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HYDROGEOLOGY OF UTAH LAKE WITH EMPHASIS ON GOSHEN BAY.

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HYDROGEOLOGY OF UTAH LAKE WITH EMPHASIS ON GOSHEN BAY

A Dissertation

Presented to the

Department of Civil Engineering

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In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

by

Jacob D. Dustin

December 1978

This dissertation by Jacob D. Dustin, is accepted in its present form by the Department of Civil Engineering of Brigham Young University as satisfying the dissertation requirement for the degree of Doctor of Philosophy.

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CHAPTER 1

INTRODUCTION

Without question, the most difficult to analyze of all water budget components in a lake is the subsurface flow. Some of the factors which give rise to this difficulty include:

1. The flow is "invisible", so to speak.

2. The water storage capacity (porosity) and transmissibility properties (permeability) vary widely among aquifers and within individual aquifers.

3. The volume of recharge to an aquifer is extremely difficult, and most often impossible, to accurately assess.

4. Water levels, and hence pressures, in ground-water reservoirs fluctuate in response to corresponding fluctuations in rates of recharge and withdrawal. However, because the velocity of ground-water movement is a function of aquifer permeability, the time/areal distribution of such fluctuations may show considerable variation.

5. Water quality may be appreciably altered by the geochemical nature of the formation through which the ground-water must pass.

6. Diffuse seepage losses may occur over broad areas as a result of upward migration caused by artesian pressures.

7. Where water levels are in close proximity to the land surface, substantial amounts of water may be lost to evapotranspiration. This situation is especially true for arid regions.

8. Subsurface discharges generally do not occur as large volume or high rate point discharges (though exceptions do exist for special geologic formations).

9. Subsurface inflows are rapidly diluted by the receiving waters due to the volume and current-induced agitation.

10. Oftentimes the characteristics of the ground-waters and the receiving waters are so similar as to be indistinguishable at field measurement sensitivities.

The preceding list is not necessarily complete but it is sufficient to provide the reader with an appreciation for the complexity of the problem. Because of this complexity, the traditional approach to subsuface flow estimating has been to measure all the other budget parameters as accurately as possible, sum them algebraically, and assign the remainder to ground-water. Under most circumstances, that is about the best that could be done. However, if errors are made in the measurements of the other parameters or if the geohydrology of the study area is not fully understood, errors of considerable magnitude may result for subsurface flow estimates.

In the arid regions typical of the western and southwestern portions of the U.S., the problem is compounded in that orographic influences cause large variations in precipitation over relatively small distances; wide-spread irrigation results in seasonal and regional changes with respect to consumptive use, return flow, and channel loss/ground-water recharge; phreatophytes flourish in these regions; and finally, and perhaps most significantly, evaporation rates may show large fluctuations with time and distance--being affected by such factors as radiation, wind, pressure (atmospheric and vapor), water temperature, and other characteristics of the evaporating body (the shallower the body, the greater the evaporation).

Background

By definition, arid regions receive relatively little precipitation and the major portion of that which they do receive falls during the winter months. Hence, water is very precious resource and efforts to entrap it, store it, conserve and preserve it receive great emphasis--and accurate water budgets assume increased importance in efficiently managing the water resource.

Central Utah Project

The U.S. Bureau of Reclamation (USBR) Central Utah Project (CUP) is a major water conservation and management effort. Basically, the project calls for transportation of Utah's portion of Colorado River water from high-mountain headwater areas to lower-lying arable lands of central Utah. The primary use of the water will be for irrigation, hydroelectric power generation, and municipal and industrial uses. The Bonneville Unit of the CUP is concerned with storage and release of water along the westernmost edge of the Wasatch Front. Releases from Strawberry Reservoir and the proposed Jordanelle Reservoir (via Deer Crrek Reservoir) will be routed through Spanish Fork and Provo Canyons, respectively. That water destined for use beyond Utah Valley will be directed through Utah Lake. Figure 1 is a false-color infrared image of this area as recorded by "LANDSAT" sensors on 23 May 1975. The figure is oriented with north at the top of the page. Watershed areas tributary to the lake basin are clearly recognizable.

