservoir, monitoring wells, and seeps. The analyses were compared by way of trilinear diagrams, Stiff diagrams, and bar graphs. These methods indicated that, over time, a reduction in SO_4 concentration was the most noticeable difference. Also, the analysis of the precipitate present at the seeps indicated relatively high concentrations of Ca, Mg, and SO_4. As a result, an evaluation of the relationship between these ions along the postulated flow path from the reservoir to the seep area was conducted. However, in the end, the water sample analyses were used for the limited purpose of providing additional support for conclusions based on the above-stated hydrogeological methods.

Previous Investigations

This project was suggested by geologists with the USBR. Since completion of the Dam in the mid-1960s, there has been some concern within the USBR and CRMWA regarding certain seeps located at the base of the left abutment. A question has arisen as to the origin of the waters emerging at these seeps. Some have suggested that the seeps are simply a manifestation of naturally occurring ground water in the area. Others believe that the seep water is derived from the reservoir. This quandary is evidenced by the specific investigations and correspondence reviewed below.

In September, 1963, a report was issued by the USBR addressing a bed of gypsum that was exposed during the excavation of the approach channel to the Flood Control Outlet Works. This report also noted that the larger grout takes in the left abutment roughly correlated with the gypsum zone. It was then concluded "that these may be portions of a solutioned gypsum bed 20 to 30 feet below the excavation grade of the flood control outlet works and spillway" (Bureau of Reclamation, 1963, p. 3).

The Final Geological Report on the Dam, issued in August, 1965, also addressed the same gypsum zone and states "solutioning of the gypsum by reservoir seepage water may result in the development of leakage through this unit of gypsiferous shale and associated gypsum beds. If leakage develops, piping of the shale is expected to follow" (Bureau of Reclamation, 1965, p. 14). In addition, the report concludes: "The upper gypsum horizon, in time, may be a source of leakage in both abutments when the reservoir is filled" (Bureau of Reclamation, 1965, p. 16).

This matter was addressed again in an October 21, 1969 USBR memorandum, which suggested that complete chemical analyses be made of water from the seepage area and from certain existing observation wells in the vicinity of the seeps. After such analyses were run, an April 29, 1970 USBR memorandum stated that they "indicate a continued lack of correlation between reservoir water and the left abutment seepage water" (Bureau of Reclamation, 1970, p. 1). This matter was considered again in 1986 when the CRMWA took samples from the same observation wells and concluded that such samples did not appear to have originated from the reservoir.

In January 1990, a USBR geologic report again focused on the left abutment (Jackson, 1990). This report concluded that the "seepage in the left abutment at Sanford Dam in the structure areas (i.e. flood control outlet works and spillway) is transmitted from the reservoir primarily along the so-called Breccia-Upper Gypsum Zone" (Jackson, 1990, p.16). However, this conclusion was questioned in an April 5, 1990 CRMWA letter which, after noting the fact that previous reports indicate the seeps were present during the construction phase of the Dam, suggested "more complete review of all available test results and their interpretation" (Canadian River Municipal Water Authority, 1990, p.2).

CHAPTER II

GEOGRAPHIC AND GEOLOGIC SETTING

Geography

Sanford Dam is located in the central part of the Texas Panhandle and in the Southern part of the Great Plains Physiographic Province (Fenneman, 1931). In this area, the flat surface of the Great Plains is broken by the valley of the Canadian River in what is commonly referred to as the Canadian River Breaks (Figure 3). The High Plains north of the Canadian River are called the Central High Plains and the area to the south is referred to as the Southern High Plains or the *Llano Estacado*. The study area lies within the Canadian River Breaks.

Tectonic Setting

The major positive tectonic element in the study area is the Amarillo Uplift, which forms the south and southwestern boundary of the Anadarko Basin (Figure 4). Tectonic activity that created this feature and other uplifts and basins in the general area occurred primarily during the Pennsylvanian Period, and was largely completed by the end of that period. Minor movements have occurred since the Permian, but they may have resulted from

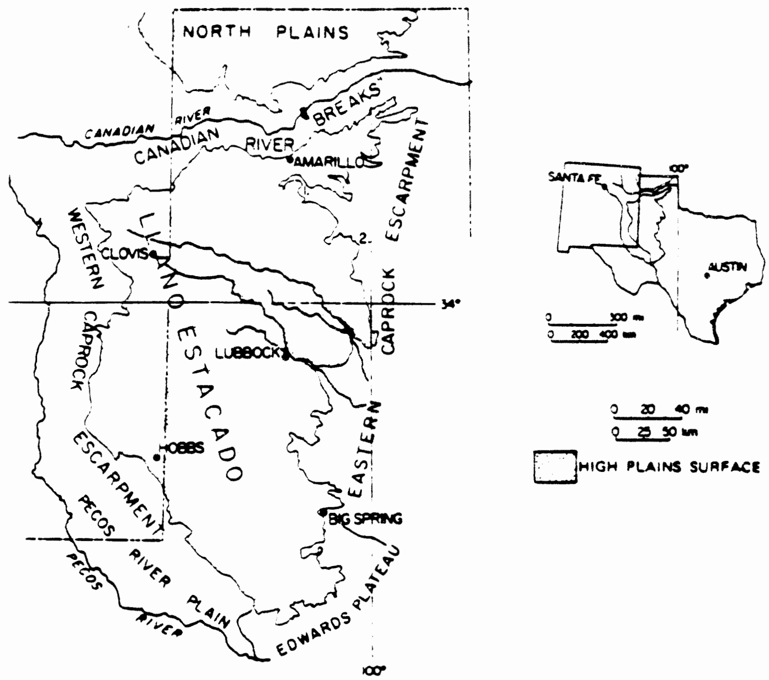


Figure 3. Map of Physiographic Units (Gustavson, Finley, and McGillis, 1980)

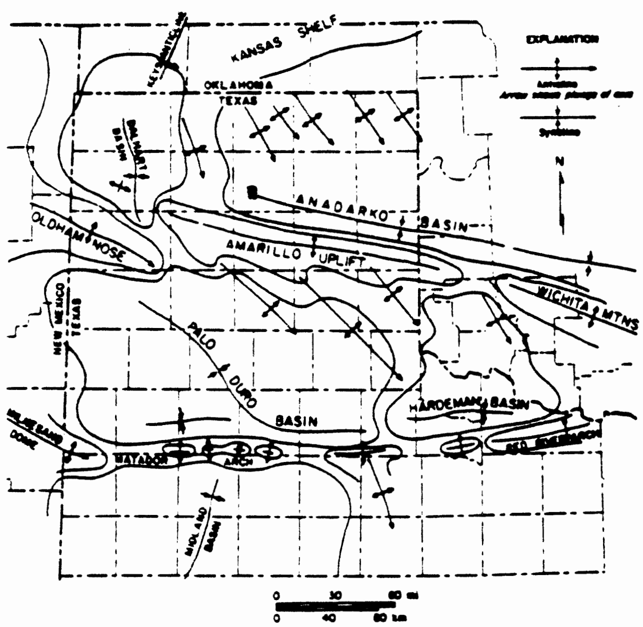


Figure 4. Map of Structural Elements (Gustavson, Finley, and McGillis, 1980)

differential compaction of basin sediments or from post-tectonic adjustments in the earth's crust (Gustavson, Finley, and McGillis, 1980).

Soils and Surface Deposits

The soils in the vicinity of the Dam are primarily composed of aeolian deposits of Recent and Pleistocene age. However, the Ogallala Formation of late Tertiary age also is present in some places, and consists of partly consolidated sand, silt, clay, and gravel, that rest unconformably on rocks of Permian age. In the specific area of the Dam, the principal Ogallala deposits are found in sinkholes that were developed in the underlying Permian rocks.

Geology of Primary Subsurface Formations

This report will focus on Permian formations because they are the formations that were excavated on the left abutment and which are in direct contact with the Canadian River alluvium and the reservoir. Also, all of the monitoring wells were drilled and screened in the Permian. The Quartermaster Formation is the uppermost Permian formation in the area (Figure 5). However, Quartermaster deposits are not particularly widespread and, as with the Ogallala, are principally preserved in sinkholes and other subsidence structures.

The Alibates Formation, also of Permian age, which forms the most common outcrop along the Canadian River, is present at the top of both the right and left abutments at

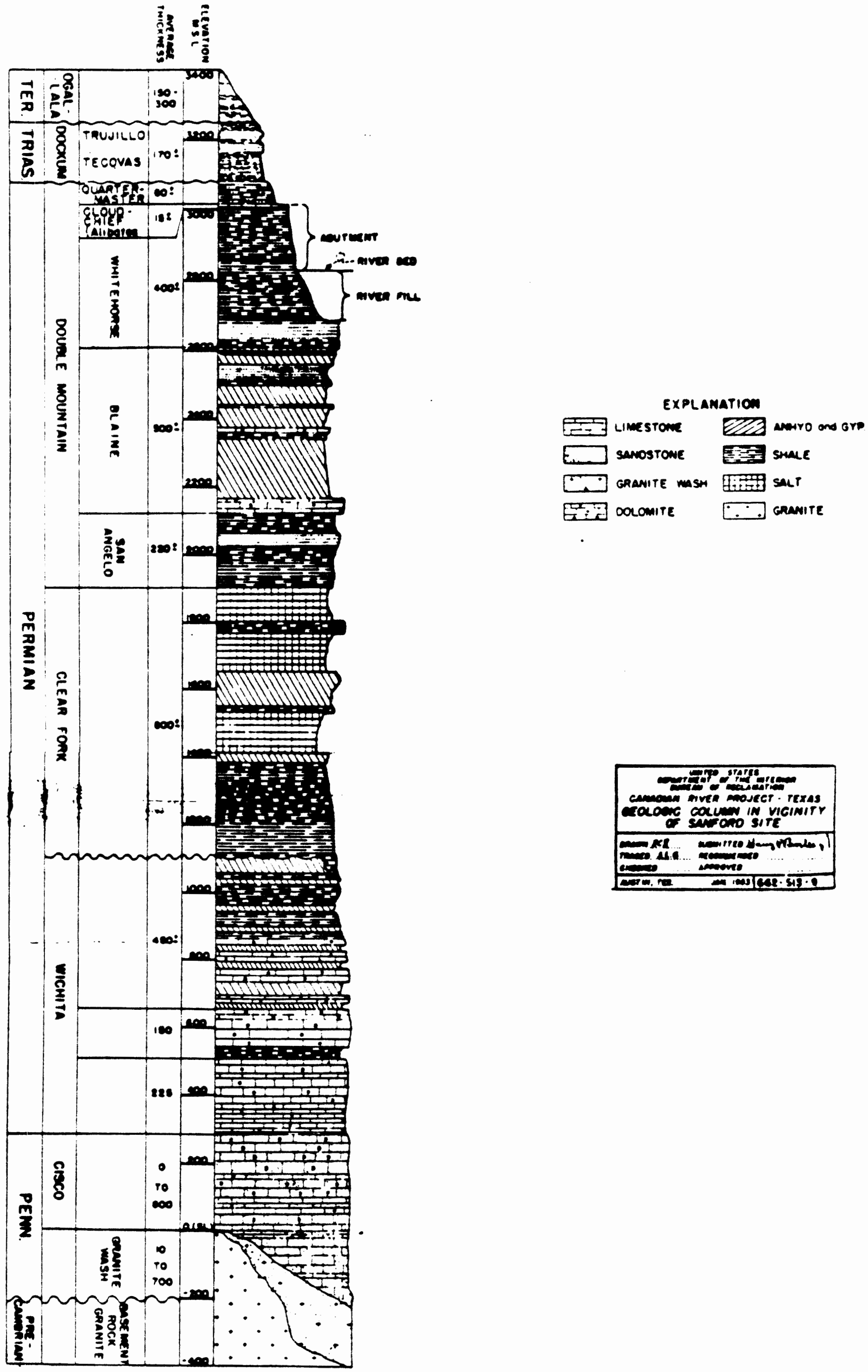


Figure 5. Geologic Column - Sanford Dam Vicinity
(Bureau of Reclamation, 1965)

the Dam. It usually consists of two dolomite members, the lower being six to 10 feet and the upper being two to four feet in thickness with intervening red and gray silty and clayey shale. The Alibates is resistant to erosion, which is evidenced by the fact that riprap (anti-erosional material) for the Dam was quarried from the Alibates. It also forms the cap on many bluffs and cliffs along the Canadian River and its tributaries, and provides a striking contrast to the surrounding formations that are, for the most part, composed of brick-red shales. When observing exposures, it is also apparent that the Alibates closely corresponds with, and provides an accurate structural picture of, the various marker beds in the Whitehorse Formation, which directly underlies the Alibates. Finally, it should be noted that the Alibates is widely known because of the flint deposits, which were mined by the American Indians for thousands of years. The nearby Alibates National Monument was created to protect and preserve these deposits.

The Whitehorse Formation, which is described in greater detail below, crops out beneath the Alibates and forms the abutments. It is also in direct contact with the reservoir and the alluvium in the river channel beneath the Dam. In the study area, the Whitehorse consists of clayey shale, in part silty to sandy, and of siltstone and silty fine sandstone, that is dull brick-red with light gray layers. The upper half of the formation is predominantly clayey shale, whereas the lower half is more sandy. A persistent bed of gypsum, two to four feet in thickness, and two or more lentils, one to four feet in thickness in places, are present in the Whitehorse. Gypsum also occurs as nodules and impregnations in clayey shale, and as secondary satin spar veinlets along joint planes. The formation is 400 feet thick in the vicinity of the Dam (Bureau of Reclamation, 1965).

The Blaine Formation immediately underlies the Whitehorse. In the vicinity of the Dam the Blaine is 500 feet thick and consists of massive gypsum, some anhydrite, thin shale and dolomite, and soft sand. The Blaine is characterized by numerous caves and sinkholes. These features were principally caused by dissolution of evaporites, a phenomenon that is more specifically addressed below.

Detailed Description of Geology of Permian Whitehorse Formation

As noted above, the Whitehorse Formation forms the abutments and the sides and bottom of the filled channel of the Canadian River. In the area of the Dam, the abutments down to the river level are composed of alternating beds of silty and clayey shale, clayey siltstone and gypsum. The beds are undulatory, with downwarps and gentle folds. The shale is rather massive, poorly laminated, and lacks well-developed bedding cleavage or fissibility characteristic of true shale. Much of the shale has a granulated texture, as though affected by internal movement. Intricate, randomlyoriented slickensided fracture planes are closely spaced in some beds, and are usually present in all beds of shale. At or near the surface, the shale is rapidly reduced to a loose mass of small fragments where exposed to weathering. Secondary gypsum, in the form of disseminated crystals and satin spar veinlets filling fractures and joints, are found in all of the beds of shale to some extent (Bureau of Reclamation, 1965).

The following is a description of two Whitehorse zones encountered in the drilling of the investigatory and monitoring wells. They also are the zones in which the monitoring wells were screened. Both zones either contain a bed of gypsum at their base or, if such bed is missing, can be correlated by reference to an underlying siltstone. Also, if the bed of gypsum is missing, the respective zones are usually recognized as zones of brecciated shale. However, in order to simplify the discussion set forth below, these zones, irrespective of whether they contain gypsum or not, will be referred to separately as the Upper Gypsum and Lower Gypsum.

Gypsum Zones

The gypsum beds in the Whitehorse are fine to coarsely crystalline, laminated to massive, and jointed. The gypsum occurs in two horizons. The Upper Gypsum is present at an elevation of approximately 2,875 feet directly underneath the crest of the Dam in the vicinity of the left abutment. The Lower Gypsum occurs at an elevation of approximately

2,805 feet in the same location. The Upper Gypsum generally consists of two beds of gypsum, ranging from one to four feet in thickness, that are separated by a bed of clayey shale that ranges from three to eight feet in thickness. However, at the time the Dam was excavated, it was noted that the Upper Gypsum was not present in the left abutment downstream from the approach channel of the flood control outlet works (Bureau of Reclamation, 1965). Also, the Upper Gypsum is usually not present in the investigatory and monitoring wells drilled in the left abutment and, as noted above, in such instances, is usually recognized as a zone of brecciated shale underlain by a massive siltstone. This appears to be a very localized phenomenon because a persistent outcrop of Upper Gypsum is present both upstream and downstream from the Dam along both sides of the Canadian River canyon and in the side drainages. This study concentrates on the Upper Gypsum because it crops out at the elevation of the seeps and presumably is the primary zone through which the seep water migrates.

The Lower Gypsum also is of interest and it usually consists of a single bed ranging from two to four feet in thickness. The gypsum is fine to coarsely crystalline, laminated to massive, and jointed. The joints are solutioned and open a half to as much as two inches in places. Most of the solutioning is at the bottom of the bed. The Lower Gypsum was exposed at the time of excavation at the toe of the slope of the left abutment at an elevation of 2,802 feet and in the chute of the spillway and flood control outlet works at elevation 2,790 feet. It is estimated to lie 10 to 20 feet below the surface of the Canadian River alluvium upstream and downstream from the Dam. The Lower Gypsum does not crop out in the seep area and has no apparent physical relation to the seeps. However, since the majority of the subject monitoring wells are screened in the Lower Gypsum, this study will address the Lower Gypsum to a limited extent in order to better understand the possible effects of the reservoir on this zone and to explain certain chemical changes that have occurred over time.

Sinkholes and Other Solution Features

As noted above, numerous filled sinkhole structures are present in the vicinity of the Dam. Many of the initial reports on the construction of the Dam refer to these structures as "chimneys", as does a majority of the literature on the Permian in this area. Although this study does not address these structures to any significant extent, they do deserve mention due to their widespread occurrence in the area.

Prior to excavation of the Dam, the sinkholes that were encountered appeared to range from 40 to 1,000 feet in diameter. As work progressed on the Dam, a total of 27 sinkholes were discovered (See Figure 2). These structures were found largely on the right (south) abutment and caused some concern during the excavation process (Bock and Crane, 1963). Basically, the Permian beds near the margin of the filled sinkholes dip into the structures, and within a sinkhole a zone of breccia derived from Permian rocks surrounds a central core of sand and clay derived from the Ogallala and Quartermaster Formations. An example of one of these structures is found in wells DH25-I and DH51-I, which lie next to the approach channel on the left abutment.

These structures were addressed in studies of evaporite dissolution in the Texas Panhandle, which were initiated by the Department of Energy in 1977 as part of a comprehensive analysis of Permian salt as a potential repository for isolation of nuclear wastes (Gustavson, Finley, and McGillis, 1980, and Simpkins, Gustavson, Alhades, and Hoadley, 1981). These studies noted that streams draining the Texas Panhandle carry a substantial volume of calcium and sulfate in their solute load, which indicate that solution of gypsum is an important process in the area. It also was noted that gypsum crops out in numerous localities along the Canadian River and that solution of gypsum has produced enlarged fractures and small caverns. However, the most interesting aspect of these studies was the discovery that, compared with salt dissolution, anhydrite/gypsum dissolution is not an important process in the deeper subsurface and that gypsum dissolution is a surface or very near surface process that has not played an important role in causing the major structural adjustments and dissolution collapse features (such as chimneys) occurring in the Texas Panhandle (Gustavson, Finley, and McGillis, 1980, and Simpkins, Gustavson, Alhades, and Hoadley, 1981). This suggests that prolonged or extensive exposure to relatively fresh water is required in order to dissolve significant volumes of gypsum.

In discussing salt dissolution and its relationship to chimneys filled with collapse breccia, the studies noted that a collapse was probably not a single event, but rather a series of roof falls. The 27 filled collapse chimneys in the Whitehorse Formation at the Dam are specifically mentioned.

Description of Dam Structures on Left Abutment

As noted above, this study is limited to the left abutment of the Dam. The left abutment was excavated in order to install the flood control outlet works and spillway, and chutes associated with both. The flood control outlet works consists of an approach channel and intake structure. It can be used to control the level of the reservoir. The spillway consists of an inlet structure, which would become a factor if the reservoir ever reached an elevation of 2,965 feet. All of these structures are identified in Figure 2.

CHAPTER III

HYDROGEOLOGICAL RELATIONSHIP BETWEEN RESERVOIR AND SEEPS

The Final Geologic Report cited above described a siltstone and shale (with basal gypsiferous zone) in the Whitehorse Formation that contained numerous seeps. This fact also was shown in a cross-section attached to the report (Figure 6). From this cross-section, it is apparent that the section described in the report is the Upper Gypsum which, due to the excavation of the area, crops out on the left abutment at the elevation of the seeps. This information is important because it indicates that the Upper Gypsum and the overlying siltstone were water-bearing zones prior to excavation, which suggests that a confining bed is present at the base of the zone. Therefore, this study concentrates on determining if the reservoir is in geologic and hydrologic connection with the Upper Gypsum and the seep area.

Maps and Cross-Sections

This study utilized core descriptions from 38 investigatory and drill holes that were drilled in 1952, 1953, and 1961, prior to construction of the Dam (identified

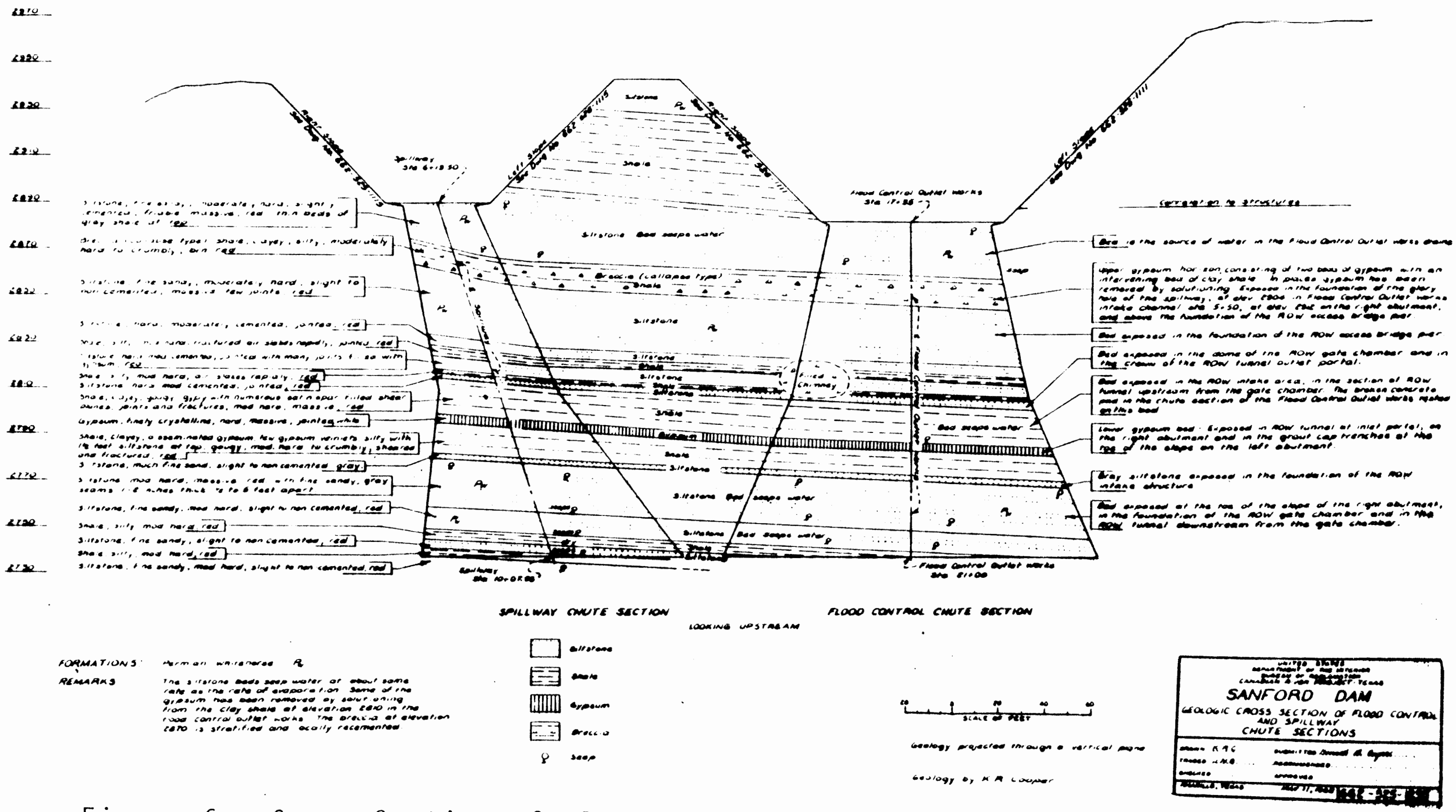


Figure 6. Cross-Section of Flood Control and Spillway Chute Sections (Bureau of Reclamation, 1965)

by prefix DH). Also used was information from monitoring wells drilled in 1967 (no prefix) and 1988 (identified by prefix DH88). All of the monitoring wells were screened in either the Upper Gypsum or Lower Gypsum (with the possible exception of two DH88 wells). The geological information provided by these wells was used to prepare structure maps and cross-sections of the base of the Alibates and Upper and Lower Gypsum. Also, potentiometric surface maps and flow nets were prepared for water bearing intervals above the respective bases of the Upper and Lower Gypsum. Although actual gypsum beds were not always present in the drill holes and monitoring wells, both the Upper and Lower Gypsum were mapped by correlating the top of the massive siltstone (and occasional thin clay) underlying the Upper Gypsum and a thinner siltstone underlying the Lower Gypsum.

Since a majority of logs used in the subject maps and cross-sections were drilled prior to the excavation of the left abutment, reconstruction of the pre-excavation structure of the respective bases was possible. As mentioned above, outcrop exposures in the area show that the structure of Alibates approximates the structure of other Permian marker beds directly below. Also, the drill holes and recorded outcrop elevations for the Alibates provided more data control points and, hence, a more detailed map (Plate I). The Alibates map indicates that the excavation for the flood control outlet works and spillway intersected what is a low area present in the subject formations. More importantly, the map of the underlying Upper Gypsum (Plate

II) shows that the excavation intersected the Upper Gypsum at the bottom of this low. Since the Upper Gypsum evidently was already water bearing, the result of the excavation was the creation of minor seeps in this zone. Its structural position also might explain the lack of bedded gypsum in that the zone had been historically subject to dissolution. The map of the Lower Gypsum (Plate III) indicates that, although it is not associated with the seeps, it is geologically connected to the Canadian River alluvium and the reservoir to some extent. The Upper and Lower Gypsum are addressed separately below.

Upper Gypsum

In September 1963, the USBR issued a report that discussed the fact that two discontinuous lenses of gypsum had been exposed in the excavation of the approach channel to the flood control outlet works (Bureau of Reclamation, 1963). These 1½ to 2½ foot thick exposures were estimated to occur at an elevation of 2,904 feet. The only investigatory well drilled in the approach channel (DH24-I) encountered the base of this gypsum zone at approximately 2,890.7 feet, a little over two feet below the bottom of the channel. Cross-sections A-A', B-B', and C-C'(Figure 7, 8, and 9, respectively) indicate that this zone is correlative with the Upper Gypsum. Cross-sections D-D', E-E', and B-B' (Figures 10, 11, and 8, respectively) show that the base of the Upper Gypsum passes below the tunnels for the flood control outlet works and spillway. The map of the Upper

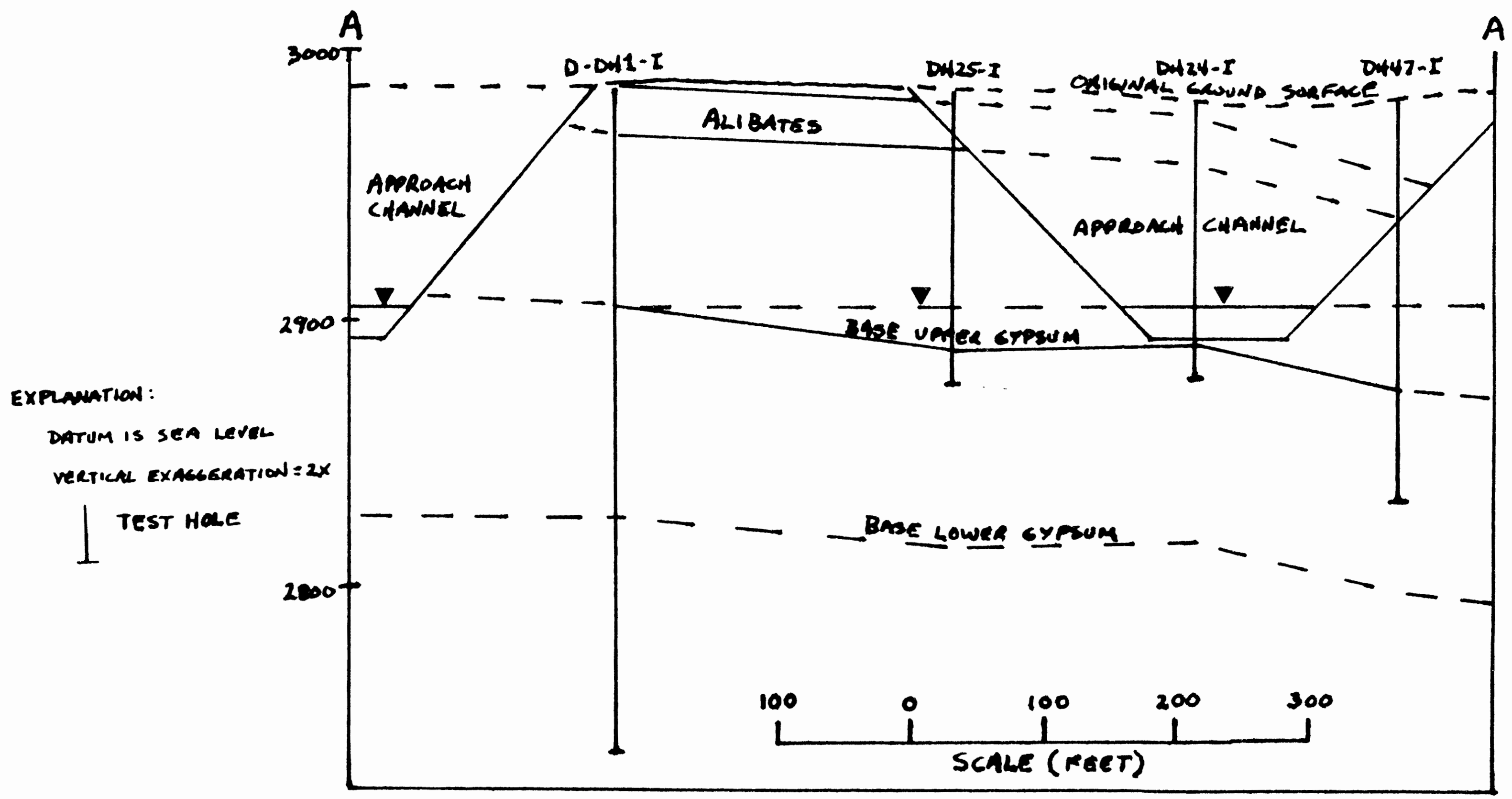


Figure 7. Cross-Section A - A'

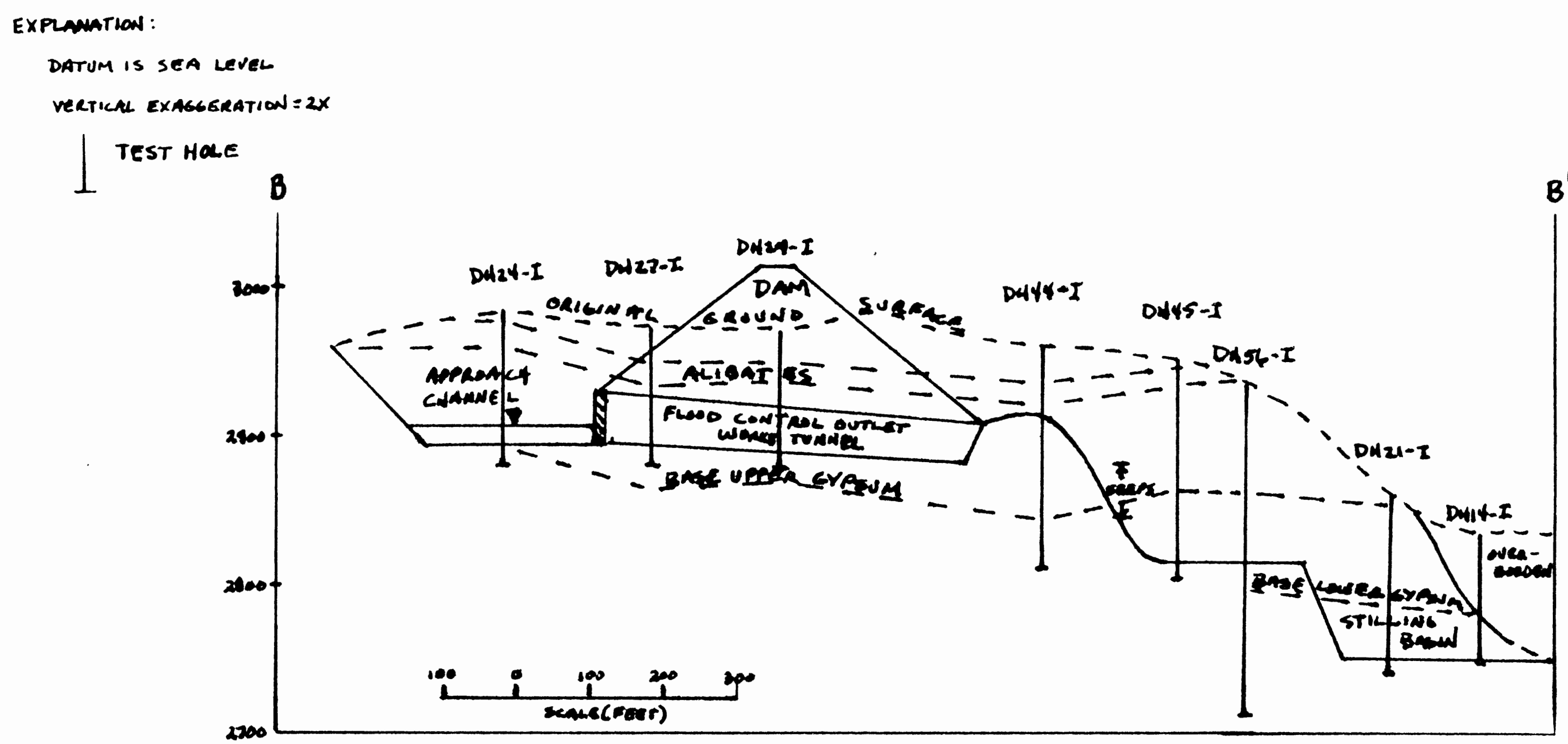


Figure 8. Cross-Section B - B'

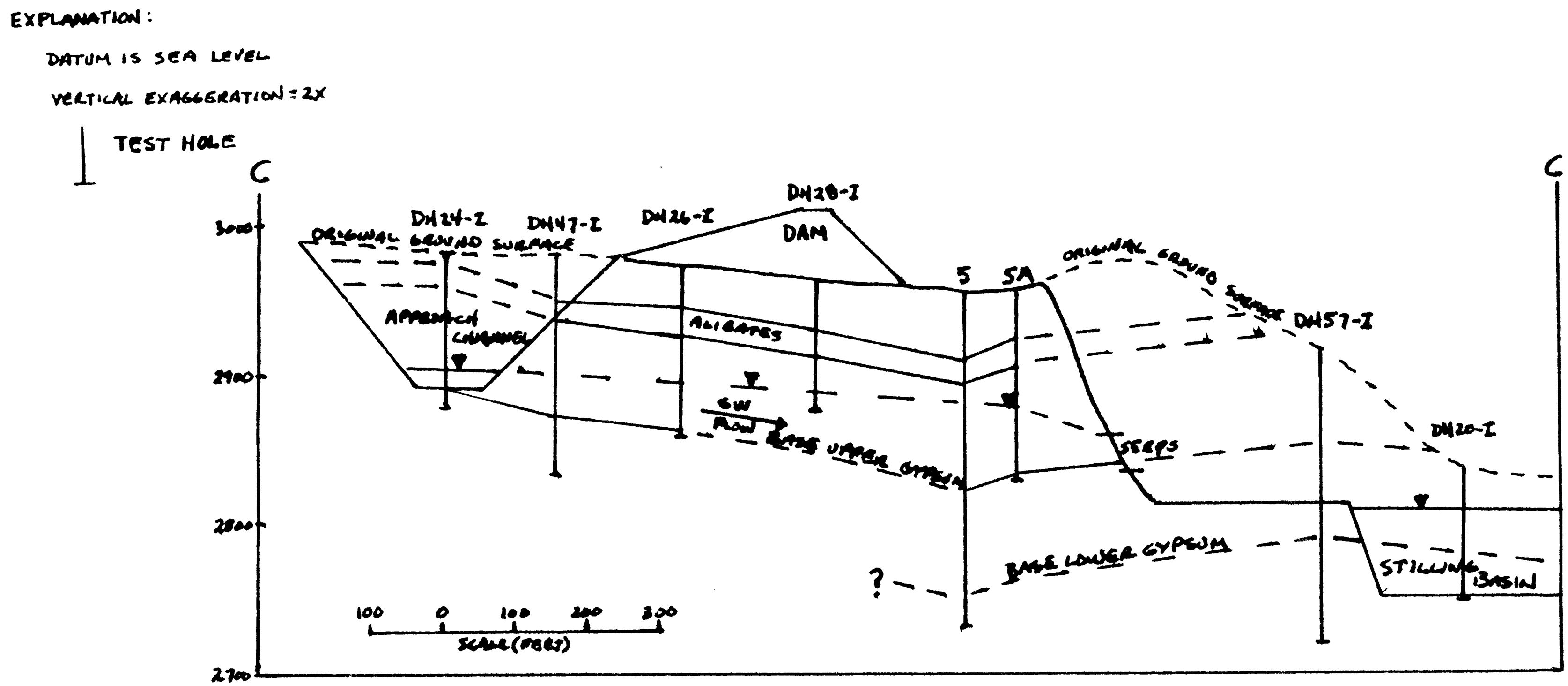


Figure 9. Cross-Section C - C'

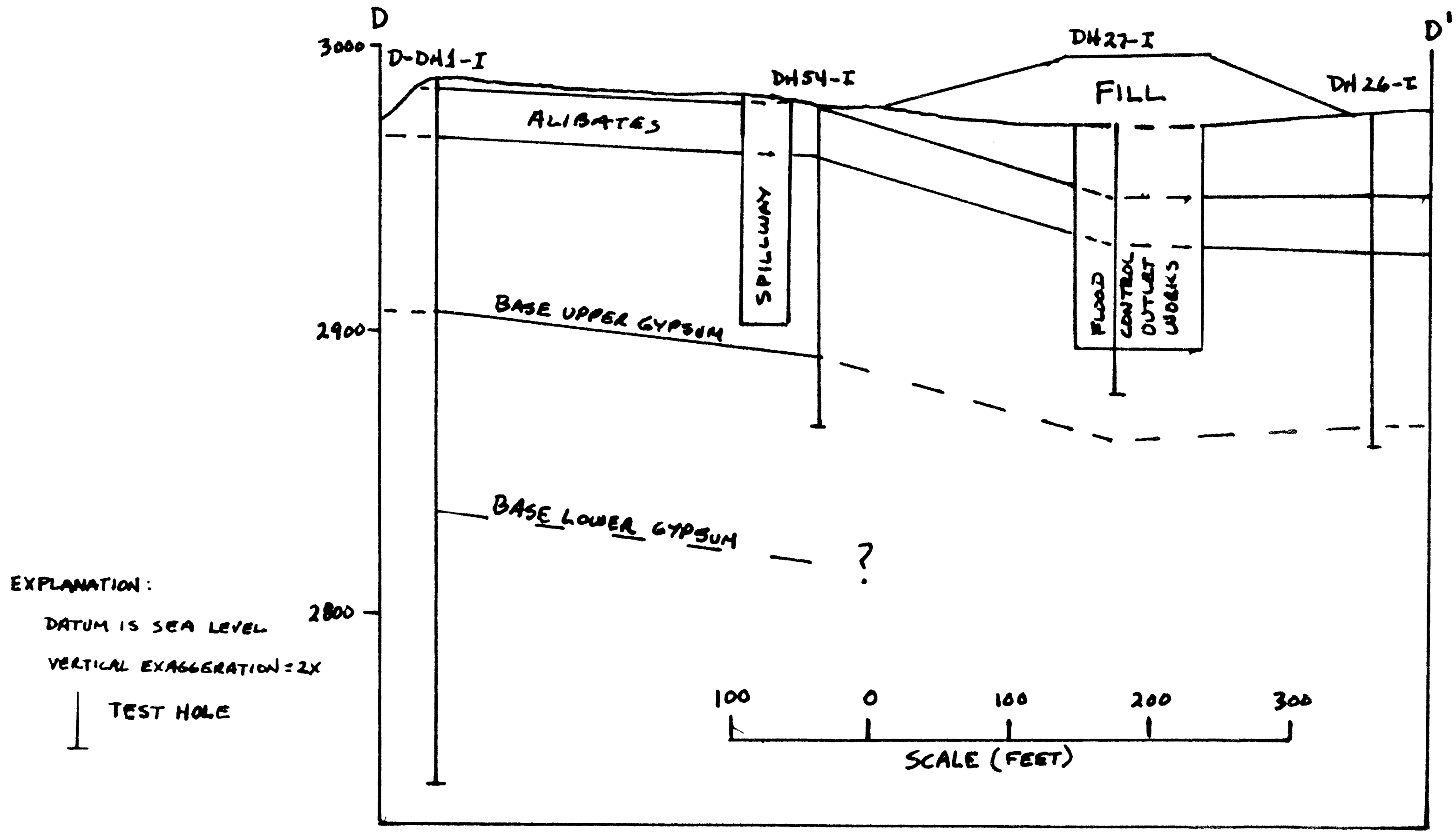


Figure 10. Cross-Section D - D'