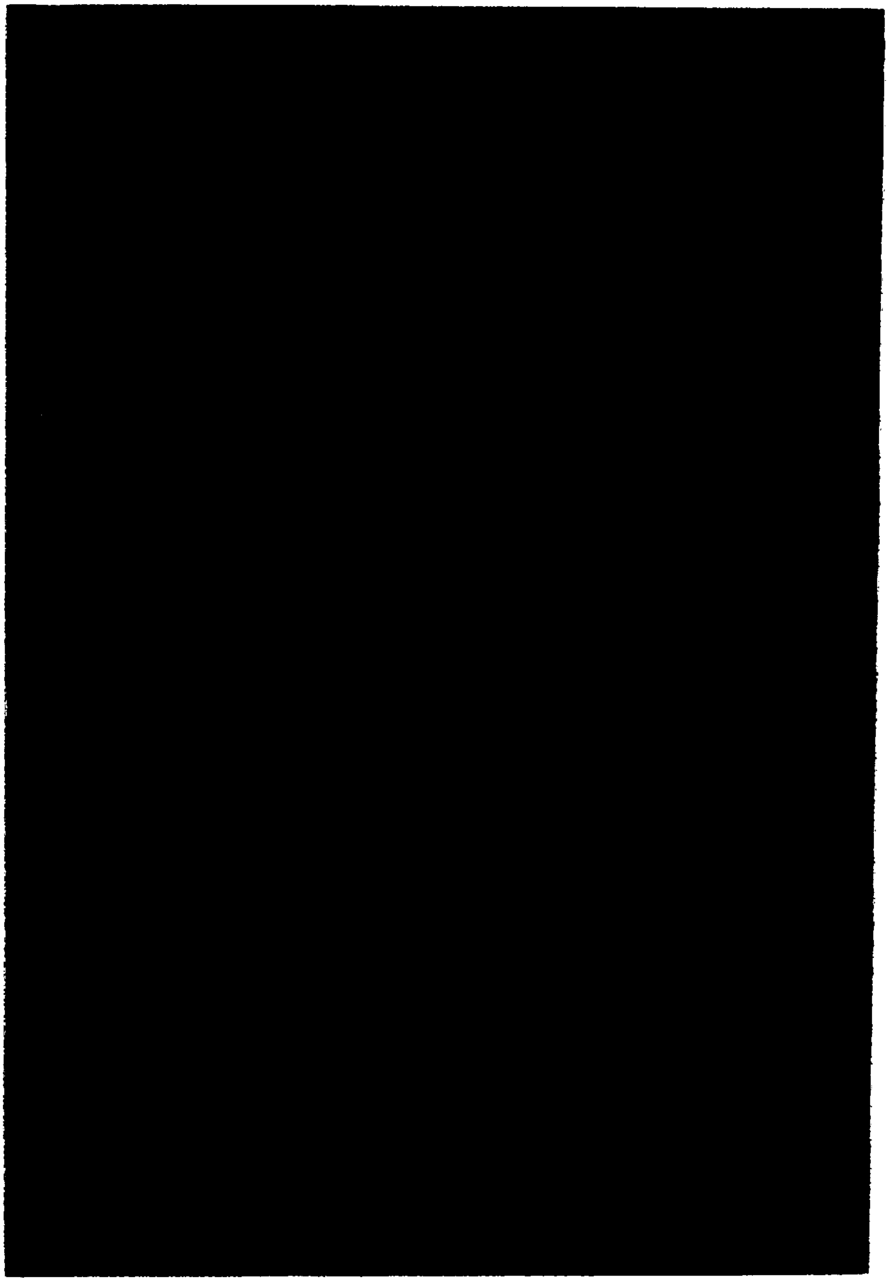

Figure 1. False-color Infrared Image of Utah Lake and Surrounding Area (courtesy EROS Data Center).

Utah Lake

Utah Lake is a shallow, hyper-eutropic fresh-water lake occupying some 95,000 arces (38,446 hectares) in the central portion of Utah County, Utah, approximately 40 miles (64 kilometers) south-southeast of the Great Salt Lake. When at "compromise level", Utah Lake is approximately 20 miles (32 kilometers) long and 10 miles (16 kilometers) wide at its maximum points while averageing only 9.5 feet (2.9 meters) in depth. "Compromise level" is currently established at elevation 4489.34 feet (1368.35 meters). It is so termed because it represents a compromise agreement as to the maximum level at which the lake should be allowed to rise before allowing free discharge into the Jordan River, the only outflow. The agreement was reached as a result of a court suit in 1885 between Salt Lake Valley irrigators, who view the lake as a storage reservoir, and Utah Valley farms with land bordering the lake shore, who viewed the lake as somewhat of a nuisance. Hostilities between the two groups have wanted over the years, but vested rights associated with Utah Lake water continue to be a matter of major concern in any project affecting the lake.

The quality of the waters of Utah Lake are generally perceived as poor due to its eutrophic state, turbidity and fairly high dissolved solids content. Based on results of several detailed scientific investigations which will be discussed in later sections, it appears that anthropogenic influences have much less impact on the quality than do physical characteristics of the lake itself. Of these characteristics, evaporation seems to have the greatest single impact. According to Fuhrima, et al. (1975:4), approximately one third of the total lake capacity and one half of the average annual inflow is lost to evaporation. Thus evaporation not only has a significant impact on quality via concentration of salts in the remaining waters, it is also responsible for a large quantity loss.

Diking Proposal

The undesirable effects of evaporation from Utah Lake have long been recognized and proposals for ways to reduce these effects date to at least as early as 1902 (Swendsen, 1903:280-281). The proposal to route high quality CUP water through Utah Lake has intensified evaporation reduction efforts. Of the various options available, the most cost-efficient and viable plan seems to be reduction of overall surface area of the lake by diking off the Provo Bay and Goshen Bay regions of the lake. In so doing, the surface area would be reduced by 35.5 percent. The prediction is that 220,000 to 270,000 acre feet (271 to 331 x 10^6 cubic meters) would be saved over a "typical" three year period. In addition, dissolved solids (TDS) concentrations would be reduced significantly. For example, total dissovled solids from 960 to 800 mg/l; sodium from 122 to 95 mg/l; and chloride from 189 to 138 mg/l (Fuhriman, et al., 1975:39).

Problem Statement

In view of the plans to dike off over one third of the lake surface, a much more detailed understanding of the subsurface flow situation is required than has previously been available. Beside the obvious environmental and hydrologic implications, less obvious vested rights issues could possibly arise if previous assumptions of both quantity and quality of subsurface inflows are in error.

This investigation is aimed at providing a comprehensive view of the geohydrology of Utah Lake and surrounding area. In particular, the following questions are addressed:

1. Is it possible that subsurface inflow is substantially greater than previously estimated? Estimates vary from a low of 20,000 to over 100,000 acre feet annually, with most ranging from 36,000-50,000 acre feet.