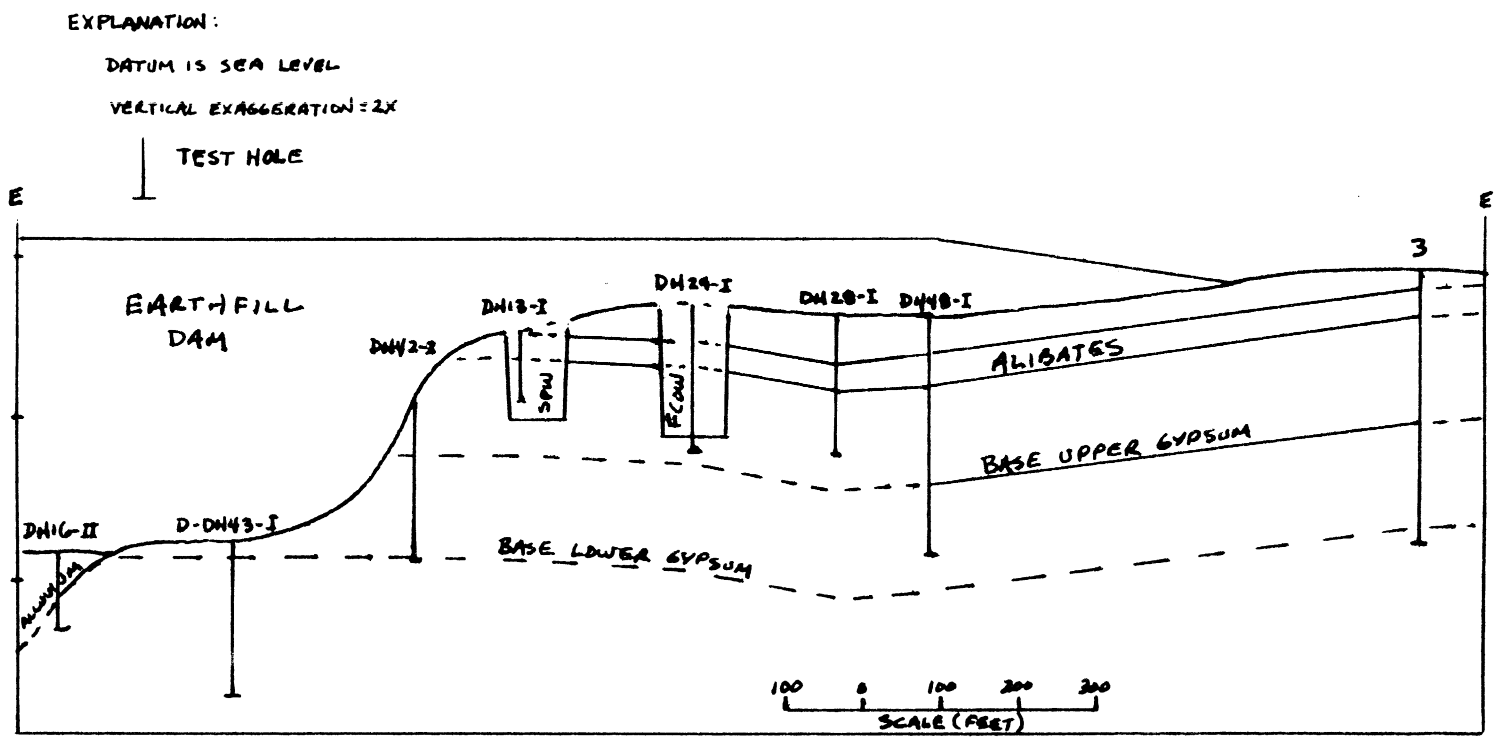


Figure 11. Cross-Section E - E'

Gypsum and cross-sections F-F', G-G', B-B', and C-C' (Figures 12, 13, 8, and 9, respectively) also indicate that the Upper Gypsum is the zone that crops out at the seep elevation of 2,830 to 2,860 feet at the base of the left abutment. Taken together, the maps and cross-sections indicate that the approach channel is geologically connected with the seep area.

A saturated interval map was constructed (Plate III) for the zone above the base of the Upper Gypsum. The geological data utilized were from wells DH24-I, 5A, 7A, and the water-level elevation data were from the reservoir and wells 5A and 7A. 1970 data are used for all water-level elevation maps in this study. This map suggests that the Upper Gypsum is recharged by water from the approach channel and that the water collects in the low area intersected by the excavation at the elevation of the seeps. It should be noted that this map may indicate both the saturated interval and the pressure head in some instances. The superimposed potentiometric surface and flow net map lends further credence to this observation because flow lines converge at the recharge and discharge points, that is, the approach channel and the seeps, respectively.

Lower Gypsum

The map of the base of the Lower Gypsum (Plate IV) also indicates a low area in the vicinity of the seeps. However, there are no outcrops present in the vicinity of the left abutment. Therefore, the Lower Gypsum was only analyzed for

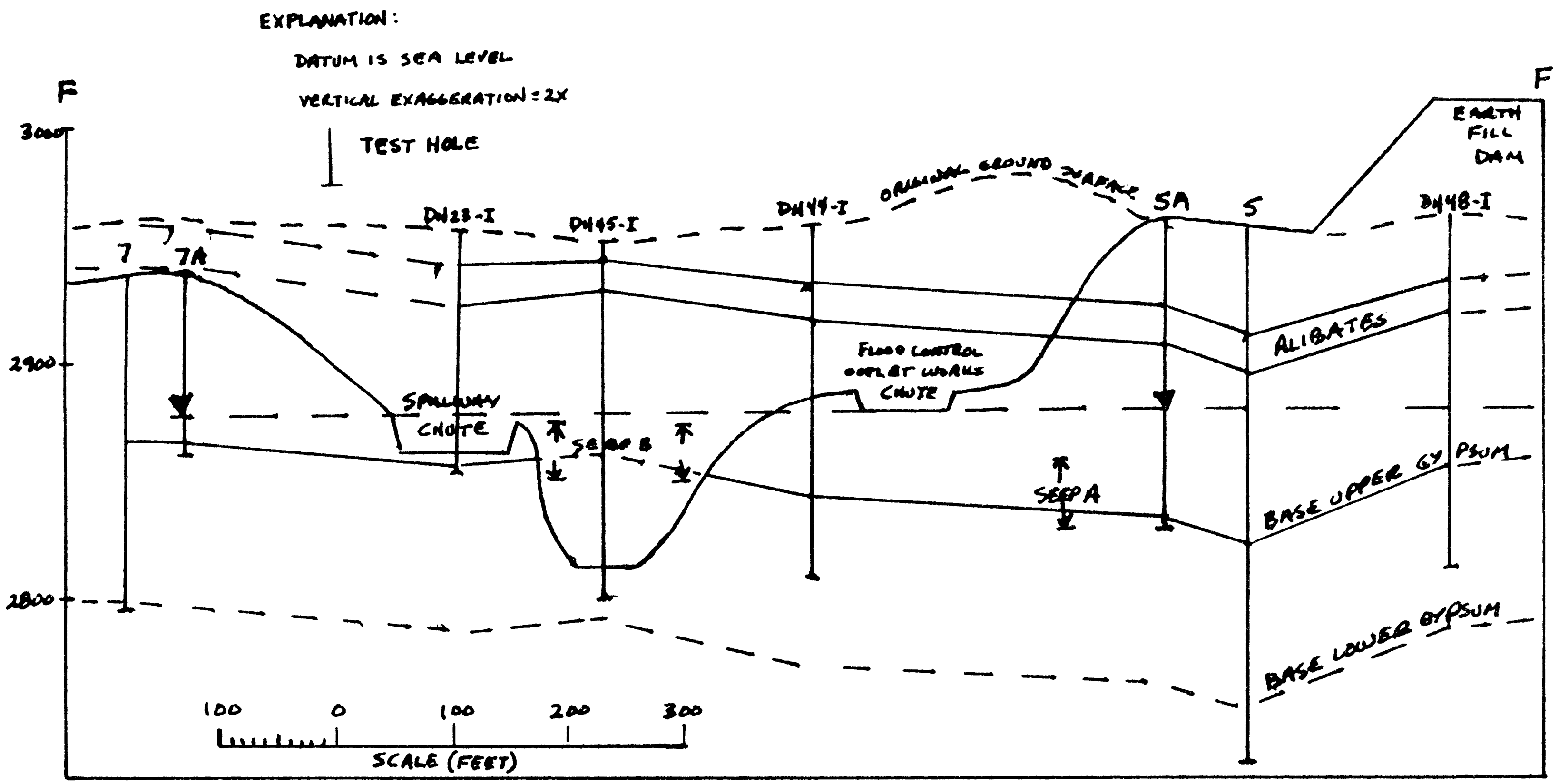


Figure 12. Cross-Section F - F'

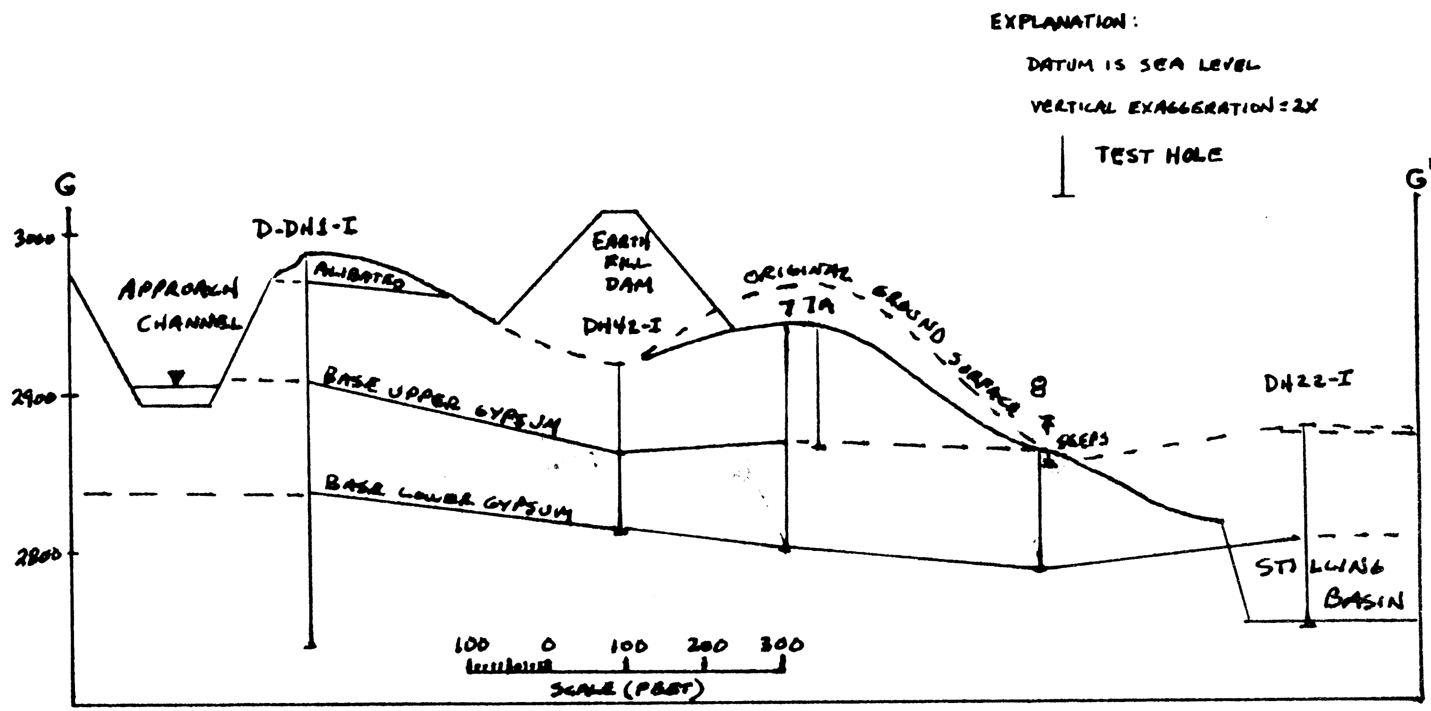


Figure 13. Cross-Section G - G'

the purpose of determining whether it is connected to the reservoir because chemical analyses indicated changes over time in the monitoring wells closest to the reservoir.

Cross-section H-H' (Figure 14) shows that the Lower Gypsum is most likely in direct contact with the alluvium under the Dam. The potentiometric surface map (Plate V) lends support to this observation by illustrating the fact that ground water in this interval is flowing in an east to northeasterly direction away from the reservoir.

Water Levels and Seep Discharge Rates

Reservoir and water level elevation and seep discharge data have been compiled by the CRMWA since the late 1960's. A comparison of the historical changes in the level of the reservoir in relation to the changes in the water levels in the monitoring wells and the discharge rate at the principal seep was instructive in determining which specific wells and zones were most readily affected by the reservoir. A series of graphs were constructed to show these relationships. The first three graphs compare the elevation of the reservoir to wells 1A, 2, 3, 4, 5, 5A, 6A, and 7A from which over 170 different measurements were taken, and well 8 from which over 130 measurements were taken (Figures 15, 16, and 17). The fourth graph compared the reservoir to the water levels in DH88-1, DH88-2 and DH88-3, which were drilled in 1988 (Figure 18). Also, the DH88-2 and DH88-3 wells were nested. The DH88-2 well contains piezometers in the Upper Gypsum and another undefined zone, while the DH88-3 well contains

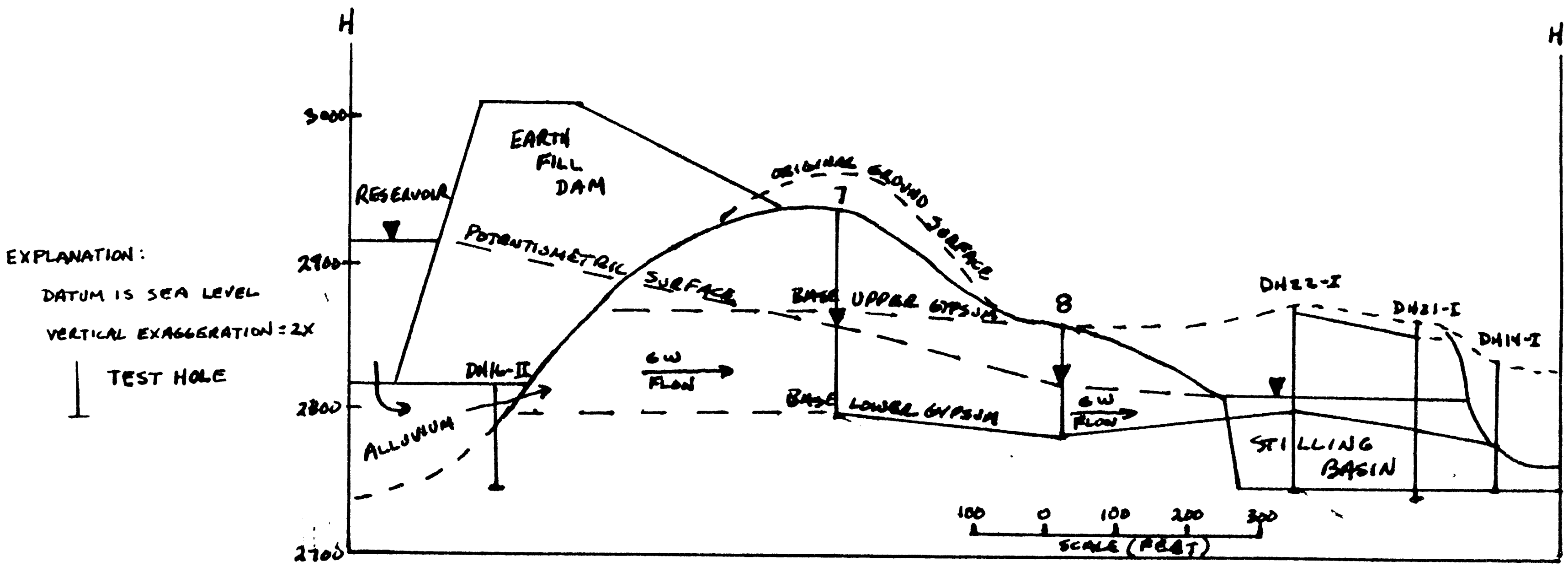


Figure 14. Cross-Section H - H'

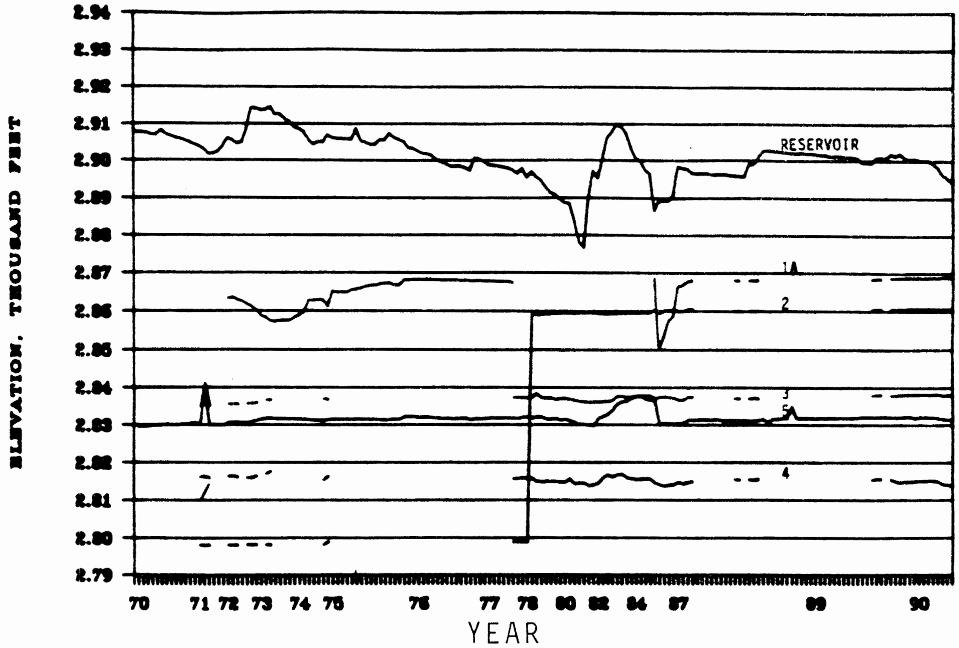


Figure 15. Water Level Elevation Graph of Reservoir v. Wells 1A, 2, 3, 4, and 5

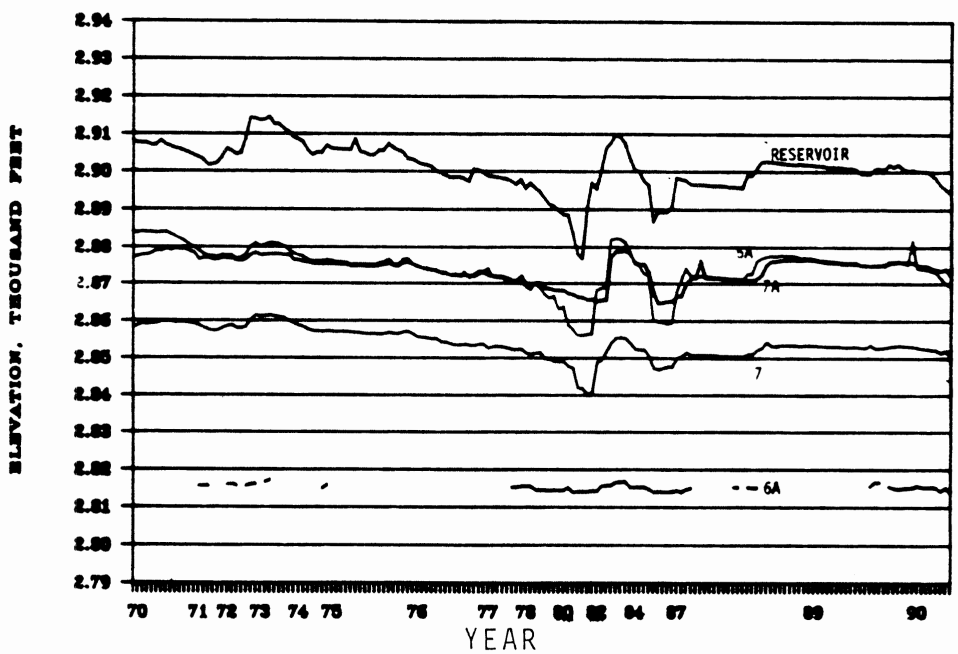


Figure 16. Water Level Elevation Graph of Reservoir v. Wells 5A, 6A, 7, and 7A

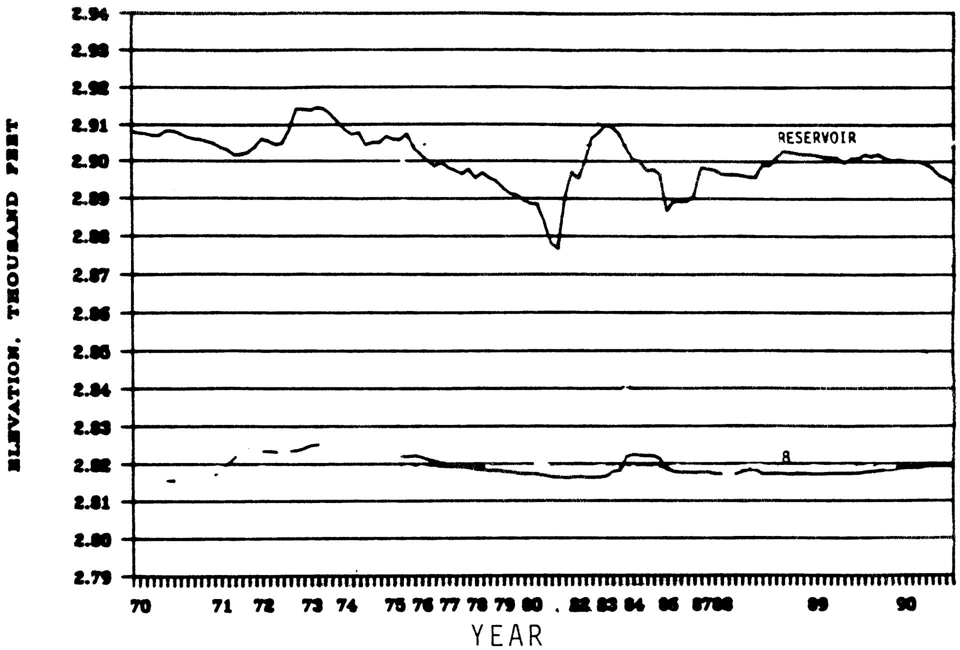


Figure 17. Water Level Elevation Graph of Reservoir v. Well 8

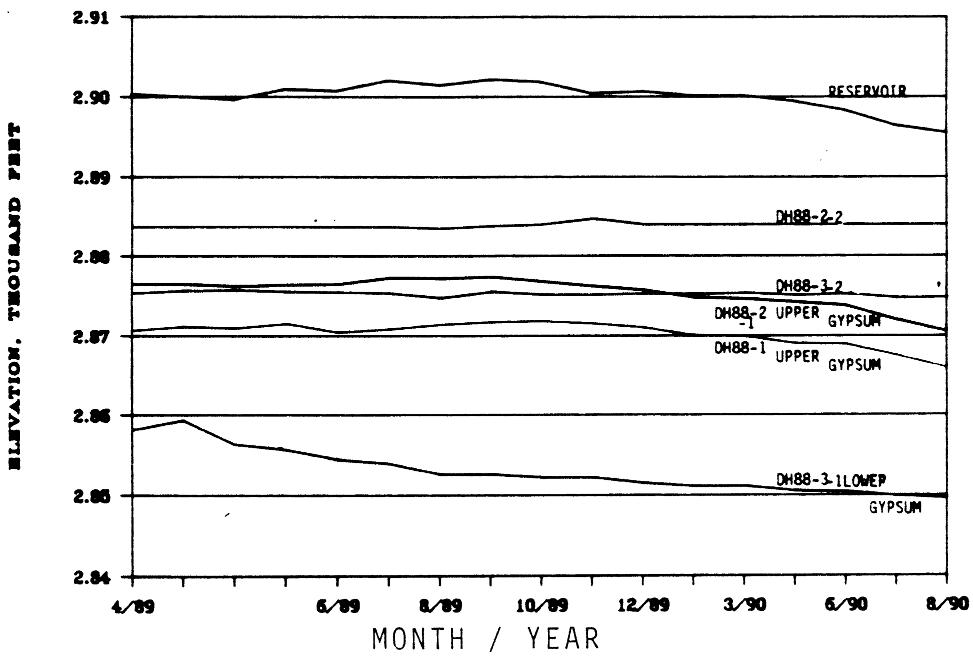


Figure 18. Water Level Elevation Graph of Reservoir v. Wells DH88-1, Dh88-2-1, DH88-2-2, DH88-3-1, and DH88-3-2

piezometers in the Lower Gypsum and an undefined zone.

From the graphs, it is clear that Upper Gypsum wells 5A and 7A are directly responsive to the reservoir. The piezometers in DH-88-1 and DH-88-2, which are located in the Upper Gypsum, also are seemingly responsive to the reservoir. It is also apparent that Lower Gypsum wells 5, 7, and 8, which are the closest to the reservoir, are somewhat responsive.

Finally, the graphs of the reservoir level versus the seep discharge rate show a very definite correlation (Figures 19 and 20). The close historical relationship indicates that the reservoir is a source for the seep. Another interesting aspect of the graph is the fact that, when the reservoir level drops below the elevation of the approach channel, discharge from the seeps ceases. This is another indication that the approach channel is the actual source of water that emerges at the seep.

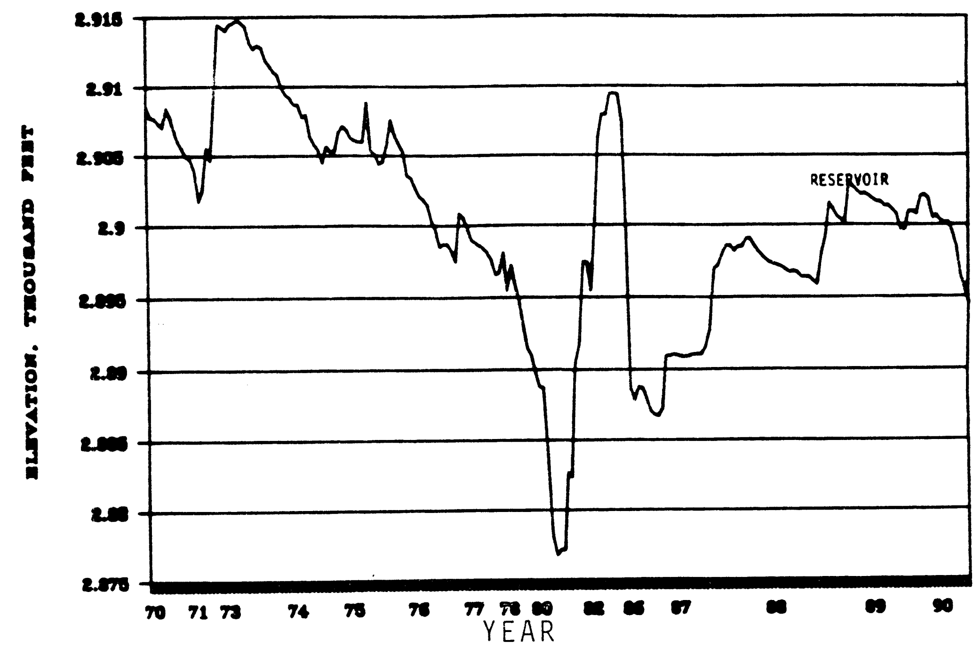


Figure 19. Water Level Elevation Graph of Reservoir

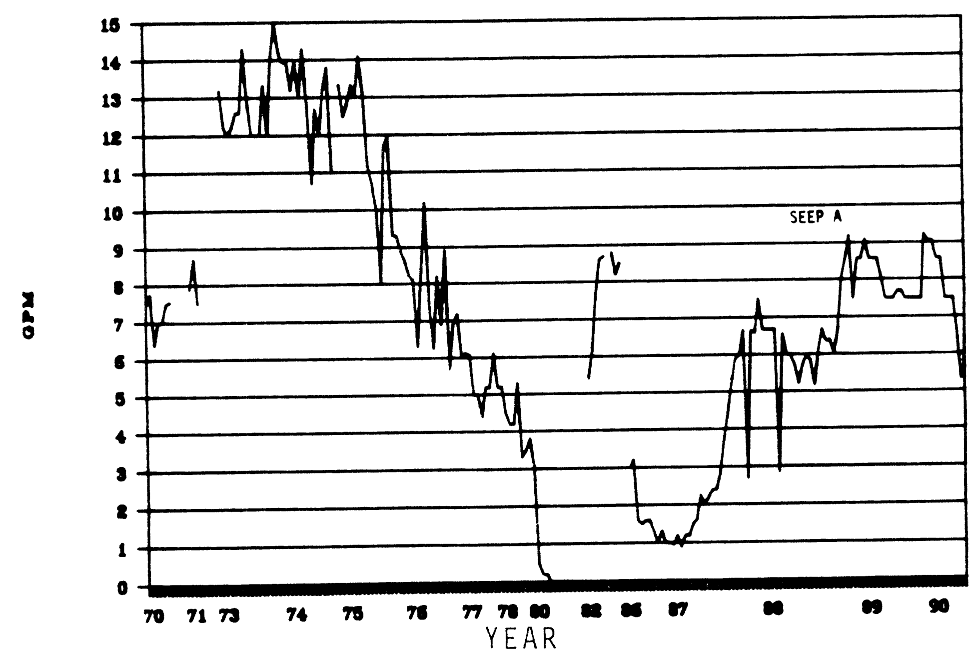


Figure 20. Seep Discharge Rate Graph
(Gallons Per Minute)

CHAPTER IV

WATER CHEMISTRY

This study utilized trilinear (Piper) diagrams, Stiff diagrams, and bar graphs to compare samples that were gathered and analyzed in 1969, 1970, 1986, and 1990. A review of all of the graphs suggests that there are (or were) three distinct waters: 1) naturally occurring ground water in wells which are distant from the reservoir in the Lower Gypsum, 2) reservoir water that began accumulating in the late 1960s on the upstream side of the Dam, and 3) reservoir water that has entirely replaced the ground water in the Upper Gypsum in a localized area around the left abutment of the Dam. This water simply shows the geochemical changes that occurred as a result of its migration from the reservoir through evaporite-rich Permian rocks.

The existing data provided only four sampling points from which the Upper Gypsum interval could be evaluated: reservoir water samples, wells 5A and 7A, and the seep area. However, other water samples from the Lower Gypsum were considered in order to approximate the original ground-water chemistry in the area and to explain the changes that occurred over time.

Trilinear Diagrams

The trilinear diagram is a convenient method for presenting large numbers of chemical analyses. It also is an effective method for showing the effects of mixing two waters from different sources. However, in this instance such diagrams were of limited value for mixing because no clear linear relationships could be established for any one sampling event. In fact, one of the most important contributions of the trilinear analyses was to suggest that mixing was not the predominant force. On the other hand, the trilinear diagrams did provide evidence indicating that reservoir water has replaced, not mixed with, the ground water in the area of the left abutment and, in the process, dissolved and removed SO_4.

Three separate trilinear diagrams were prepared for analyses of samples taken in 1969, 1970, and 1986 (Figures 21a, 21b, and 21c, respectively). It should be noted that certain surface waters were also sampled during the 1970 sampling event but were not included because they were not sampled in either of the other two events. Also, the seep sample included in the 1986 data was actually taken in 1990. These diagrams show that in 1969, all of the ground water was relatively rich in $CaSO_4$. The anomalous position of well 8 can be explained by its relatively high Cl concentration as opposed to the other samples (See Figure 21a).

The 1970 analyses were the first to sample the

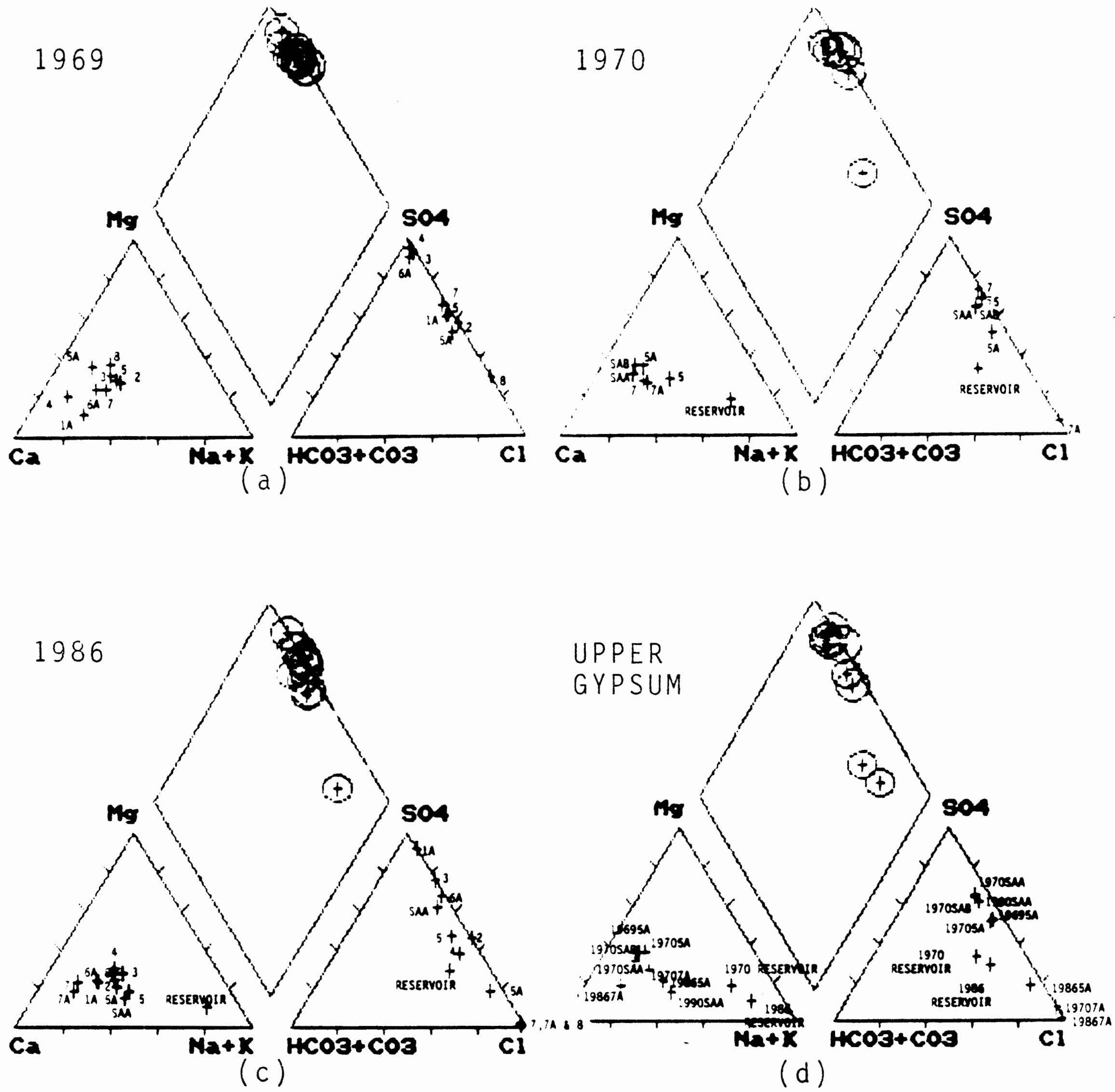


Figure 21. Trilinear Diagrams

reservoir water. The reservoir sample was taken at the intake structure and is definitely different from the ground water sampled in 1969 and 1970. The reservoir water plots in the NaCl rich area on the diagram. The 1970 samples also cause well 7A to plot close to the Cl endmember. An examination of the data indicates that this occurrence also is the result of relatively high Cl concentration.

The 1986 diagram was most instructive of all (Figure 21c). Wells 5A and 7 joined wells 7A and 8 at the Cl endmember. At first glance, it seems that this is the result of Cl enrichment, however, the following review suggests that it was more likely the result of SO_4 removal.

The Upper Gypsum analyses can be separated into three different groups: 1) the seep samples, which are high in SO_4 and did not change to any significant extent over time, 2) the reservoir water, which became more NaCl rich over time, and 3) wells 5A and 7A, which show a SO_4 decrease over time (Figure 21d). Also there is an indication of decreasing SO_4 concentration in most of the Lower Gypsum wells, especially those which are in close proximity to the reservoir. However, the trilinear diagrams pointed out one troubling aspect: the wells subject to SO_4 removal did not appear to be decreasing in relative concentrations of Ca. Assuming that the Upper Gypsum was rich in $CaSO_4$ (the original reports indicated gypsum in the fractures in such zones), an opposite result would have been expected.

Considering the above, a reasonable conclusion was that over a 16-year period the relatively fresh reservoir water had flushed the Upper Gypsum and the soluble gypsum contained therein and was beginning to have an effect on the Lower Gypsum. This is consistent with the hydrogeological conclusions described earlier. However, the above-noted Ca problem remained to be explained. Therefore, the following additional visual methods also were utilized.

Stiff Diagrams

Stiff diagrams are comprised of three parallel axes extending on each side of a vertical zero axis, with cations on the left and anions on the right. These diagrams provide a quick visual comparison of individual chemical analyses and are an especially useful tool when a small number of samples are at issue.

Analyzing the historical data using the Stiff method yielded some interesting results. The Stiff diagrams confirmed that the samples from the seeps and the reservoir were consistent and did not change significantly from 1970 to the most recent sampling event in 1990. They also confirm the trilinear suggestion of a localized ground-water system that, over a 16-year period, became increasingly subject to invasion from waters from the reservoir (Figures 22a, b, c, and d). The Upper Gypsum samples (Figures 22e and f) show a situation in which the wells on the south (wells 7 and 7A) and north (wells 5 and 5A) sides of the flood control outlet works and spillway are slightly different (wells 7 and 7A have higher chloride concentrations), while wells 1A, 2, and 3 are not associated and arguably are indicative of the