2. If inflow is larger than previous estimates, where does it enter the lake? Have all inflow areas been identified or are that locations which have previously escaped recognition?

3. What are the major sources and recharge areas of the incoming ground-water?

4. What is the quality of these ground-water inflows?

5. Can the subsurface inflows be segregated and quantified?

6. Will subsurface inflows affect the viability or locations of proposed dikes in Utah Lake?

Framework and Delimitations

The physical boundaries of the study area are depicted in Figure 2. As a base of reference, this area will be referred to as the "Utah Lake Basin" throughout the remainder of the discussion. Other subareas (e.g., Cedar Valley, Genola Gap, etc.) receiving specific attention are also shown.

The primary focus of this study is ground water. The extent to which other water budget parameters are discussed will vary in proportion to their bearing and/or effect on subsurface flow. Subsurface flow, for purposes of this investigation, also includes shoreline seeps and

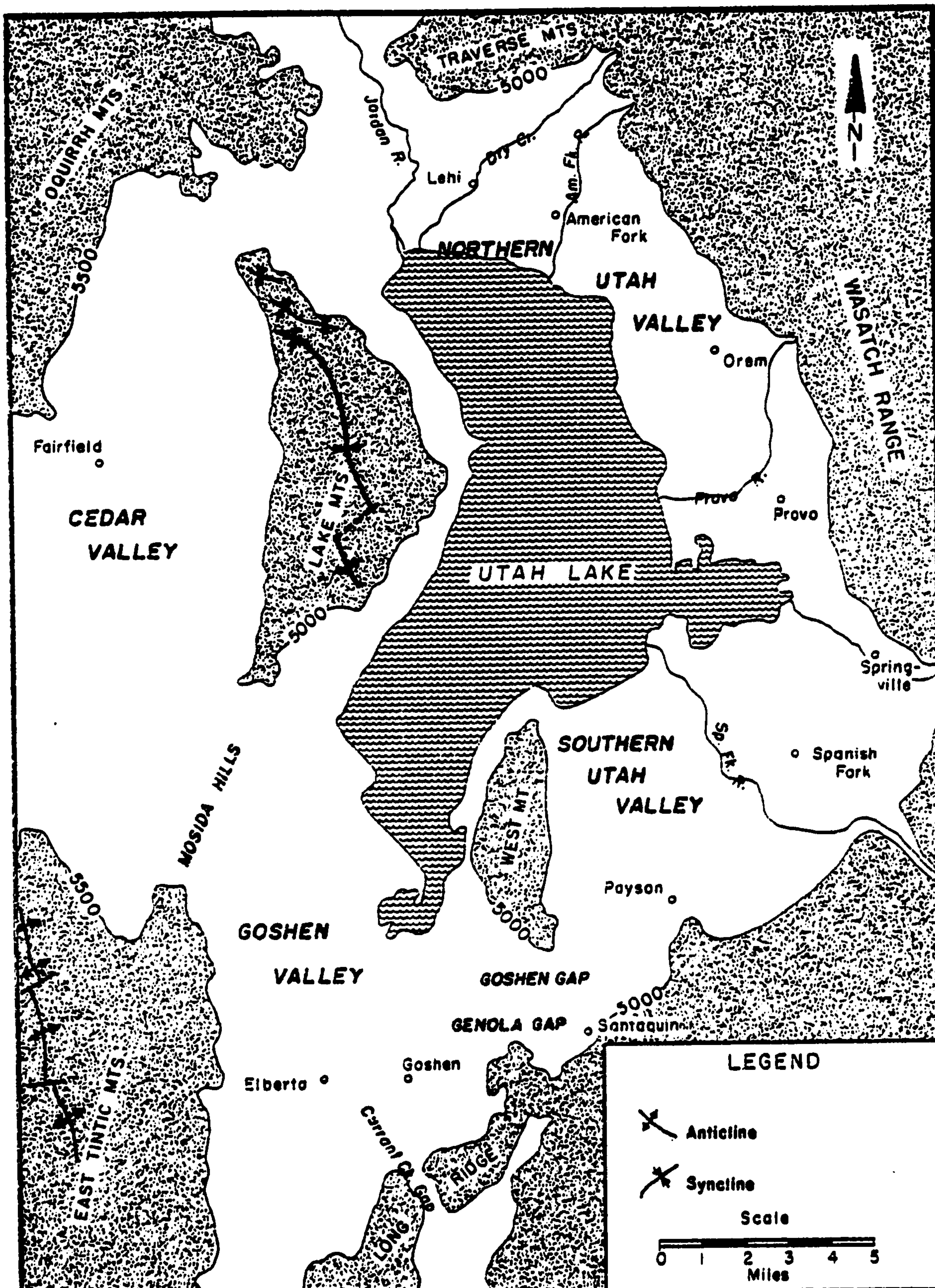

Figure 2. "Utah Lake Basin" Study Area.

springs. The single exception to the latter statement is Powell Slough which has been historically measured as a surface tributary. The major components of the investigation will include:

1. A review and discussion of results and observations of previous Utah Lake investigators;

2. An examination of the geology and geohydrology of the Utah Lake Basin;

3. The advancement of a format to be used for the systematic evaluation of subsurface inflow, followed by a discussion of results obtained; and,

4. Conclusions and recommendations.

The format mentioned in item 3 is developed in Chapter 3.