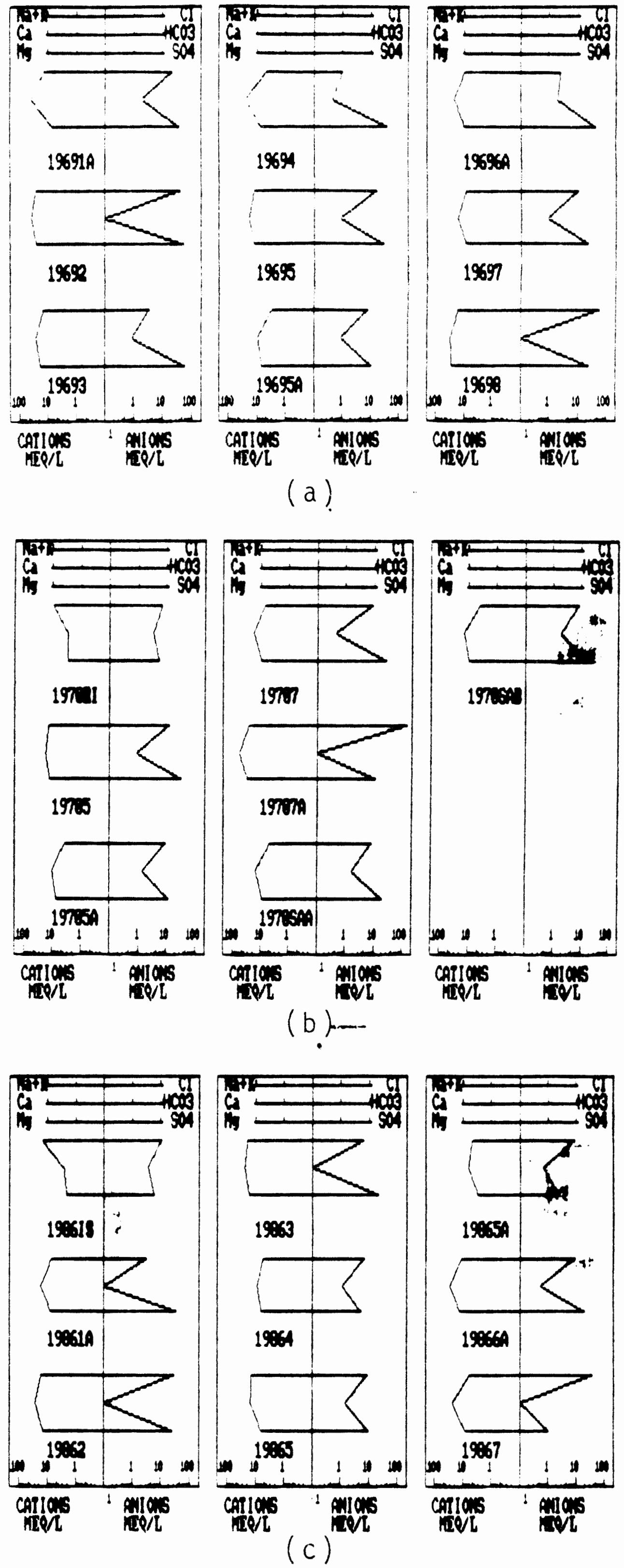


Figure 22. Stiff Diagrams

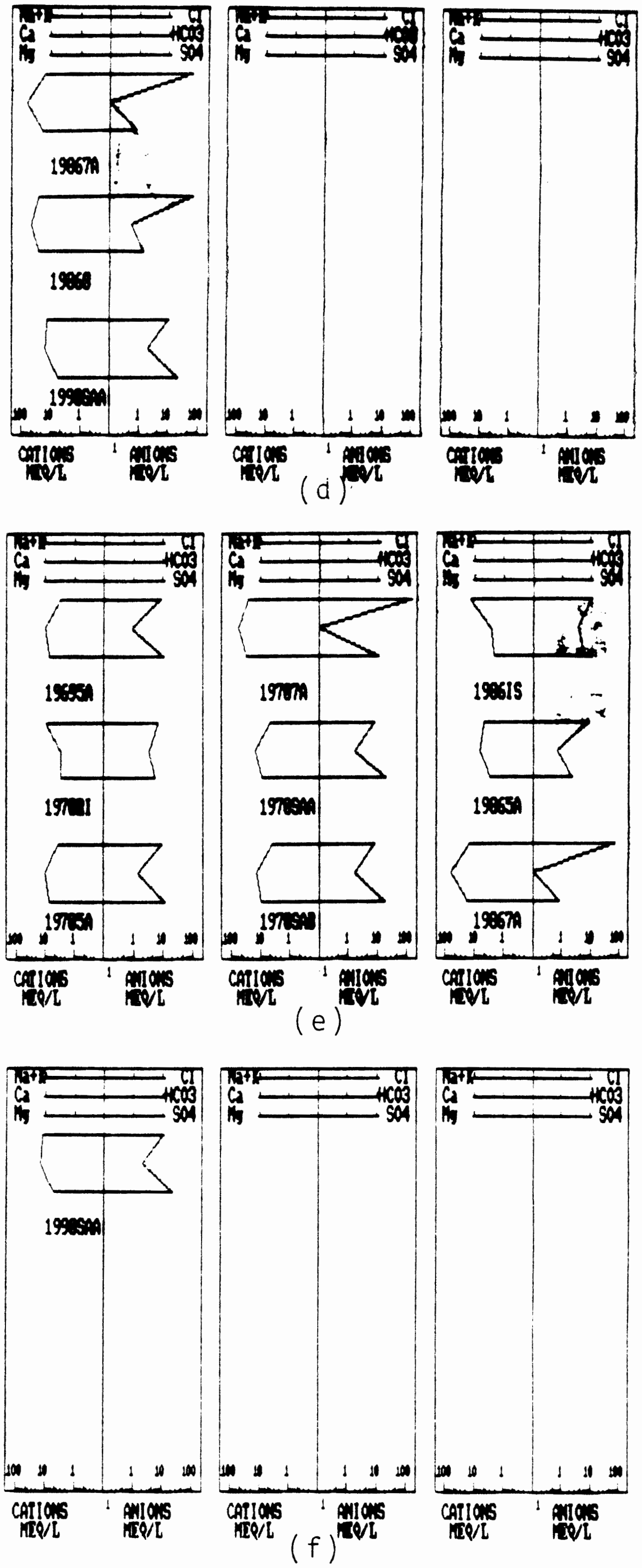


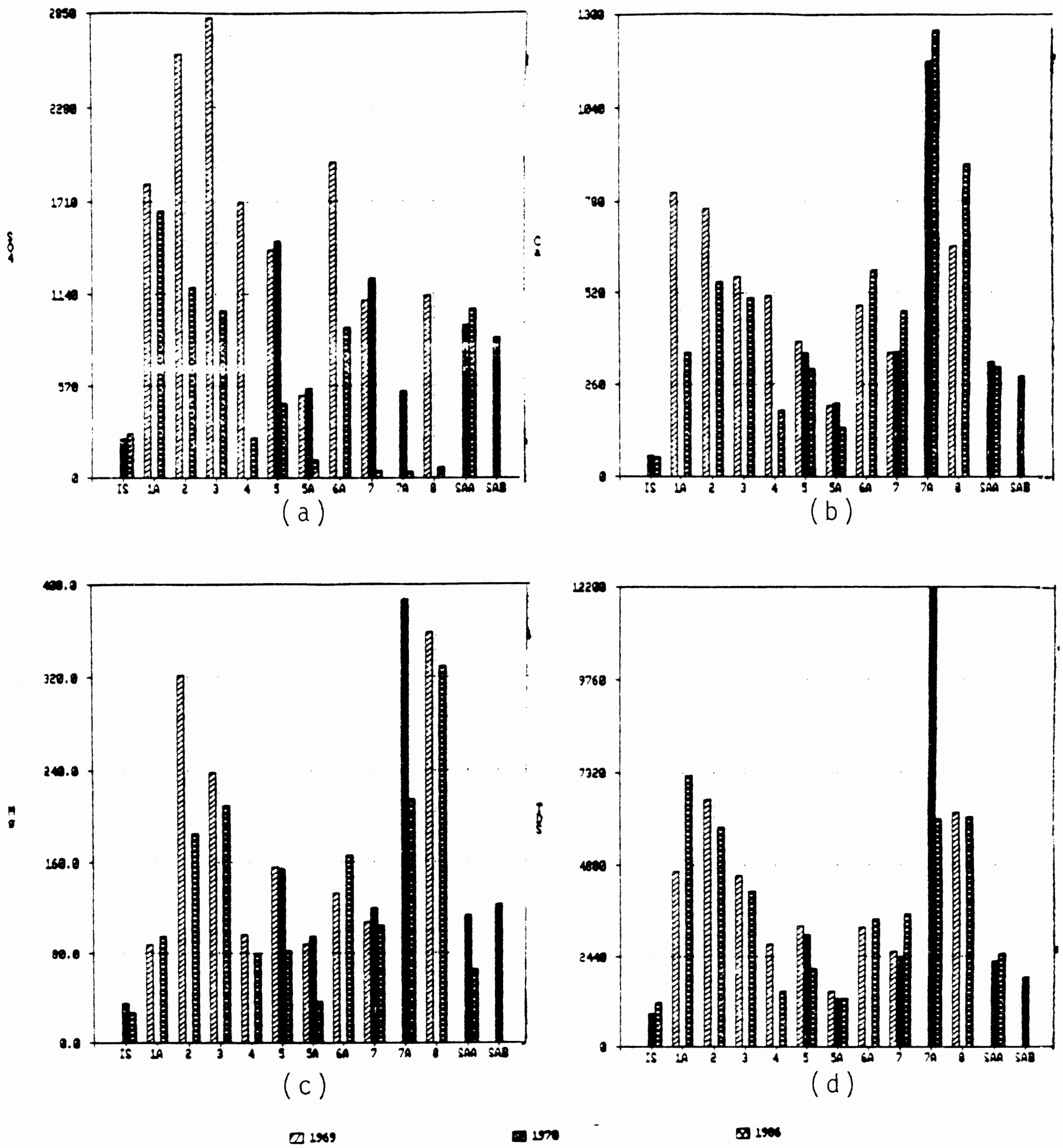
Figure 22 (cont.). Stiff Diagrams

natural ground water of the area (Figure 22a). Finally, the Stiff diagrams confirm the fact that there were drastic reductions in SO_4 concentrations in wells 4, 5, 5A, 7, 7A, and 8 in the 1986 samples. As indicated above, this reduction of SO_4 concentration seemingly provides the key element in this analysis. However, this method provided no visual clue as to the lack of movement of the Ca cation point on the trilinear diagrams.

Bar Graphs

Overall, the bar graphs show a general decrease in both SO_4 and TDS concentrations in all of the wells from 1969-1970 to 1986. Conversely, there was a slight increase in SO_4 and TDS concentrations in the reservoir water and seep sample over essentially this same period. However, the most notable result was the almost total removal of $S0_4$ from wells 5A, 7, 7A, and 8, and a major reduction in wells 4 and 5 (Figure 23a). These results again confirm the trilinear and Stiff diagram analyses.

The bar graph did visualize one important aspect that the trilinear and Stiff methods did not. From 1969-1970 to 1986, both Ca and Mg decreased in concentration (Figures 23b and 23c). This explains why the trilinear and Stiff methods did not provide a visual explanation. In other words, the point on the trilinear diagrams and the relative slope of the line connecting the points on the Stiff diagrams would remain almost the same or, in some instances, increase toward Ca if more Mg were being removed. Also, an analysis



mg/l

Figure 23. Bar Graphs

of a sample of the precipitate at the seep showed significant concentrations of Mg (as well as Ca and SO_4). The following is an attempt to analyze the relationship along the postulated flowpath from the reservoir to the seeps in order to clarify the results of the visual methods outlined above.

Relationship Between Ca and Mg

Table I shows the change in concentration of Ca and Mg that occurs between the reservoir and well 5A in 1970 and 1986. It indicates that in 1970 both Ca and Mg are being dissolved and added along the flowpath. By 1986, Ca is the only ion being added in significant amounts, while the contribution of Mg has been drastically reduced.

TABLE I

CHANGE IN CONCENTRATION ALONG FLOWPATH

(mmole/l)	1970 Reservoir → 5A	1986 Reservoir → 5A
Ca	5.1461 - 1.4433 = 3.7028	3.3954 - 1.3723 = 2.0231
Mg	3.8877 - 1.4491 = 2.4386	1.5229 - 1.1106 = 0.4123
	1970 5A → Seep	1986 5A → Seep
Ca	8.0483 - 5.1461 = 2.9022	7.6877 - 3.3954 = 4.2923
Mg	4.6562 - 3.8877 = 0.7685	2.6790 - 1,5229 = 1.1561

Table I also shows a continued increase in Ca and Mg concentration from 1970 to 1990 along the flowpath from 5A to the seep. This can possibly be explained by the resolution of the precipitate in the area of the seep. However, the primary result of this analysis was to confirm that Mg, as well as Ca, was being dissolved along the flowpath.

Finally, the change in concentration over time from wells 5A and 7A were examined in Table II. Although the concentrations in well 7A are much higher than those in well 5A, the decrease in Mg, in milliequivalents per liter, in each well is very similar.

TABLE II

ANALYSIS OF CA AND MG
FROM UPPER GYPSUM

	1970		1986	
(Meq/l)	**Well 5A**			
Ca	10.2922	47.3%	6.7908	46.5%
Mg	7.7752	35.7%	3.0457	20.8%
	Well 7A			
Ca	58.5351	49.6%	62.7067	65.7%
Mg	31.1852	27.0%	17.6698	18.5%

One possible source of Mg is the dolomite that is prevalent in the area. The process of dedolomitization could explain the fact that the percentage in milliequivalents per liter of Mg in the system has decreased gradually over time, while the percentage of Ca has increased or remained essentially constant (See Hem, 1989).

CHAPTER IV

CONCLUSION

The question surrounding the origin of water emerging at the seeps at the base of the abutment of the Dam was evaluated by using both hydrogeological and hydrochemical analyses. The geological methods showed that the approach channel to the flood control outlet works is connected to the seep area through the Upper Gypsum. The chemical analyses showed that the movement of the reservoir water in the Upper and Lower Gypsum has most likely resulted in the continued removal of SO_4 from these zones.

From this information, it was concluded that the Upper Gypsum in the area of the seeps is a structurally low zone that is water bearing. The excavation intersected this zone in both the seep area and the upgradient approach channel. Therefore, the excavation not only created the seeps, it provided the source.

A solution to this problem would seemingly be accomplished by lining the approach channel with an impermeable liner. However, more data should be collected from the area at the entrance to the approach channel in order to prove that the Upper Gypsum is only in contact with the approach channel, and not the reservoir itself.

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APPENDICES

APPENDIX A

GEOLOGICAL AND WELL COMPLETION DATA

GEOLOGICAL AND WELL COMPLETION DATA (Feet Above Sea Level)

WELL	ELEVATION	ALIBATES DOLOMITE Top	ALIBATES DOLOMITE Base	UPPER GYPSUM BASE	LOWER GYPSUM BASE	T.D.	SCREENED INTERVAL Top	SCREENED INTERVAL Base	GRAVEL PACK Top	GRAVEL PACK Base	BENTONITE Top	BENTONITE Base
1A	2999.8	2964.8	2953.8	2883.8	2813.8	2809.8	2830.8	2810.8	2830.8	2810.8	2832.8	2830.8
2	2961.2	2958.5	2944.4	2874.7	2802.2	2798.2	2818.5	2798.5	2826.2	2798.5	2830.2	2826.2
3	2993.8	2980.3	2963.8	2896.6	2829.0	2823.8	2844.8	2824.8	2848.8	2824.8	2850.8	2848.8
4	2855.5	NP	NP	NP	2809.5	2804.3	2804.5	OH	2825.5	2804.5	2827.5	2825.5
5	2957.1	2912.9	2895.6	2824.1	2754.1	2732.1	2763.1	2742.1	2767.1	2732.1	2772.1	2767.1
5A	2961.3	2926.8	2910.3	2835.3	NDE	2831.3	2856.3	2836.3	2865.3	2831.3	2868.3	2865.3
6A	2871.7	NP	NP	NP	2800.8	2795.7	2817.7	2795.7	2817.7	2795.7	2818.7	2817.7
7	2937.1	NP	NP	2866.1	2797.1	2794.1	2816.1	2796.1	2815.1	2795.1	2817.1	2815.1
7A	2938.0	NP	NP	2865.5	NDE	2860.5	2883.0	2860.5	2883.0	2860.5	2885.0	2883.0
8	2857.5	NP	NP	NP	2781.5	2781.5	2821.5	2801.5	2823.5	2781.5	2824.5	2823.5
88-1	2932.6	NP	2927.6	2859.6	2794.0	2759.3	2853.6	2851.6	2857.6	2837.6	2832.6	2759.6
											2837.6	2832.6
88-2	2963.0	2928.5	2907.5	2832.0	NDE	2807.8	2886.0	2884.0	2898.0	2871.0	2908.0	2898.0
							2837.0	2835.0	2843.0	2831.0	2871.0	2843.0
											2831.0	2810.1
88-3	2973.6	2950.6	2932.6	2872.6	NDE	2803.6	2875.6	2873.6	2885.6	2863.6	2923.6	2885.6
							2835.6	2833.6	2843.6	2829.6	2863.6	2843.6
											2829.6	2809.6
D-DH1-I	2988.8	2986.9	2970.0	2906.1	2836.6	2753.9						
DH13-I	2954.0	2953.0	2937.0	NDE	NDE	2909.0						
DH14-I	2834.0	NP	NP	NP	?	2746.0						
DH15-I	2839.7	NP	NP	NP	2784.7	2749.7						
DH16-I	2821.0	NP	NP	NP	?	2745.0						
DH16-II	2815.9	NP	NP	NP	NP	2765.5						
DH18-I	2849.1	NP	NP	NP	2783.9	2744.1						
DH19-I	2831.5	NP	NP	NP	?	2750.0						
DH20-I	2835.8	NP	NP	NP	2781.8	2749.8						
DH20-IA	2835.8	NP	NP	NP	2779.6	2748.7						

GEOLOGICAL AND WELL COMPLETION DATA (Feet Above Sea Level)

WELL	ELEVATION	ALIBATES DOLOMITE Top	ALIBATES DOLOMITE Base	UPPER GYPSUM BASE	LOWER GYPSUM BASE	T.D.	SCREENED INTERVAL Top	SCREENED INTERVAL Base	GRAVEL PACK Top	GRAVEL PACK Base	BENTONITE Top	BENTONITE Base
DH21-I	2861.4	NP	NP	2853.4	2786.4	2739.8						
DH22-I	2872.5	NP	NP	2869.5	2801.7	2745.2						
DH23-I	2956.4	2942.0	2924.4	2856.4	NDE	2854.4						
DH24-I	2983.2	2976.7	2958.4	2890.7	NDE	2878.2						
DH25-I	2986.7	2973.0	2967.7	2889.2	NDE	2876.8						
DH26-I	2976.0	2947.5	2928.5	2864.0	NDE	2861.0						
DH27-I	2972.0	2946.0	2931.0	NDE	NDE	2878.0						
DH28-I	2965.9	2932.9	2914.5	NDE	NDE	2876.8						
DH29-I	2971.1	2946.8	2932.6	NDE	NDE	2877.0						
D-DH42-I	2916.0	NP	NP	2860.1	2812.1	2809.9						
D-DH43-I	2820.6	NP	NP	?	?	2722.5						
DH44-I	2959.8	2934.5	2918.1	2842.6	NDE	2809.8						
DH45-I	2950.6	2944.6	2930.4	2862.6	NDE	2800.6						
DH46-I	2945.8	2940.3	2927.3	2858.3	NDE	2795.8						
DH47-I	2983.0	2953.0	2938.0	2874.0	NDE	2833.0						
DH48-I	2963.5	2940.0	2924.0	2858.5	NDE	2813.5						
DH49-I	2953.9	2915.4	2898.4	2823.9	NDE	2803.9						
DH50-I	2858.2	NP	NP	NP	2790.2	2708.2						
DH51-I	2986.7		Possible Sinkhole (Chimney)			2836.7						
DH52-I	2903.0	?	?	?	?	2753.0						
DH53-I	2959.6	NP	NP	2906.6	2835.6	2809.6						
DH54-I	2978.3	2978.3	2960.8	2890.8	NDE	2866.7						
DH54-IA		?	?	?	?	?						
DH55-I	2976.4	2952.4	2936.4	2867.9	NDE	2857.4						
DH55-IA	2976.3	2951.4	2936.4	2865.4	NDE	2856.4						
DH56-I	2934.2	NP	NP	2860.2	2796.2	2710.2						
DH56-IA	2934.2	?	?	?	?	?						
DH57-I	2917.5	NP	NP	2855.4	2787.9	2717.5						
DH57-IA	2917.5	?	?	?	?	2717.5						

APPENDIX B

WATER LEVEL ELEVATIONS (RESERVOIR AND WELLS 1A, 2, 3, 4, 5, 5A, 6A, 7 AND 7A)

WATER LEVEL ELEVATIONS

(Feet Above Sea Level)

DATE	RESERVOIR	1A	2	3	4	5	5A	6A	7	7A
11/20/69	2908.5						2884.0		2857.9	2876.9
01/08/70	2907.8	2809.8	2798.3	2833.5	2816.2	2829.6	2883.8	2815.5	2858.7	2877.4
01/28/70	2907.7					2829.9	2884.1		2859.2	2877.8
02/12/70	2907.6					2829.8	2883.9		2859.0	2877.8
03/17/70	2907.1	2809.7	2798.3	2833.5	2816.6	2830.0	2884.0	2815.9	2859.3	2878.3
04/15/70	2907.1					2830.1	2883.6		2859.3	2879.1
05/12/70	2908.5	2809.9	2798.3	2834.1	2816.8	2830.1	2883.9	2816.2	2859.8	2878.9
06/23/70	2907.3					2830.2	2884.0		2859.8	2879.5
07/09/70	2906.8	2809.8	2798.3	2834.4	2816.1	2830.1	2883.4	2815.6	2859.7	2879.1
08/12/70	2906.3					2830.1	2882.8		2859.4	2879.6
09/15/70	2906.0	2809.9	2798.3	2834.4	2816.4	2830.3	2882.1	2815.9	2859.6	2879.3
10/20/70	2905.5					2830.4	2881.5		2859.4	2879.3
11/19/70	2905.0	2809.8	2798.3	2834.9	2816.5	2830.5	2880.6	2815.9	2859.3	2878.7
12/17/70	2904.4					2830.7	2879.9		2859.0	2878.3
01/18/71	2903.9	2809.8	2798.3	2834.8	2816.2	2830.3	2879.1	2815.7	2858.7	2876.5
03/11/71	2903.3	2811.7	2798.1	2841.0	2816.2	2839.4	2878.1	2815.8	2858.0	2876.9
05/10/71	2901.8	2814.2	2798.2	2835.0	2815.9	2830.1	2877.5	2815.7	2857.5	2876.9
06/22/71	2902.0					2830.2	2877.4		2857.1	2876.4
07/29/71	2902.6	2816.2	2798.2	2834.9	2815.4	2830.1	2877.1	2815.2	2857.3	2876.5
09/03/71	2904.1					2830.2	2877.8		2858.0	2877.0
02/01/72	2906.3	2863.2	2798.2	2835.5	2816.4	2830.8	2877.6	2816.1	2858.5	2876.7
03/12/72	2905.6	2863.6	2798.2	2835.5	2816.4	2830.8	2877.6	2816.2	2858.8	2876.6
05/18/72	2904.7	2862.8	2798.2	2835.5	2816.1	2830.8	2876.6	2815.8	2857.9	2876.1
07/13/72	2905.1	2862.4				2830.7	2877.0		2857.8	2876.1
08/09/72	2909.0	2861.7	2798.3	2835.7	2815.9	2830.7	2878.1	2815.7	2858.4	2876.6
09/19/72	2914.5	2861.1	2798.3	2835.7	2815.9	2831.0	2880.1	2816.2	2860.2	2877.8
11/21/72	2914.3	2860.3	2798.3	2835.9	2816.5	2831.5	2881.1	2816.3	2861.5	2878.4
02/15/73	2913.8	2858.7				2831.7	2880.2		2861.1	2877.6
03/14/73	2914.0	2858.3	2798.3	2836.6	2817.0	2831.9	2880.6	2816.8	2861.3	2877.8
05/07/73	2914.8	2857.3	2798.3	2836.6	2817.6	2831.9	2881.1	2817.3	2861.5	2878.0
07/16/73	2912.7	2857.2				2831.7	2880.9		2861.1	2878.0
08/17/73	2912.8	2857.5				2831.8	2880.8		2860.9	2878.0
09/17/73	2911.5	2857.5				2831.7	2880.2		2860.7	2877.6
11/06/73	2910.8	2857.5	2798.3	2836.5	2816.1	2831.7	2879.2	2817.4	2859.8	2877.9
12/14/73	2909.2	2858.3				2831.7	2878.3		2859.3	2876.3
01/16/74	2908.7	2858.9				2831.6	2877.7		2858.6	2876.2
05/01/74	2908.0	2859.8	2798.2	2836.7	2816.1	2831.6	2877.3	2816.0	2858.3	2875.8
06/19/74	2905.8	2862.7				2831.5	2876.5		2857.5	2875.6
07/17/74	2904.5	2862.6				2831.3	2876.0		2857.1	2875.3
09/16/74	2905.3	2862.8				2831.4	2876.1		2857.1	2875.3
09/20/74	2905.1	2862.7	2798.3	2836.9	2815.3	2831.3	2876.1	2815.0	2856.9	2875.2