CHAPTER 2

PREVIOUS INVESTIGATIONS

It is difficult to say whether scientific curiosity or economic considerations have provided the greater impetus for previous ground-water studies in the Utah Lake Basin; but in view of the high value placed on water supplies in the area, the latter stimulus is likely dominant. Regardless of the reason, the efforts of several researchers have shed considerable light on the geohydrology of this region. The following discussion is organized by topics. These topics cover general observations, springs and seeps, previous inflow estimates, a chemical quality summary, and a review of selected statistical distributions. More detailed treatment of the information relating to ground-water conditions is found in the chapter which deals with the geology and geohydrology of the basin.

General Observations

In 1906 Richardson completed the first "comprehensive" ground-water survey in this area. In his report (Richardson, 1906) he made several observations. Among these are:

1. Artesian conditions are the rule rather than the exception throughout northern and southern Utah Valley.

2. Flowing wells in and near Lehi cease to flow in the summer when field wells between the town and lake are used for irrigation.

The wells begin flowing again shortly after field wells are capped for the winter (:48-49).

3. Artesian flow in Goshen Valley is limited primarily to the Currant Creek basin and the near-vicinity of the lakeshore (:55).

4. Slight artesian pressures are evidenced near Pelican Point by two "feebly" flowing wells (:56).

5. The bulk of underground water in Utah Valley is provided by channel losses (:28).

Hunt, Varnes and Thomas (1953) note that ground-water levels show seasonal and long-term fluctuations in response to runoff, aquifer withdrawals, drought cycles, etc. (1953:77). In comparing piezometric data from selected points in northern Utah Valley, they found that a pronounced hydraulic gradient toward the lake is evident both in the artesian and the water table aquifer(s) (:82-83). These gradients, combined with the observation that both artesian pressures and general water quality increase with depth, lead the authors to the conclusion that the confining layers are not absolutely impervious and that it is probable that large quantities of water move upward from the underlying aquifers to discharge into Utah Lake by seepage (:84-85). This condition appears to have been first postulated by Harding (April 1941:2) when he noted that wells around the east shore of the lake showed fairly high pressures from relatively shallow depths. As a result, he concluded that a large part of the lake bed appeared to be under artesian pressure and that inflow occurs via "general artesian sweating" (diffuse seepage) through confining clays and via "artesian leakage" (springs) through the breaks which occur in the clay strata. Bissell (1963) and Cordova

(1970) noted similar piezometric conditions in southern Utah and Goshen Valleys.

The above evidence would tend to support rather substantial inflow estimates and yet, with the exception of Fuhriman, et al. (1975), estimates made by each of the previous researchers seem to be quite conservative. The concensus of opinion of these earlier researchers also seems to be that inflow along the west side of the lake and in the Goshen Bay area are negligible to non-existent. A more detailed treatment of inflow estimates will be given later in this chapter.

Springs and Seeps

Many springs and several shoreline seeps have been identified and documented by Swendsen (1905), Richardson (1906), Harding (April 1941), Viers (1964), Milligan, et al. (1966), and Brimhall, et al. (1976a). To reduce confusion and facilitate ease of discussion, these seeps and springs will be divided into general groupings according to location. Figure 3 depicts these groupings.

Northwest Springs

Springs in this grouping are the largest, deepest, warmest, and best documented springs of the entire Utah Lake Basin. Swendsen (1905) provided the first published scientific documentation of these springs and noted that a two-inch pipe driven near them "...brings a flow of water to the surface..." In some cases the water was hot and others, cold. In two cases the artesian pressure was "...sufficient to force the water 12 to 15 feet above the surface..." (:497). The most complete and comprehensive works on these springs are provided

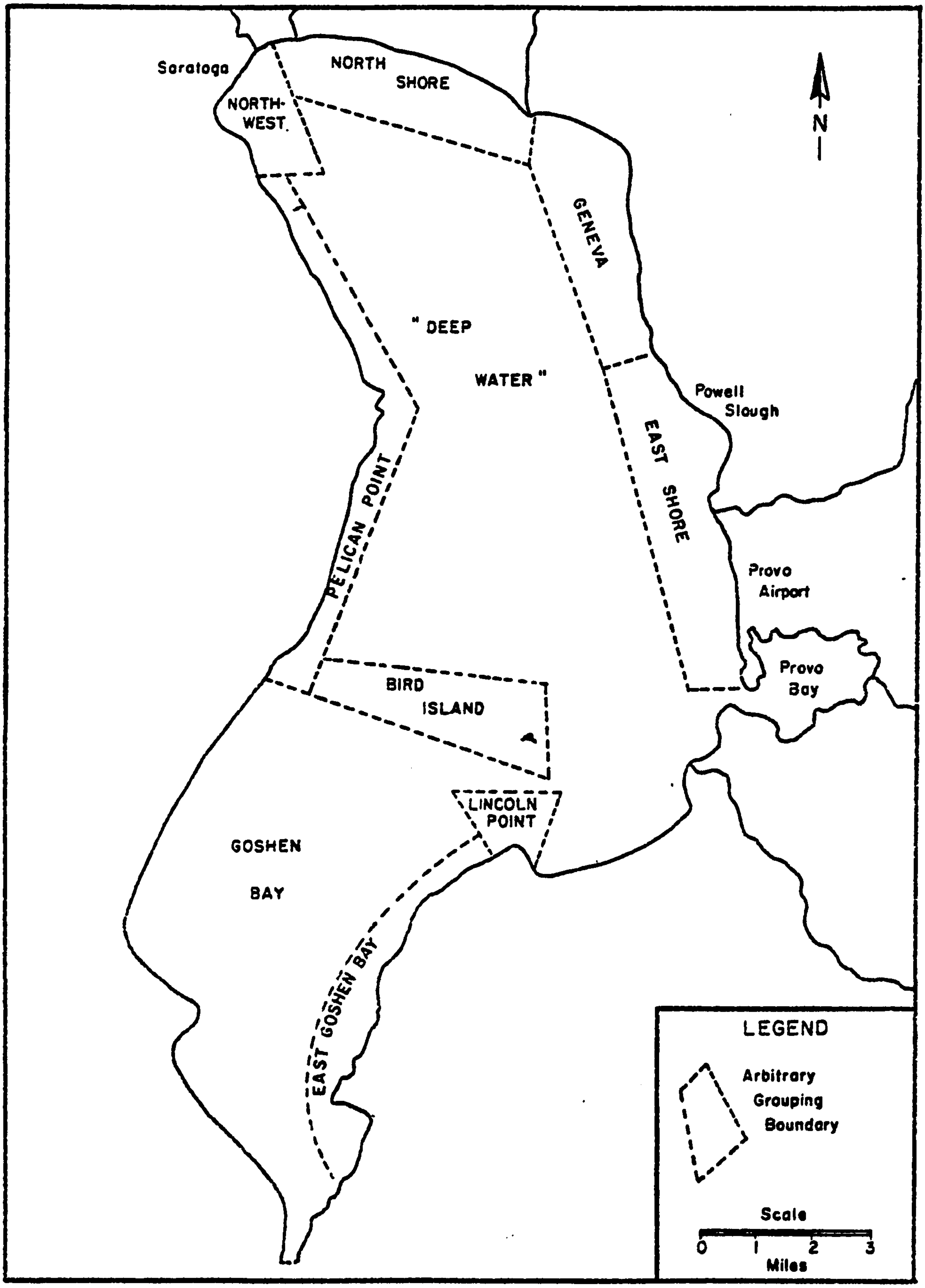

Figure 3. Generalized Spring/Seep Groupings.

by Harding (April 1941) and Viers (1964), although Viers draws heavily upon Harding for much of his background information.

In this grouping of springs there are at least six distinct springs and several other small groups of springs. Their locations are shown in Figure 4 and descriptive information on the major ones is listed in Table 1.

TABLE 1

MAJOR NORTHWEST SPRINGS (Adapted fromViers, 1964)

Number	Size, feet	Maximum depth below compromise, feet	Also known as
1	500 x 250	75	Big Spring
2	diameter 20	27	---
3	100 x 100	77	---
4	700 x 100	62	Kidney Spring
5	350 x 200	54	Snyder or Crater Spring
6	diameter 40	---	Unnumbered Spring

Figures 5 and 6 are reproductions of USBR photos of Kidney and Snyder (Crater) Springs respectively. Both pictures were taken during September 1961 when the lake level was over nine feet (2.7 meters) below compromise. Note the nearly continuous shoreline seeps in both photos indicating the sort of diffuse upward flow or "artesian sweating" phenomenon mentioned earlier. Attempts to channelize these seeps for flow measurement have been futile in most cases.

Viers made a thorough survey of the area close to shore and just east of the Saratoga boat harbor during 1961. He found two large