WATER LEVEL ELEVATIONS

(Feet Above Sea Level)

DATE	RESERVOIR	1A	2	3	4	5	5A	6A	7	7A
11/07/74	2907.2	2861.1	2799.0	2836.7	2816.3	2831.6	2876.4	2816.0	2857.2	2875.3
01/02/75	2906.3	2865.1				2831.6	2876.1		2857.0	2875.3
01/15/75	2906.1	2864.8				2831.6	2875.8		2856.9	2875.1
02/03/75	2906.0	2864.8				2831.6	2875.8		2857.0	2875.1
03/03/75	2906.0	2864.8				2831.6	2875.7		2856.9	2875.0
03/07/75	2905.9	2865.5	2799.0	2837.0	2816.2	2831.6	2875.2	2815.9	2856.7	2874.6
03/18/75	2908.9	2865.7				2831.7	2875.3		2856.7	2874.7
04/16/75	2905.4	2865.9				2831.6	2875.3		2856.6	2874.7
05/01/75	2905.1	2866.4				2831.6	2875.2		2856.4	2874.6
05/21/75	2904.4	2866.7				2831.6	2875.2		2856.4	2874.6
06/18/75	2904.6	2866.7				2831.6	2875.2		2856.4	2874.7
07/01/75	2905.9	2867.1				2831.5	2875.6		2856.2	2874.9
07/17/75	2905.8	2867.2				2831.5	2875.9		2856.4	2875.1
08/07/75	2907.6	2867.3	2799.0	2837.0	2816.2	2831.6	2876.6	2816.4	2856.8	2875.4
09/04/75	2906.5	2866.7				2831.6	2875.2		2856.4	2874.7
09/19/75	2905.8	2866.7				2831.6	2875.2		2856.4	2874.7
10/03/75	2905.3	2868.1				2832.3	2876.6		2857.0	2875.7
11/26/75	2903.6	2868.1	2799.0	2837.0	2816.6	2832.3	2876.7	2816.4	2857.0	2875.7
12/05/75	2903.4	2868.2				2832.3	2875.3		2856.3	2875.0
01/14/76	2902.7	2868.2				2832.0	2874.4		2855.5	2874.6
02/20/76	2902.1	2868.2				2832.1	2874.2		2855.4	2874.0
03/01/76	2901.9	2868.2	2799.0	2837.5	2815.8	2832.1	2874.1	2815.7	2855.2	2873.8
03/18/76	2901.5	2868.2				2832.0	2873.7		2855.0	2873.5
05/14/76	2900.3	2868.1	2799.0	2837.4	2815.8	2831.9	2873.3	2815.7	2855.1	2873.5
06/17/76	2899.7	2868.0				2831.8	2873.0		2854.1	2872.7
06/30/76	2899.2	2868.0				2831.8	2872.9		2854.1	2872.6
07/20/76	2898.5	2868.0				2831.6	2872.2		2853.7	2872.1
08/09/76	2898.7	2868.0				2831.8	2872.1		2853.4	2872.4
08/11/76	2898.7	2867.9	2799.0	2837.3	2815.3	2831.8	2872.1	2815.3	2853.4	2871.9
08/19/76	2898.2	2868.0				2831.8	2873.1		2853.6	2872.3
09/03/76	2897.5	2867.8				2831.5	2871.5		2853.3	2871.9
10/01/76	2900.9	2867.9				2831.8	2872.5		2853.3	2871.9
10/14/76	2900.6	2867.9				2831.7	2873.4		2853.6	2872.6
11/18/76	2899.9	2867.8	2799.0	2837.3	2815.6	2831.7	2873.1	2815.5	2853.6	2873.0
01/14/77	2899.0	2867.8				2832.0	2874.1		2852.5	2872.1
02/04/77	2898.8	2867.7				2831.9	2871.7		2853.0	2871.9
02/24/77	2898.6	2867.6				2831.9	2871.5		2853.0	2871.7
03/03/77	2898.4	2867.7	2799.0	2837.6	2815.7	2832.0	2871.5	2815.5	2852.9	2871.7
03/16/77	2898.1	2867.6				2831.9	2870.5		2852.6	2871.3
05/10/77	2897.6	2867.4	2799.0	2837.3	2815.6	2831.9	2870.4	2815.4	2852.2	2870.7
08/18/77	2896.7		2799.0	2837.3	2815.6	2831.8	2870.3	2815.4	2852.2	2870.6

WATER LEVEL ELEVATIONS

(Feet Above Sea Level)

DATE	RESERVOIR	1A	2	3	4	5	5A	6A	7	7A
11/18/77	2898.1		2799.0	2837.2	2815.9	2832.2	2870.6	2815.7	2852.4	2872.1
03/29/78	2895.6		2799.0	2837.2	2815.7	2832.1	2869.2	2815.6	2851.2	2869.7
07/26/78	2897.2		2859.2	2837.3	2815.7	2832.0	2868.3	2815.7	2850.9	2868.9
03/30/78	2895.8		2859.2	2838.4	2814.9	2832.2	2870.3	2814.6	2851.3	2870.1
12/21/78	2894.8		2859.3	2837.2	2814.8	2832.2	2868.8	2814.6	2851.4	2870.1
03/28/79	2893.1		2859.4	2837.1	2814.9	2831.6	2867.1	2814.5	2849.7	2868.6
05/29/79	2891.5		2859.4	2837.2	2814.9	2831.7	2866.0	2814.4	2849.6	2868.6
08/14/79	2891.0		2859.6	2836.7	2814.9	2831.9	2866.6	2814.6	2849.0	2868.1
11/28/79	2889.8		2859.6	2837.0	2814.7	2831.4	2863.1	2814.5	2848.9	2868.0
04/07/80	2888.8		2859.7	2837.0	2814.7	2831.6	2863.7	2814.5	2849.0	2868.1
05/23/80	2888.7		2859.6	2836.8	2815.6	2831.2	2858.9	2815.4	2847.6	2867.2
09/22/80	2883.9		2859.5	2836.4	2814.2	2830.8	2857.7	2813.9	2847.3	2866.9
03/06/00	2878.3		2859.7	2836.2	2814.4	2830.3	2856.1	2814.2	2841.9	2866.3
05/15/81	2876.8		2859.7	2836.1	2814.4	2830.2	2856.0	2814.2	2841.7	2866.2
08/18/81	2890.4		2859.6	2835.9	2813.7	2830.0	2856.3	2814.2	2840.3	2865.5
11/18/81	2897.4		2859.6	2836.0	2814.0	2829.9	2856.5	2814.4	2840.5	2865.8
03/08/82	2895.5		2859.5	2836.0	2814.4	2831.9	2868.3	2814.3	2848.7	2865.2
07/28/82	2900.4		2859.4	2836.2	2815.9	2832.4	2868.8	2815.7	2849.5	2865.5
08/30/82	2906.4		2859.4	2836.2	2816.7	2833.0	2869.1	2815.9	2851.7	2865.7
11/16/82	2908.0		2859.4	2836.5	2816.0	2834.1	2881.9	2815.9	2854.0	2877.2
03/28/83	2910.0		2859.6	2837.6	2816.7	2835.7	2882.4	2816.7	2855.3	2878.7
05/20/83	2909.5		2859.6	2837.6	2816.9	2836.3	2882.1	2816.8	2855.5	2878.7
08/04/83	2907.6		2859.6	2837.3	2815.9	2836.5	2881.2	2816.9	2855.1	2879.0
11/08/83	2903.8		2859.6	2837.4	2815.5	2837.4	2878.6	2815.4	2854.0	2877.8
03/20/84	2900.7		2859.6	2837.7	2815.4	2837.7	2875.4	2815.3	2852.4	2875.6
05/04/84	2900.1		2859.7	2837.7	2815.5	2837.8	2874.9	2815.4	2852.1	2875.1
08/22/84	2897.7		2859.7	2837.7	2815.5	2836.9	2872.6	2815.4	2852.2	2875.3
11/06/84	2896.6		2859.7	2837.7	2815.5	2836.8	2872.4	2814.9	2850.4	2872.8
08/06/86	2886.9	2868.5	2860.5	2836.9	2814.4	2836.5	2860.2	2814.0	2847.2	2867.7
09/11/86	2889.5	2850.0	2859.6	2837.4	2813.9	2830.4	2859.7	2814.2	2846.9	2864.6
09/25/86	2889.5	2853.2	2860.3	2837.5	2813.6	2830.5	2859.5	2814.1	2847.3	2864.9
10/25/86	2889.6	2857.4	2860.3	2837.2	2813.9	2830.4	2859.2	2814.1	2847.6	2865.2
11/14/86	2891.0	2858.8	2860.4	2837.1	2814.0	2830.4	2859.5	2814.2	2847.6	2865.3
07/02/87	2898.6	2866.4	2860.0	2836.6	2814.7	2830.5	2867.7	2814.5	2850.0	2866.5
08/04/87	2898.1	2866.8	2860.0	2836.5	2814.2	2830.6	2871.0	2814.0	2850.5	2866.7
11/17/87	2897.9	2867.8	2860.5	2837.4	2814.6	2831.5	2874.2	2814.9	2851.4	2870.0
02/24/88	2896.8	2868.0	2860.5	2837.4	2814.9	2831.5	2872.0	2815.2	2850.7	2871.4
02/29/88	2896.7					2831.5	2871.9		2850.7	2871.4
03/08/88	2896.8	2868.1	2860.4	2837.5	2815.0	2831.6	2871.9	2815.3	2850.8	2876.4
03/14/88	2896.7					2831.5	2871.9		2850.7	2871.4
03/28/88	2896.4					2831.5	2871.7		2850.7	2871.4

WATER LEVEL ELEVATIONS
(Feet Above Sea Level)

DATE	RESERVOIR	1A	2	3	4	5	5A	6A	7	7A
04/05/88	2896.4	2868.2	2860.4	2837.5	2815.3	2831.6	2871.6	2815.1	2850.7	2871.3
04/11/88	2896.4					2831.3	2871.5		2850.4	2871.2
04/26/88	2896.4					2831.3	2871.4		2850.4	2871.2
05/10/88	2896.1					2831.3	2871.2		2850.4	2871.0
05/13/88	2896.1	2868.0	2860.0	2837.0	2815.4	2831.3	2871.2	2815.4	2850.4	2871.0
05/18/88	2895.9	2868.0	2860.0	2837.0	2815.4	2831.3	2871.2	2815.4	2850.4	2871.0
05/24/88	2895.9					2831.3	2870.9		2850.4	2871.0
06/22/88	2899.2	2868.0	2860.1	2837.0	2815.4	2831.2	2872.7	2815.4	2851.0	2870.7
07/05/88	2899.2	2868.1	2860.1	2837.2	2815.3	2831.2	2872.7	2815.1	2851.0	2870.8
08/03/88	2901.1	2868.2	2860.1	2837.0	2815.5	2831.5	2876.1	2815.3	2852.2	2871.2
09/21/88	2902.8					2831.7	2876.9		2852.7	2872.4
09/27/88	2903.0	2868.3	2860.2	2837.1	2815.4	2830.8	2877.3	2815.4	2854.3	2875.1
10/10/88	2902.8					2831.8	2877.6		2853.1	2876.0
10/13/88	2902.7	2868.3	2859.9	2836.9	2815.4	2831.7	2877.5	2815.4	2853.1	2876.0
10/24/88	2902.5					2832.0	2877.7		2853.4	2876.4
11/03/88	2902.3	2868.5	2860.2	2838.1	2815.7	2832.0	2877.6	2815.5	2853.4	2876.4
11/07/88	2902.2					2834.9	2877.6		2853.4	2876.4
11/14/88	2902.1	2868.4	2860.1	2837.1	2815.6	2831.9	2877.5	2815.5	2853.4	2876.4
12/05/88	2902.3					2831.9	2877.0		2853.1	2876.3
12/19/88	2902.1					2832.0	2877.0		2853.4	2876.5
12/20/88	2902.1	2868.5	2860.1	2837.2	2815.5	2832.0	2877.0	2815.5	2853.4	2876.5
01/03/89	2901.9					2831.8	2876.7		2853.3	2876.2
01/16/89	2901.7	2868.5	2859.9	2837.1	2815.7	2832.0	2876.4	2815.6	2853.1	2876.0
01/30/89	2901.7					2832.0	2876.3		2853.1	2875.8
02/13/89	2901.4					2832.0	2876.1		2853.0	2875.6
02/14/89	2901.4	2868.5	2860.0	2837.3	2815.7	2832.0	2876.1	2815.7	2853.0	2875.6
02/28/89	2901.4					2832.0	2875.9		2853.1	2875.6
03/09/89	2901.2	2868.5	2860.1	2837.2	2815.7	2832.0	2875.8	2815.6	2852.9	2875.3
03/14/89	2901.1					2832.0	2875.7		2852.9	2875.3
03/16/89	2901.1	2868.5	2860.1	2837.4	2815.8	2832.0	2875.7	2815.7	2852.9	2875.3
03/28/89	2900.8					2832.1	2875.7		2853.0	2875.2
05/08/89	2899.7					2832.2	2875.0		2852.7	2874.9
05/08/89	2899.7					2832.2	2875.0		2852.7	2874.9
05/10/89	2899.7	2868.4	2860.5	2837.9	2815.3	2832.1	2874.9	2815.6	2853.5	2874.8
05/23/89	2901.0	2868.5	2860.5	2838.0	2815.5	2832.2	2875.1	2816.7	2852.6	2874.9
05/23/89	2901.0	2868.5	2860.5	2838.0	2815.5	2832.2	2875.1	2816.7	2852.6	2874.9
06/09/89	2900.8					2832.3	2875.4		2852.8	2874.9
07/07/89	2902.1	2868.7	2860.5	2837.8	2815.4	2832.1	2876.0	2815.5	2853.0	2875.5
08/02/89	2901.5	2868.7	2860.6	2837.9	2814.9	2832.1	2876.0	2815.1	2853.2	2875.7
09/07/89	2902.2	2868.8	2860.6	2838.1	2814.5	2832.2	2876.2	2814.9	2853.4	2875.9
10/25/89	2901.0	2868.8	2860.6	2838.0	2814.8	2832.3	2875.5	2815.1	2853.2	2875.9

WATER LEVEL ELEVATIONS

(Feet Above Sea Level)

DATE	RESERVOIR	1A	2	3	4	5	5A	6A	7	7A
11/08/89	2900.5	2868.8	2860.7	2838.1	2814.9	2832.3	2875.2	2815.2	2853.1	2875.8
12/18/89	2900.7	2868.8	2860.7	2838.1	2814.9	2832.0	2881.7	2815.3	2853.0	2875.6
01/16/90	2900.3	2868.8	2860.7	2838.1	2815.0	2832.2	2874.2	2815.8	2852.7	2874.9
02/06/90	2900.2	2868.8	2860.7	2838.2	2815.0	2832.2	2873.9	2815.4	2852.5	2874.8
03/15/90	2900.2	2868.8	2860.7	2838.1	2815.1	2832.2	2873.8	2815.4	2852.4	2874.8
05/09/90	2899.5	2868.9	2860.7	2838.2	2815.1	2832.1	2873.4	2815.4	2852.2	2874.0
06/06/90	2898.4	2868.8	2860.6	2838.1	2814.9	2832.0	2873.0	2815.2	2852.0	2873.8
07/12/90	2896.5	2868.9	2860.6	2837.9	2814.0	2831.7	2871.4	2814.3	2851.3	2873.4
08/22/90	2895.6	2868.9	2860.7	2838.0	2813.9	2831.6	2869.9	2815.3	2852.1	2873.9
09/13/90	2894.5	2869.0	2860.7	2837.9	2813.6	2831.4	2869.4	2814.0	2850.4	2872.0

APPENDIX C

WATER LEVEL ELEVATIONS

(RESERVOIR AND WELL 8)

WATER LEVEL ELEVATIONS (Feet Above Sea Level)

DATE	RESERVOIR	8
11/20/69	2908.5	
01/08/70	2907.8	2815.2
02/12/70	2907.6	
03/17/70	2907.1	2815.3
04/02/70	2907.1	
05/12/70	2908.5	2815.6
05/12/70	2908.5	2815.6
06/09/70	2907.8	
07/09/70	2906.8	2815.7
08/12/70	2906.3	
09/15/70	2906.0	2816.5
10/20/70	2905.5	
11/19/70	2905.0	2817.2
01/18/71	2903.9	2818.4
03/11/71	2903.3	2820.4
05/10/71	2901.8	2822.2
06/22/71	2902.0	
07/29/71	2902.6	2822.8
09/03/71	2904.1	
02/01/72	2906.3	2823.5
03/12/72	2905.6	2823.5
05/18/72	2904.7	2823.3
07/13/72	2905.1	
08/03/72	2909.0	2823.6
09/19/72	2914.5	2823.9
11/21/72	2914.3	2824.4
03/14/73	2914.0	2825.2
05/07/73	2914.8	2825.3
06/01/73	2914.3	
08/17/73	2912.8	
11/06/73	2910.8	2825.1
01/08/74	2908.7	
04/12/74	2907.4	
05/01/74	2908.0	2824.4
07/17/74	2904.5	
09/16/74	2905.3	
09/20/74	2905.1	2823.2
11/26/74	2906.9	
03/03/75	2906.0	
03/07/75	2905.9	2822.1
08/07/75	2907.6	2822.0
11/26/75	2903.6	2822.4
03/01/76	2901.9	2821.8
05/14/76	2900.3	2821.2
08/11/76	2898.7	2820.7
11/18/76	2899.9	2820.2

DATE	RESERVOIR	8
03/03/77	2898.4	2819.9
05/10/77	2897.6	2819.4
08/18/77	2896.7	2819.3
11/18/77	2898.1	2818.9
03/29/78	2895.6	2818.6
07/26/78	2897.2	2818.4
08/30/78	2895.8	2818.2
12/21/78	2894.8	2818.2
03/28/79	2893.1	2817.9
05/29/79	2891.5	2817.9
08/14/79	2891.0	2817.5
11/27/79	2889.8	2817.3
04/07/80	2888.8	2817.5
05/23/80	2888.7	2817.1
09/22/80	2883.9	2816.9
03/31/81	2878.3	2816.5
05/15/81	2876.8	2816.5
08/18/81	2890.4	2816.2
11/18/81	2897.4	2816.5
03/08/82	2895.5	2816.6
07/28/82	2900.4	2816.3
08/30/82	2906.4	2816.4
11/16/82	2908.0	2816.5
03/28/83	2910.0	2816.7
05/20/83	2909.5	2818.1
08/04/83	2907.6	2818.2
11/08/83	2903.8	2822.0
03/20/84	2900.7	2822.6
05/04/84	2900.1	2822.3
08/22/84	2897.7	2822.2
09/06/84	2898.1	2822.2
11/06/84	2896.6	2821.3
08/06/86	2886.9	2818.5
09/11/86	2889.5	2817.8
09/25/86	2889.5	2817.7
10/25/86	2889.6	2817.7
11/14/86	2891.0	2817.6
07/02/87	2898.6	2817.7
08/04/87	2898.1	2817.7
11/17/87	2897.9	2817.3
02/24/88	2896.8	2817.3
02/29/88	2896.7	
03/08/88	2896.8	2817.2
04/05/88	2896.4	2818.0
05/13/88	2896.1	2818.5
05/18/88	2895.9	2818.5

DATE	RESERVOIR	8
06/22/88	2899.2	2817.3
07/05/88	2899.2	2817.4
08/03/88	2901.1	2817.4
09/27/88	2903.0	2817.4
10/13/88	2902.7	2817.1
11/03/88	2902.3	2817.3
11/14/88	2902.1	2817.3
12/20/88	2902.1	2817.2
01/16/89	2901.7	2817.2
02/14/89	2901.4	2817.3
03/09/89	2901.2	2817.4
03/16/89	2901.1	2817.4
05/10/89	2899.7	2817.4
05/23/89	2901.0	2817.4
05/23/89	2901.0	2817.4
07/07/89	2902.1	2817.7
08/02/89	2901.5	2817.9
09/07/89	2902.2	2818.1
10/25/89	2901.0	2818.4
11/08/89	2900.5	2818.4
12/18/89	2900.7	2818.7
01/16/90	2900.3	2818.9
02/06/90	2900.2	2819.0
03/15/90	2900.2	2818.9
05/09/90	2899.5	2819.3
06/06/90	2898.4	2819.4
07/12/90	2896.5	2819.3
08/22/90	2895.6	2819.5
09/13/90	2894.5	2819.4

APPENDIX D

WATER LEVEL ELEVATIONS (RESERVOIR AND WELLS DH88-1, DH88-2-1, DH88-2-2, DH88-3-1 AND DH88-3-2)