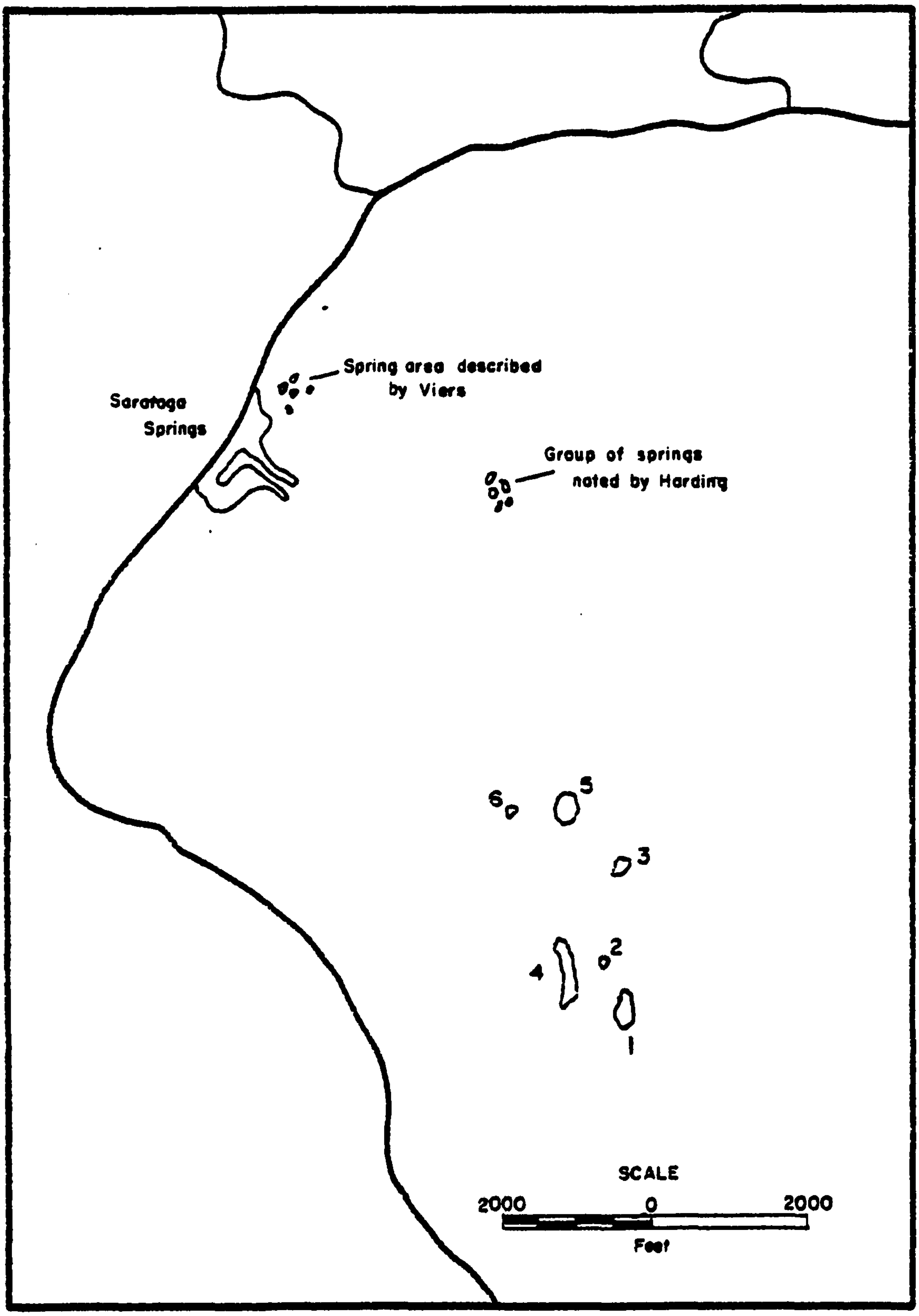

Figure 4. Springs of the Northwest Grouping.

Figure 5. "Kidney" Spring (courtesy USBR).

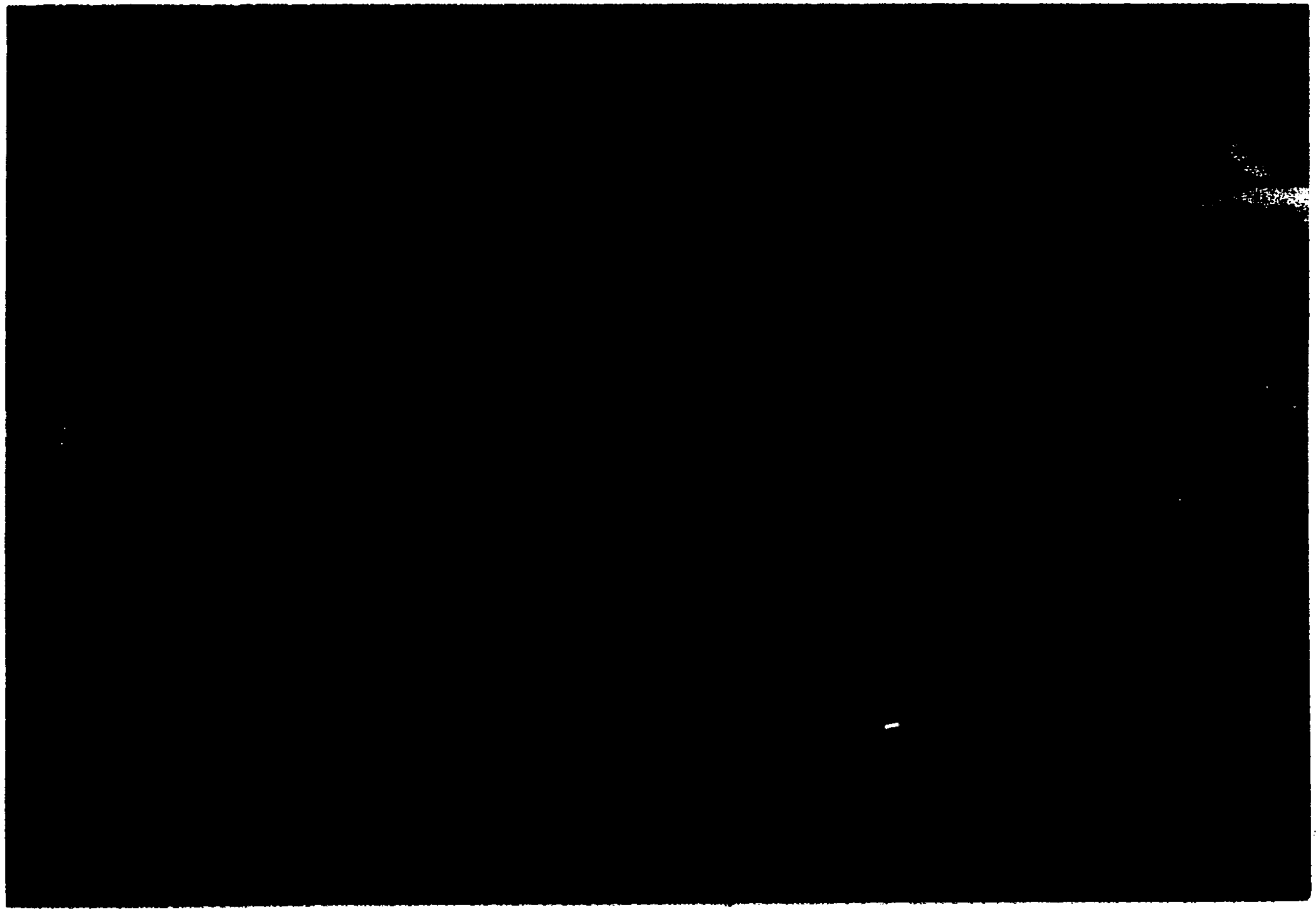

Figure 6. "Snyder" or "Crater" Spring (Courtesy USBR).