WATER LEVEL ELEVATIONS
(Feet Above Sea Level)

DATE	RESERVOIR	DH88-1	DH88-2-1	DH88-2-2	DH88-3-1	DH88-3-2
04/14/89	2900.4	2870.6	2876.5	2883.7	2858.1	2875.4
04/24/89	2900.1	2871.1	2876.5	2883.7	2859.3	2875.7
05/08/89	2899.7	2870.9	2876.2	2883.7	2856.3	2875.8
05/23/89	2901.0	2871.5	2876.4	2883.7	2855.6	2875.6
06/09/89	2900.8	2870.4	2876.5	2883.7	2854.4	2875.5
07/06/89	2902.1	2870.8	2877.3	2883.7	2853.9	2875.4
08/02/89	2901.5	2871.4	2877.2	2883.5	2852.6	2874.8
09/07/89	2902.2	2871.7	2877.4	2883.8	2852.6	2875.6
10/13/89	2901.9	2871.8	2876.8	2884.0	2852.2	2875.2
11/08/89	2900.5	2871.5	2876.2	2884.7	2852.2	2875.2
12/18/89	2900.7	2871.0	2875.7	2884.0	2851.5	2875.3
02/06/90	2900.2	2870.0	2874.8	2884.0	2851.1	2875.3
03/15/90	2900.2	2869.9	2874.6	2884.0	2851.1	2875.4
05/09/90	2899.5	2869.0	2874.2	2884.0	2850.5	2875.1
06/06/90	2898.4	2868.9	2873.8	2884.0	2850.4	2875.3
07/12/90	2896.5	2867.5	2872.0	2884.0	2849.9	2874.8
08/22/90	2895.6	2865.9	2870.5	2884.0	2849.6	2874.9
SCREENED		2,853.6	2,837.0	2,886.0	2,835.6	2875.6
INTERVAL		2,851.6	2,835.0	2,884.0	2,833.6	2873.6

APPENDIX E

RESERVOIR ELEVATION AND

SEEP DISCHARGE RATE

RESERVOIR ELEVATION AND SEEP DISCHARGE RATE
(Feet Above Sea Level and Gallons Per Minute)

DATE	RESERVOIR	SEEP A	DATE	RESERVOIR	SEEP A	DATE	RESERVOIR	SEEP A
11/20/69	2908.5	7.5	05/01/74	2908.0	14.3	11/18/76	2899.9	6.1
01/14/70	2907.8	7.8	05/30/74	2906.4	12.8	01/14/77	2899.0	6.1
01/28/70	2907.7	6.4	06/19/74	2905.8	10.7	02/04/77	2898.8	5.0
02/26/70	2907.4	7.0	06/28/74	2905.4	12.7	02/24/77	2898.6	5.0
03/17/70	2907.1	7.0	07/17/74	2904.5	12.0	03/03/77	2898.4	4.4
05/15/70	2908.5	7.5	09/05/74	2905.7	13.2	03/16/77	2898.1	5.2
06/09/70	2907.8	7.6	09/16/74	2905.3	13.8	05/10/77	2897.6	5.2
07/09/70	2906.8	0.0	10/03/74	2905.3	11.0	08/15/77	2896.6	6.1
09/15/70	2906.0	0.0	10/17/74	2906.7	0.0	08/17/77	2896.7	5.2
10/20/70	2905.5	9.5	11/07/74	2907.2	13.3	11/18/77	2898.1	5.2
11/24/70	2904.9	0.0	11/26/74	2906.9	12.5	03/28/78	2895.5	4.5
12/03/70	2904.7	7.9	01/02/75	2906.3	12.8	07/26/78	2897.2	4.2
01/18/71	2903.9	8.7	01/15/75	2906.1	13.3	08/30/78	2895.8	4.2
05/10/71	2901.8	7.5	02/03/75	2906.0	13.0	12/21/78	2894.8	5.3
07/29/71	2902.6	0.0	03/03/75	2906.0	14.1	04/02/79	2893.1	3.3
03/17/72	2905.6	0.0	03/18/75	2908.9	13.0	05/15/79	2891.5	3.5
05/18/72	2904.7	0.0	04/16/75	2905.4	11.2	08/14/79	2891.0	3.8
08/03/72	2909.0	0.0	05/01/75	2905.1	10.7	11/30/79	2889.8	3.0
09/19/72	2914.5	0.0	05/21/75	2904.4	10.0	04/01/80	2888.8	0.5
11/21/72	2914.3	13.2	06/18/75	2904.6	8.0	05/15/80	2888.7	0.2
03/14/73	2914.0	12.2	07/16/75	2905.8	11.7	09/15/80	2883.9	0.2
04/05/73	2914.5	12.0	08/06/75	2907.6	12.0	03/31/81	2878.3	0.0
04/17/73	2914.6	12.2	09/04/75	2906.5	9.3	05/15/81	2876.8	0.0
05/07/73	2914.8	12.6	09/19/75	2905.8	9.3	08/06/81	2877.2	0.0
05/17/73	2914.6	12.6	10/03/75	2905.3	8.9	08/07/81	2877.2	0.0
06/01/73	2914.3	14.3	11/17/75	2903.6	8.6	08/14/81	2882.7	0.0
07/03/73	2913.2	12.9	12/05/75	2903.4	8.2	08/17/81	2882.4	0.0
07/16/73	2912.7	12.0	01/14/76	2902.7	8.1	08/18/81	2890.4	0.0
08/03/73	2913.0	12.0	02/20/76	2902.1	6.3	08/20/81	2891.8	0.0
08/17/73	2912.8	12.0	03/01/76	2901.9	8.2	11/16/81	2897.5	0.0
09/05/73	2911.9	13.3	03/18/76	2901.5	10.2	11/18/81	2897.4	0.0
09/17/73	2911.5	12.0	05/17/76	2900.3	7.4	03/11/82	2895.5	5.4
10/02/73	2911.1	14.0	06/17/76	2899.7	6.3	08/02/82	2900.4	6.2
11/06/73	2910.8	15.0	07/20/76	2898.5	8.2	09/01/82	2906.4	7.7
11/16/73	2909.9	14.2	08/09/76	2898.7	6.9	11/03/82	2908.0	8.6
12/05/73	2909.4	14.0	08/11/76	2898.7	8.9	11/17/82	2908.0	8.7
12/14/73	2909.2	14.0	08/19/76	2898.2	5.7	05/17/83	2909.5	0.0
01/08/74	2908.7	13.2	09/03/76	2897.5	6.9	05/19/83	2909.5	8.8
01/16/74	2908.7	14.0	10/01/76	2900.9	7.2	05/24/83	2909.4	8.2
04/02/74	2907.8	13.0	10/14/76	2900.6	6.0	08/08/83	2907.4	8.5

DATE	RESERVOIR	SEEP A	DATE	RESERVOIR	SEEP A
08/22/84	2897.7	0.0	03/28/88	2896.4	5.2
05/15/86	2888.7	3.0	04/11/88	2896.4	5.7
05/30/86	2887.8	3.2	04/26/88	2896.4	6.0
06/13/86	2888.8	1.6	05/10/88	2896.1	5.8
07/02/86	2888.7	1.5	05/24/88	2895.9	5.2
07/15/86	2888.0	1.6	06/09/88	2898.0	6.1
08/01/86	2887.1	1.6	07/05/88	2899.2	6.7
08/18/86	2886.8	1.3	07/18/88	2901.6	6.4
08/28/86	2886.7	1.0	08/01/88	2901.2	6.4
09/02/86	2887.3	1.3	08/15/88	2900.6	6.0
11/14/86	2891.0	1.0	08/29/88	2900.4	6.7
12/03/86	2891.0	1.0	09/12/88	2900.2	8.0
12/13/86	2891.1	1.0	09/26/88	2903.0	8.6
01/05/87	2891.0	1.2	10/10/88	2902.8	9.2
01/16/87	2890.9	0.9	10/24/88	2902.5	7.5
02/02/87	2890.9	1.2	11/07/88	2902.2	8.6
02/16/87	2891.0	1.2	12/05/88	2902.3	8.6
03/02/87	2891.1	1.5	12/19/88	2902.1	9.1
03/11/87	2891.1	1.6	01/03/89	2901.9	8.6
04/16/87	2891.1	2.3	01/16/89	2901.7	8.6
05/01/87	2891.6	2.0	01/30/89	2901.7	8.6
05/19/87	2892.8	2.2	02/13/89	2901.4	8.1
06/04/87	2897.0	2.4	02/28/89	2901.4	7.5
06/04/87	2897.2	2.4	03/14/89	2901.1	7.5
06/16/87	2898.0	2.9	03/28/89	2900.8	7.5
07/02/87	2898.6	3.8	05/08/89	2899.7	7.7
07/14/87	2898.6	4.4	05/08/89	2899.7	7.7
08/03/87	2898.2	5.3	05/23/89	2901.0	7.5
08/18/87	2898.5	5.9	05/23/89	2901.0	7.5
08/31/87	2898.5	6.0	06/05/89	2900.8	7.5
09/15/87	2899.1	6.7	07/07/89	2902.1	7.5
10/01/87	2899.1	2.7	09/07/89	2902.2	7.5
10/16/87	2898.6	6.7	10/13/89	2901.9	9.2
11/06/87	2898.2	6.6	11/09/89	2900.5	9.1
11/17/87	2897.9	7.5	12/18/89	2900.7	9.1
12/01/87	2897.6	6.7	01/16/90	2900.3	8.6
12/23/87	2897.4	6.7	02/06/90	2900.2	8.6
01/04/88	2897.3	6.7	03/15/90	2900.2	7.5
01/14/88	2897.2	6.7	05/10/90	2899.5	7.5
02/01/88	2897.1	2.9	06/06/90	2898.4	7.5
02/16/88	2896.9	6.6	07/12/90	2896.5	6.7
02/29/88	2896.7	6.0	08/22/90	2895.6	5.3
03/08/88	2896.8	6.0	09/13/90	2894.5	5.6
03/14/88	2896.7	5.7			

APPENDIX F

WATER QUALITY ANALYSES

WATER QUALITY ANALYSES

Well		ppm	mg/l	mmole/l	meq/l	%meq/l	TDS mg/l	pH	COND
19691A	Na	313	314.1	13.6637	13.6637	22.2	4701.1	8.1	4760
	K	23	23.1	0.5904	0.5904	1			
	Ca	800	802.9	20.0329	40.0657	65.1			
	Mg	87	87.3	3.5915	7.1831	11.7			
	Cl	767	769.8	21.7132	21.7132	35.4			
	SO4	1810	1816.6	18.9111	37.8222	61.6			
	HCO3	112	112.4	1.8423	1.8423	3			
	CO3	0	0	0	0	0			
19692	Na	639	642.4	27.9398	27.9398	30.1	6618.8	3.9	7520
	K	19	19.1	0.4885	0.4885	0.5			
	Ca	756	760	18.9616	37.9232	40.9			
	Mg	320	321.7	13.2315	26.463	28.5			
	Cl	1406	1413.4	39.867	39.867	42.4			
	SO4	2587	2600.6	27.0729	54.1458	57.6			
	HCO3	0	0	0	0	0			
	CO3	0	0	0	0	0			
19693	Na	345	346.4	15.0675	15.0675	23.9	4582.8	7.6	4416
	K	10	10	0.2568	0.2568	0.4			
	Ca	562	564.3	14.0795	28.159	44.7			
	Mg	237	238	9.7883	19.5766	31			
	Cl	128	128.5	3.6252	3.6252	5.7			
	SO4	2808	2819.5	29.3517	58.7035	92.9			
	HCO3	53	53.2	0.8722	0.8722	1.4			
	CO3	0	0	0	0	0			
19694	Na	97	97.2	4.2296	4.2296	11.2	2787	6.7	2767
	K	6.3	6.3	0.1615	0.1615	0.4			
	Ca	510	511.3	12.7563	25.5127	67.5			
	Mg	96	96.2	3.9585	7.9171	20.9			
	Cl	36	36.1	1.018	1.018	2.8			
	SO4	1699	1703.2	17.7311	35.4621	96			
	HCO3	27	27.1	0.4436	0.4436	1.2			
	CO3	0	0	0	0	0			
19695	Na	290	290.8	12.6472	12.6472	28.4	3256.7	7.5	3641
	K	7	7	0.1795	0.1795	0.4			
	Ca	378	379	9.4563	18.9125	42.5			
	Mg	155	155.4	6.3924	12.7849	28.7			
	Cl	589	590.6	16.6578	16.6578	35.5			
	SO4	1406	1409.7	14.6757	29.3513	62.6			
	HCO3	55	55.1	0.9038	0.9038	1.9			
	CO3	0	0	0	0	0			

WATER QUALITY ANALYSES

Well		ppm	mg/l	mmole/l	meq/l	%meq/l	TDS mg/l	pH	COND
19695A	Na	64	64.1	2.7869	2.7869	13.8	1497.7	7.8	1853
	K	5.9	5.9	0.1511	0.1511	0.8			
	Ca	199	199.2	4.9707	9.9414	49.4			
	Mg	88	88.1	3.6237	7.2474	36			
	Cl	295	295.3	8.3303	8.3303	42			
	SO4	509	509.6	5.3048	10.6096	53.5			
	HCO3	55	55.1	0.9024	0.9024	4.5			
	CO3	0	0	0	0	0			
19696A	Na	219	219.6	9.5534	9.5534	21.4	3227.5	8.3	3263
	K	6.3	6.3	0.1616	0.1616	0.4			
	Ca	482	483.4	12.0613	24.1225	53.9			
	Mg	132	132.4	5.4454	10.8907	24.3			
	Cl	85	85.2	2.4046	2.4046	5.4			
	SO4	1939	1944.7	20.2446	40.4892	90.3			
	HCO3	117	117.3	1.9232	1.9232	4.3			
	CO3	0	0	0	0	0			
19697	Na	205	205.4	8.935	8.935	25.3	2573.3	7.8	2899
	K	7.4	7.4	0.1896	0.1896	0.5			
	Ca	348	348.7	8.7006	17.4012	49.2			
	Mg	107	107.2	4.4102	8.8204	25			
	Cl	369	369.8	10.4297	10.4297	30.6			
	SO4	1094	1096.3	11.4123	22.8245	66.9			
	HCO3	53	53.1	0.8704	0.8704	2.6			
	CO3	0	0	0	0	0			
19698	Na	391	392.5	17.0736	17.0736	21.5	6264.6	4.6	6918
	K	8.2	8.2	0.2105	0.2105	0.3			
	Ca	648	650.5	16.2313	32.4625	41			
	Mg	357	358.4	14.7419	29.4837	37.2			
	Cl	1960	1967.7	55.5019	55.5019	70.3			
	SO4	1123	1127.4	11.7366	23.4732	29.7			
	HCO3	0	0	0	0	0			
	CO3	0	0	0	0	0			
1970RI	Na	220	220.2	9.577	9.577	61.6	888.7	8.4	1458
	K	7.42	7.4	0.1899	0.1899	1.2			
	Ca	57.8	57.8	1.4433	2.8866	18.6			
	Mg	35.2	35.2	1.4491	2.8981	18.6			
	Cl	241	241.2	6.8034	6.8034	44.8			
	SO4	246	246.2	2.563	5.1261	33.7			
	HCO3	195	195.2	3.1986	3.1986	21			
	CO3	2.1	2.1	0.035	0.07	0.5			

WATER QUALITY ANALYSES

Well		ppm	mg/l	mmole/l	meq/l	%meq/l	TDS mg/l	pH	COND
19705	Na	312	312.8	13.606	13.606	31.1	3031.9	7.8	3441
	K	6.25	6.3	0.1603	0.1603	0.4			
	Ca	346	346.9	8.6553	17.3106	39.6			
	Mg	153	153.4	6.3096	12.6193	28.9			
	Cl	454	455.2	12.8391	12.8391	29.1			
	SO4	1458	1461.8	15.2177	30.4353	68.9			
	HCO3	53	53.1	0.8709	0.8709	2			
	CO3	0	0	0	0	0			
19705A	Na	81.6	81.7	3.5536	3.5536	16.3	1273.6	7.8	1880
	K	6.25	6.3	0.16	0.16	0.7			
	Ca	206	206.3	5.1461	10.2922	47.3			
	Mg	94.4	94.5	3.8877	7.7754	35.7			
	Cl	326	326.4	9.2067	9.2067	41.6			
	SO4	553	553.7	5.764	11.528	52.1			
	HCO3	84.7	84.8	1.3899	1.3899	6.3			
	CO3	0	0	0	0	0			
19707	Na	161	161.3	7.0175	7.0175	20.4	2409.1	7.6	2721
	K	5.47	5.5	0.1402	0.1402	0.4			
	Ca	350	350.7	8.751	17.502	50.8			
	Mg	119	119.3	4.905	9.8101	28.5			
	Cl	312	312.7	8.819	8.819	25.3			
	SO4	1228	1230.6	12.8107	25.6214	73.4			
	HCO3	27.4	27.5	0.45	0.45	1.3			
	CO3	0	0	0	0	0			
19707A	Na	623	626.8	27.2613	27.2613	23.1	12141.3	3.1	14099
	K	13	13.1	0.3345	0.3345	0.3			
	Ca	1166	1173	29.2676	58.5351	49.6			
	Mg	384	386.3	15.8901	31.7802	27			
	Cl	5147	5178.1	146.0552	146.0552	92.9			
	SO4	534	537.2	5.5926	11.1852	7.1			
	HCO3	0	0	0	0	0			
	CO3	0	0	0	0	0			
1970SAA	Na	100	100.2	4.3573	4.3573	14.6	2312.1	8.3	2394
	K	4.69	4.7	0.1202	0.1202	0.4			
	Ca	322	322.6	8.0483	16.0967	53.9			
	Mg	113	113.2	4.6562	9.3125	31.2			
	Cl	298	298.5	8.4206	8.4206	28.3			
	SO4	940	941.7	9.8031	19.6062	65.9			
	HCO3	104	104.2	1.7075	1.7075	5.7			
	CO3	0	0	0	0	0			

WATER QUALITY ANALYSES

Well		ppm	mg/l	mmole/l	meq/l	%meq/l	TDS mg/l	pH	COND
1970SAB	Na	83	83.1	3.6161	3.6161	13	1859.1	8.3	2236
	K	4.69	4.7	0.1201	0.1201	0.4			
	Ca	282	282.5	7.0476	14.0952	50.5			
	Mg	122	122.2	5.0264	10.0529	36.1			
	Cl	284	284.5	8.0239	8.0239	28.9			
	SO4	861	862.4	8.978	17.9561	64.7			
	HCO3	107	107.2	1.7566	1.7566	6.3			
	CO3	0	0	0	0	0			
1986IS	Na		340	14.7884	14.7884	74.9	1189	8.3	2336
	K		0	0	0	0			
	Ca		55	1.3723	2.7445	13.9			
	Mg		27	1.1106	2.2211	11.2			
	Cl		377	10.6338	10.6338	53.4			
	SO4		275	2.8628	5.7256	28.7			
	HCO3		217	3.5564	3.5564	17.9			
	CO3		0	0	0	0			
19861A	Na	172	172.4	7.4985	7.4985	22.8	7237.8	3.7	4640
	K	6.3	6.3	0.1615	0.1615	0.5			
	Ca	347	347.8	8.6778	17.3555	52.8			
	Mg	95	95.2	3.9166	7.8332	23.8			
	Cl	106	106.2	2.9968	2.9968	8			
	SO4	1650	1653.8	17.2166	34.4332	92			
	HCO3	0	0	0	0	0			
	CO3	0	0	0	0	0			
19862	Na	403	404.2	17.5825	17.5825	29	5860	3.7	5730
	K	11.9	11.9	0.3053	0.3053	0.5			
	Ca	550	551.7	13.7647	27.5294	45.4			
	Mg	184	184.6	7.5915	15.1831	25.1			
	Cl	1025	1028.2	29.0004	29.0004	54.2			
	SO4	1178	1178.6	12.2695	24.5391	45.8			
	HCO3	0	0	0	0	0			
	CO3	0	0	0	0	0			
19863	Na	426	427.1	18.5768	18.5768	30.2	4179.8	5.1	3720
	K	23	23.1	0.5897	0.5897	1			
	Ca	503	504.3	12.5823	25.1645	40.9			
	Mg	209	209.5	8.6187	17.2375	28			
	Cl	234	234.6	6.6173	6.6173	23.4			
	SO4	1030	1032.7	10.7501	21.5002	76.2			
	HCO3	6.4	6.4	0.1052	0.1052	0.4			
	CO3	0	0	0	0	0			

WATER QUALITY ANALYSES

Well		ppm	mg/l	mmole/l	meq/l	%meq/l	TDS mg/l	pH	COND
19864	Na	130	130.1	5.6597	5.6597	26.3	1492.4	7.7	1560
	K	4.1	4.1	0.105	0.105	0.5			
	Ca	186	186.2	4.645	9.2901	43.1			
	Mg	79	79.1	3.2525	6.5049	30.2			
	Cl	249	249.2	7.0299	7.0299	52.6			
	SO4	248	248.2	2.5841	5.1683	38.7			
	HCO3	71.2	71.3	1.168	1.168	8.7			
	CO3	0	0	0	0	0			
19865	Na	307	307.5	13.3735	13.3735	37.4	2101.2	7.8	2570
	K	20	20	0.5123	0.5123	1.4			
	Ca	303	303.5	7.5715	15.1429	42.3			
	Mg	82	82.1	3.378	6.756	18.9			
	Cl	316	316.5	8.9269	8.9269	44.6			
	SO4	461	461.7	4.8064	9.6129	48			
	HCO3	90.9	91	1.4921	1.4921	7.4			
	CO3	0	0	0		0			
19865A	Na	106	106.1	4.6135	4.6135	31.6	1305.8	7.7	1330
	K	6.5	6.5	0.1663	0.1663	1.1			
	Ca	136	136.1	3.3954	6.7908	46.5			
	Mg	37	37	1.5229	3.0457	20.8			
	Cl	312	312.2	8.8061	8.8061	75.6			
	SO4	106	106.1	1.1042	2.2084	19			
	HCO3	38.8	38.8	0.6363	0.6363	5.5			
	CO3	0	0	0	0	0			
19866A	Na	264	264.6	11.5101	11.5101	21.2	3430.2	7.6	2820
	K	6.4	6.4	0.1641	0.1641	0.3			
	Ca	580	581.4	14.5055	29.0111	53.4			
	Mg	165	165.4	6.8029	13.6059	25.1			
	Cl	300	300.7	8.4821	8.4821	29.9			
	SO4	927.5	929.7	9.6784	19.3569	68.2			
	HCO3	32.4	32.5	0.5323	0.5323	1.9			
	CO3	0	0	0	0	0			
19867	Na	124	124.2	5.4023	5.4023	14.4	3556.8	5.7	3130
	K	8.2	8.2	0.2101	0.2101	0.6			
	Ca	465	465.8	11.6208	23.2416	62.1			
	Mg	104	104.2	4.2847	8.5695	22.9			
	Cl	1220	1222	34.4682	34.4682	97.2			
	SO4	45	45.1	0.4692	0.9385	2.6			
	HCO3	4	4	0.0657	0.0657	0.2			
	CO3	0	0	0	0	0			

WATER QUALITY ANALYSES

Well		ppm	mg/l	mmole/l	meq/l	%meq/l	TDS mg/l	pH	COND
----		---	----	-------	-----	------	--------	--	----
19867A	Na	308	309.1	13.4462	13.4462	14.1	6087.6		7950
------	K	62	62.2	1.5915	1.5915	1.7			
	Ca	1252	1256.6	31.3534	62.7067	65.7			
	Mg	214	214.8	8.8349	17.6698	18.5			
	Cl	2245	2253.3	63.5581	63.5581	98.8			
	SO4	36	36.1	0.3762	0.7523	1.2			
	HCO3	0	0	0	0	0			
	CO3	0	0	0	0	0			
19868	Na	602	604.3	28.2824	26.2824	26.9	6129	7.4	7510
-----	K.	6.2	6.2	0.1592	0.1592	0.2			
	Ca	880	883.3	22.0385	44.077	45.2			
	Mg	328	329.2	13.5419	27.0838	27.7			
	Cl	2350	2358.8	66.5337	66.5337	97.1			
	SO4	68	68.3	0.7105	1.4211	2.1			
	HCO3	34	34.1	0.5593	0.5593	0.8			
	CO3	0	0	0	0	0			
1990SAA	Na		294.6	12.8135	12.8135	38	2526.1	7.9	2250
-------	K		5.4	0.1384	0.1384	0.4			
	Ca		308.1	7.6877	15.3754	45.6			
	Mg		65.1	2.679	5.358	15.9			
	Cl		384.7	10.8507	10.8507	31.4			
	SO4		1041.1	10.8379	21.6757	62.7			
	HCO3		124.3	2.0364	2.0364	5.9			
	CO3		0	0	0	0			

APPENDIX G

SEEP PRECIPITATE ANALYSIS

SEEP PRECIPITATE ANALYSIS
(ppm)

Seep Precipitate	Mg/kg
Mg	7,380
Cu	6
Fe	880
Mn	26
Zn	10
Na	4,700
K	570
Ca	195,200
Cl	30,700
SO_4	485,100
CO_3	55,754
TOTAL	**780,326**

VITA

David Warren Simpson

Candidate for the Degree of

Master of Science

Thesis: DETERMINATION OF SOURCE OF SEEPS AT BASE OF LEFT ABUTMENT OF SANFORD DAM, HUTCHINSON COUNTY, TEXAS

Major Field: Geology

Biographical:

Personal Data: Born in St. Louis, Missouri, July 21, 1955, the son of Samuel W. and Charlotte E. Simpson.

Education: Graduated from McCluer Senior High School, Florissant, Missouri, in 1973; received Bachelor of Science Degree in Geology and Bachelor of Arts Degree in Political Science from the University of Missouri - Columbia in 1978; received Juris Doctor Degree (With Honors) from Oklahoma City University in 1984; completed requirements for the Master of Science Degree at Oklahoma State University in December, 1992.

Professional Experience: Jr. Geologist, Terra Resources,Inc., 1978-1979; Geologist, Champlin Petroleum Company, 1979-1981; Geologist, Woods Petroleum Corporation, 1981-1984; Attorney, Watson & McKenzie P.C., 1984-1988; Attorney, MESA Inc., 1988 to present.

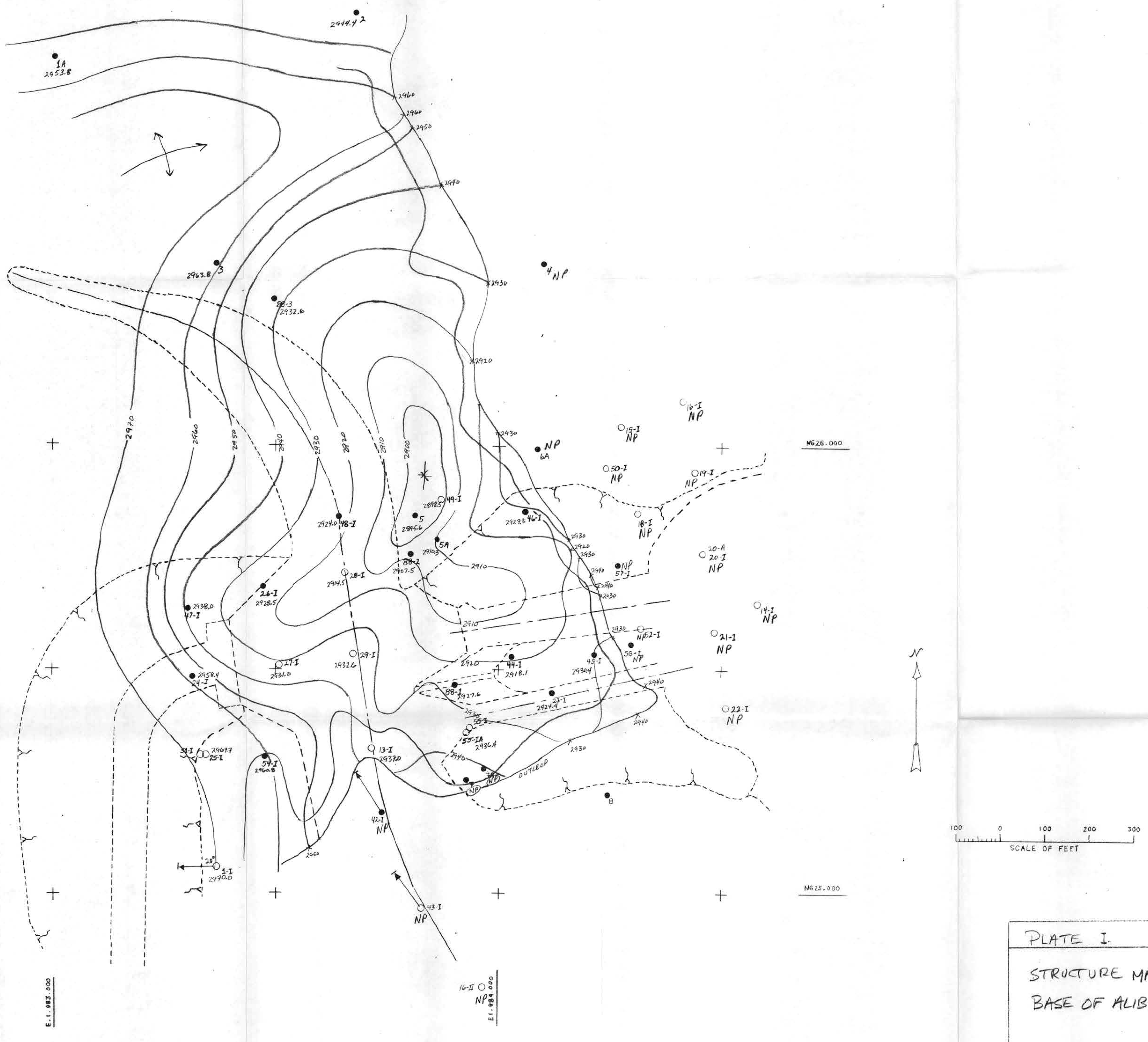

PLATE I.

STRUCTURE MAP
BASE OF ALIBATES

CI=10'

D. SIMPSON

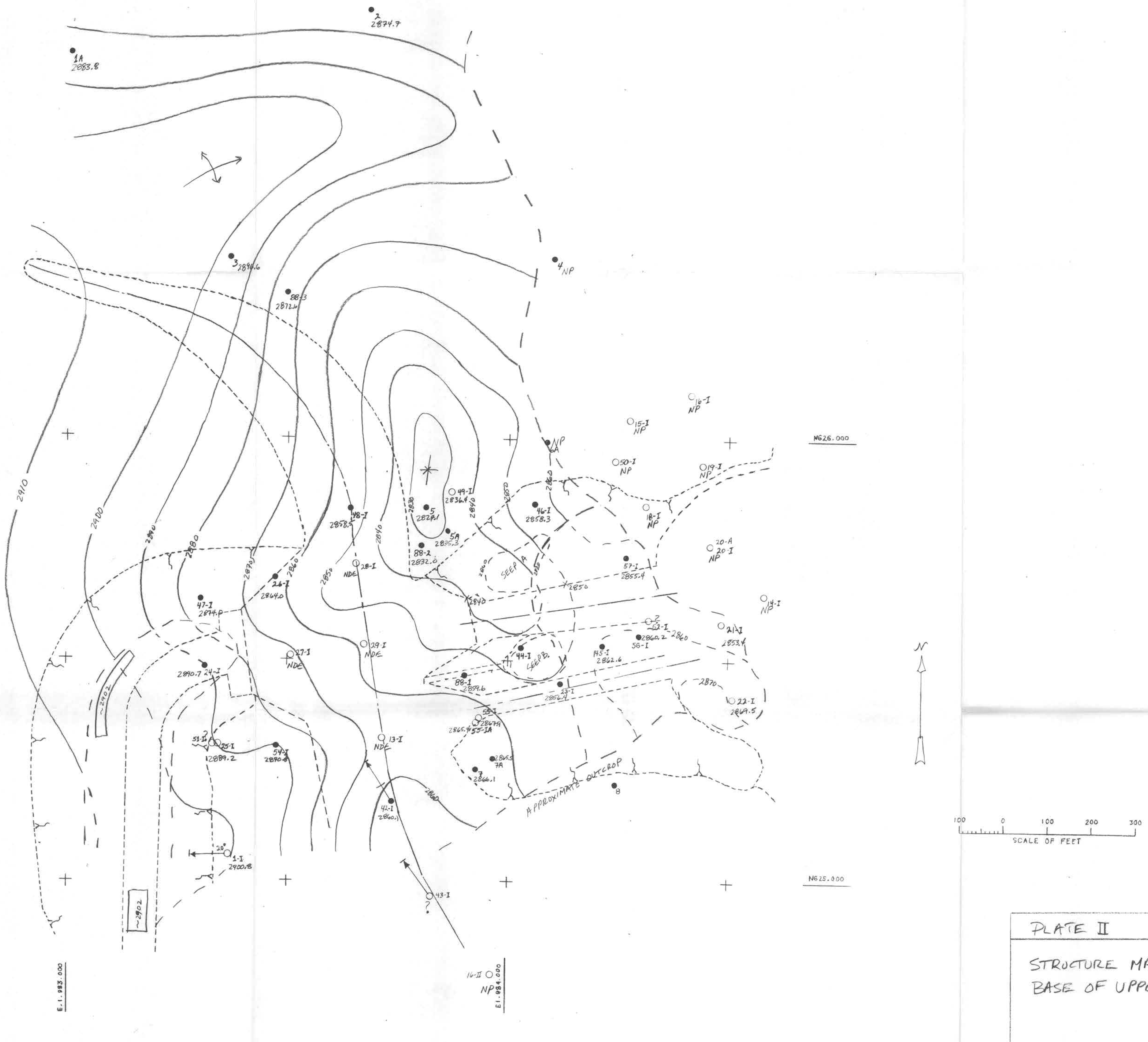

PLATE II

STRUCTURE MAP
BASE OF UPPER GYPSUM

CF=10'

D. SIMPSON

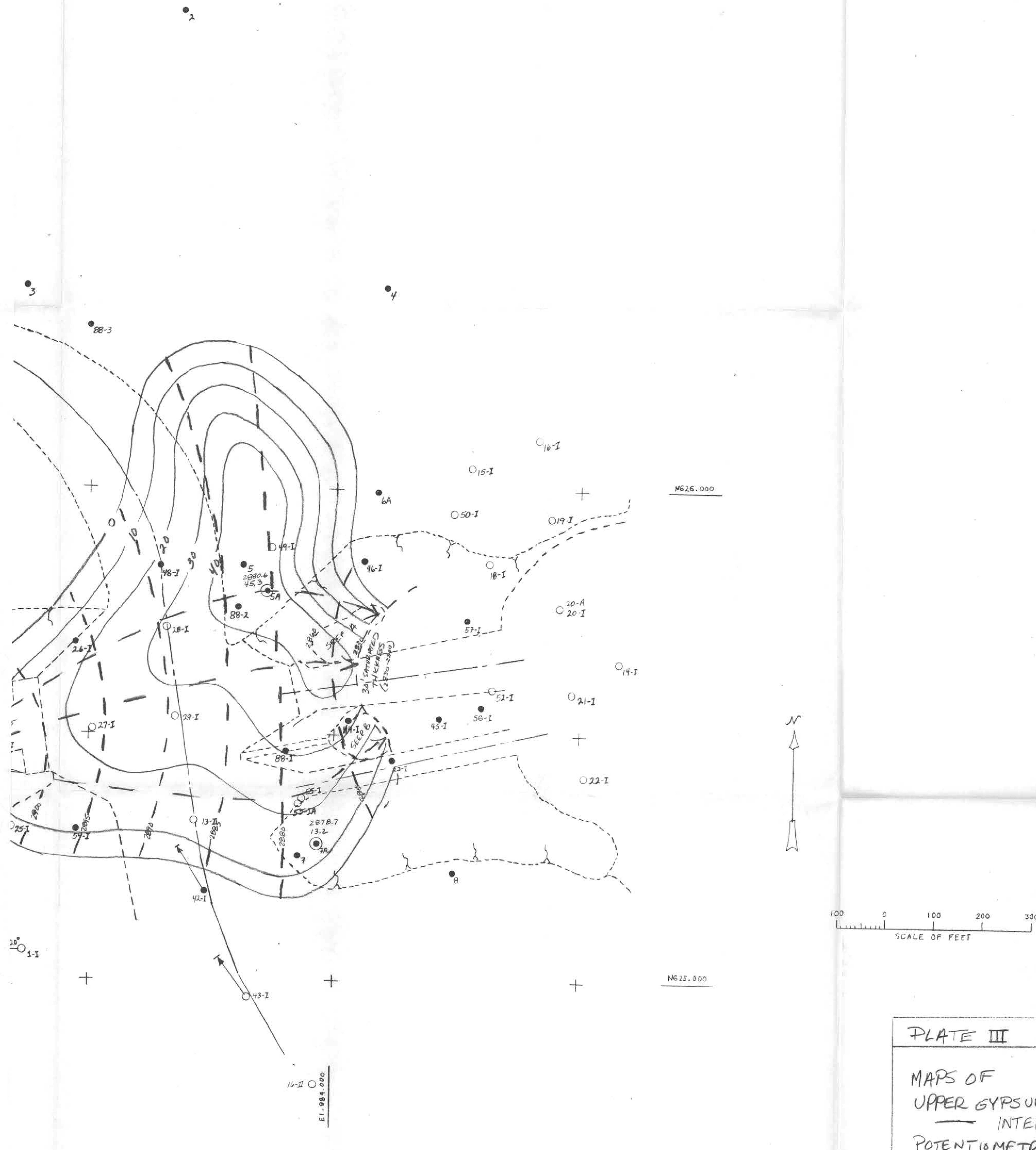

PLATE III

MAPS OF
UPPER GYPSUM SATURATED INTERVAL (CI=10')
POTENTIOMETRIC SURFACE (CI=5'
FLOW LINES

D. SIMPSON

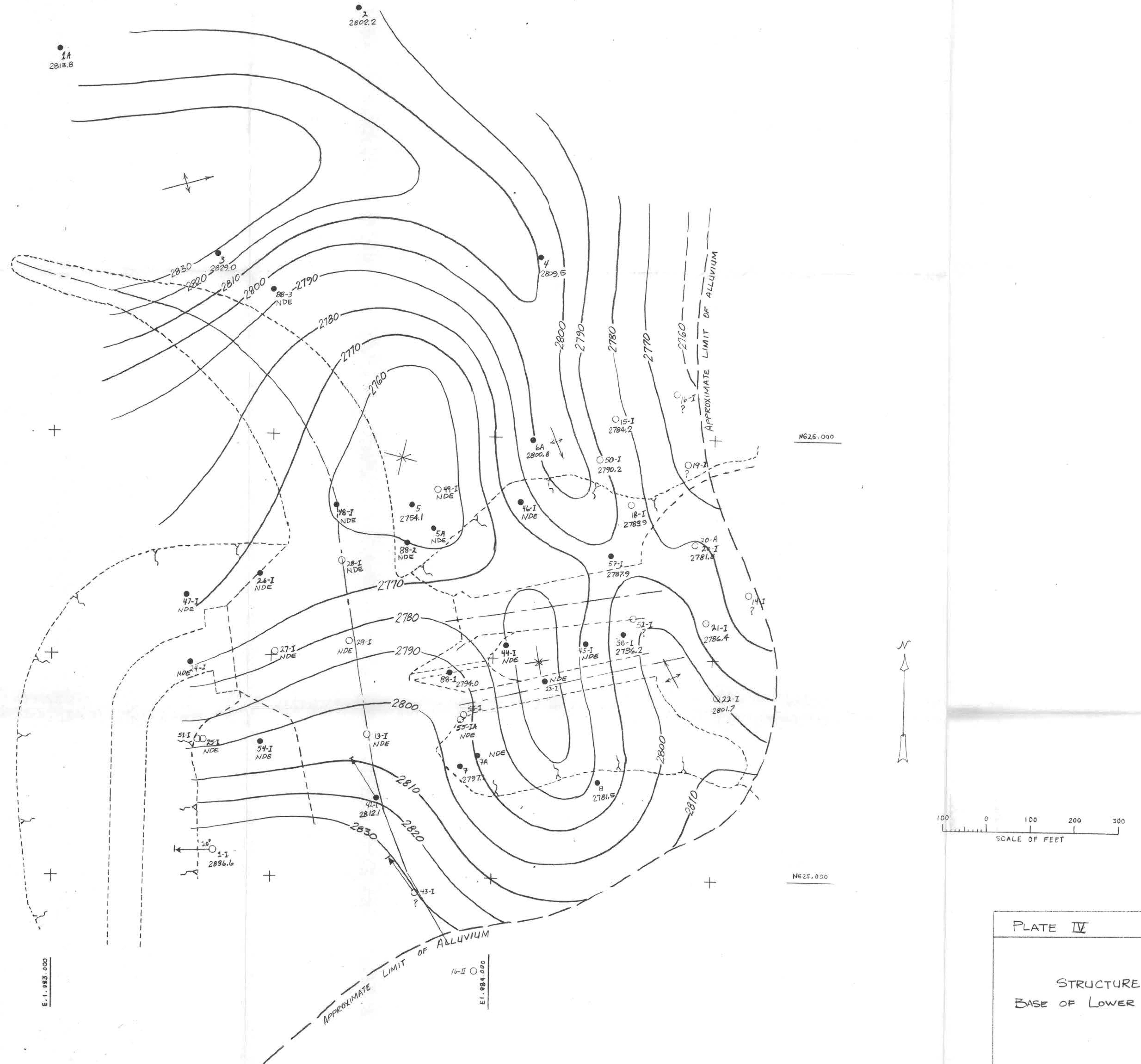

PLATE IV

STRUCTURE MAP
BASE OF LOWER GYPSUM

C.I. = 10'

D. SIMPSON

PLATE V

POTENTIOMETRIC
MAP
LOWER GYPSUM

C.I. = 10'

D. SIMPSON

PLATE VI

INDEX MAP FOR
CROSS-SECTIONS