springs and numerous small springs and seeps--all of which were thermal (Viers, 1964:47). He describes these springs as follows:

> Some of the springs emerged as sand boils 6 to 10 feet across into which a 6-foot pole could be thrust without touching bottom...these springs gushed violently at times, rolling the sand about a foot in the air. The big pools appeared to be quite deep and craterlike, and were a light blue-green color with no suspended sediments.

Various attempts have been made to measure the flows from the springs in this Northwest grouping. The best figures available for the larger springs are contained in the Harding report of April 1941, which shows discharges of "0.46 second feet" from Big Spring, "0.3 second feet" from Kidney Spring, and "0.43 second feet" from Snyder (Crater) Spring. In addition, he reports that the cummulative flow from some 65 seeps and other inflows in the area just east of the present Saratoga boat harbor was "approximately 3.90 second feet" in October of 1935 (April 1941:4-14). This last area appears to be the same area surveyed and described by Viers above. However, when Viers determined the flows, he arrived at a figure of 5.95 to 7.95 cubic feet per second (cfs) (0.17 to 0.22 cubic meters per second) (1964:52). This represents quite a discrepancy between the two sets of figures, but it should be pointed out that the 1935 figures are a results of measured flows whereas Viers' figures represent estimates. An important point to recognize in both cases is that these flows were determined at times when the lake level was extremely low as a result of drought conditions. Besides the fact that artesian pressures fluctuate with drought cycles, a sizeable amount of the water from these seeps and springs was most likely being transpired by the heavy growth of tules and cattails prevalent at the time. Such being the case, these estimates are probably not representative and so should likely be considered as minimums.

The waters flowing from each of the springs and seeps in this northwest corner of the lake appear to be eminating from a common source inasmuch as there is little variation in quality from one sample point to another. Based on the data compiled by Milligan, et al. (1966:Table 6), the mean concentration of total dissolved solids (TDS) is 1483 mg/l with a standard deviation of only 54 mg/l. Similarly, temperatures vary from 101°F (38.3°C) to 111°F (43.9°C) with a mean of 108°F (42.2°C) and a standard deviation of 3°F (1.7°C).

North Shore Springs

This area extends from an arbitrary point between the Jordan River and Dry Creek eastward to the American Fork boat harbor and from the shoreline out for a distance of approximately one mile (1.6 kilometers). Insofar as can be determined, all the springs in this area produce high quality fresh water flows. Harding (April 1941) referenced these springs with respect to their proximity to the "Worlton Ranch" and the "Bull Pasture Drain". He described one of these springs located approximately one half mile (0.8 kilometers) off shore as "...a cold spring having a clear flow suitable for drinking..." (:12).

Viers has provided the most complete information on this grouping and Figure 7 is a reproduction of a photograph he took in September of 1961. Three springs are evident in the photo. Two of these appear to be joined and are located along the left edge approximately one third of the way up from the bottom corner. The other is centered about one inch (2.54 centimeters) from the bottom edge. This third spring is most likely the one Harding was referring to. Viers described the smallest spring as being about 10 yards (9 meters) in diameter

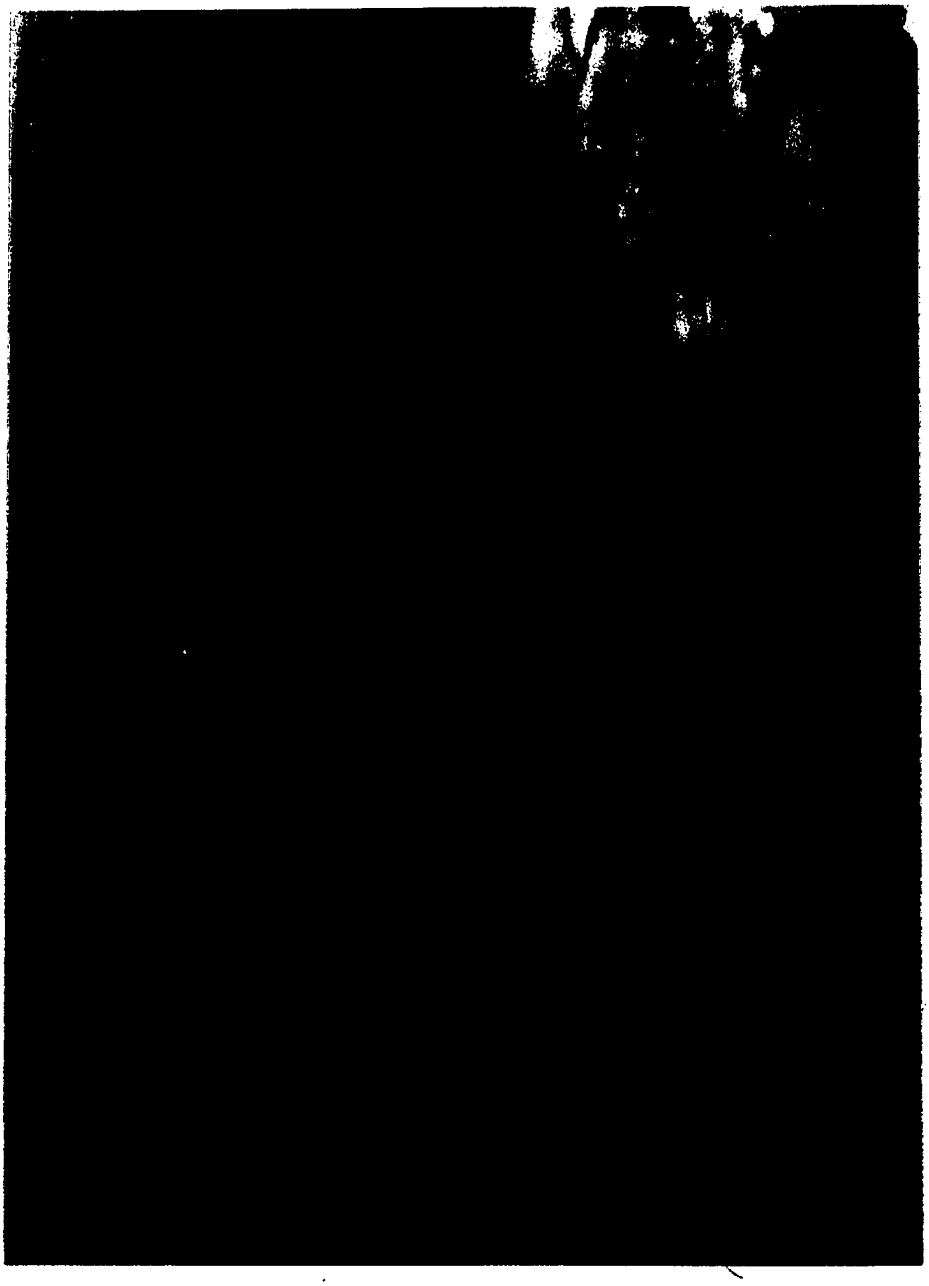

Figure 7. North Shore Springs (Courtesy USBR).

and its larger companion as roughly 20 by 30 yards (18 by 27 meters). The depth of both was approximately 10 feet (3 meters) and the water tended to rise in a series of boils, causing the fine sand sediments to mound around the edges of the pools. The combined flow was estimated at about 0.5 cfs (0.01 m^3/s). The third spring was reported to be about 20 yards (18 meters) in diameter and 26 feet (7.9 meters) deep with a flow of approximately 0.5 cfs (0.01 m^3/s). All three pools were filled with suspended sediment and the electroconductivity (EC) at 25°C was 517 micromhos/cm in the two shore springs and 482 micromhos/cc in the offshore pool. Temperatures were 63°F (17.2°C) and 68°F (20°C) respectively (Viers, 1964:42).

Geneva Springs

The springs in this area also produce cool water of fairly high quality and appear to be associated with the "Shallow Pleistocene" artesian aquifer (Fuhriman, et al., 1975:24). The main grouping of springs lies in a roughly north-south line from one fourth to one half mile offshore in Section 7, Township 6 South, Range 2 East. Another spring is located further north and near the shore. Figure 8, also reproduced from a USBR file photo by Viers, shows the effect of these springs on winter ice.

Generally, these springs can only be found by sounding or by the use of sonar gear, owing to the turbidity and depth of the overlying lake water. In the case of springs with a strong enough discharge to keep the fine sediments in suspension, even sonar is not all that useful in that the sediments trigger "false bottom" reflections (Viers, 1964:18). The sizes of the springs vary from 20 to 50 yards (18 to 46 meters)

Figure 8. Geneva Springs (Winter) (Courtesy USBR).

in diameter and from 9 to 15 feet (2.7 to 4.6 meters) deep (Viers, 1964:39); however, Harding (April 1941:22) describes a spring 23 feet (7 meters) deep and another 37 feet (11 meters) deep. The springs are rimmed with clay embankments (Viers, 1964:39) but the information supplied to Harding by various old-time trappers and fishermen indicates that flows are generally quite small (the largest being approximately 0.5 cfs or 0.01 m^3/s) (Harding, April 1941:21-23). The electroconductivity of these springs varies from 678 to 735 micromhos/cm at 25°C and the temperature from 68 to 76°F (20 to 24.4°C) (Viers, 1964:42).

East Shore Springs

The area covered by this grouping extends roughly from the Lake Bottom Canal drain just south of the U.S. Steel Geneva plant to the Provo Bay area. The major area of offshore spring activity is concentrated in the vicinity of Powell Slough. Another inflow area was spotted approximately 600 yards (550 meters) offshore just south of the Provo airport. There are also numerous shoreline seeps located from Powell Slough north to the Lake Bottom Canal drain.

Figure 9 is another of the photographs taken in September of 1961 (Viers, 1974:36,38). A fairly large crater-like hole is clearly visible in the lower center area of the picture. Viers stated that this spring is approximately 40 feet (12 meters) across and is located north of the Powell Slough inflow (:36). Two days after the photo was taken, an unsuccessful attempt was made to locate the hole from a boat. The party did locate two other smaller springs submerged in the lake and one onshore, however. These springs were less than 10 yards (9 meters) in diameter and from 10 to 15 feet (3 to 4.6 meters)

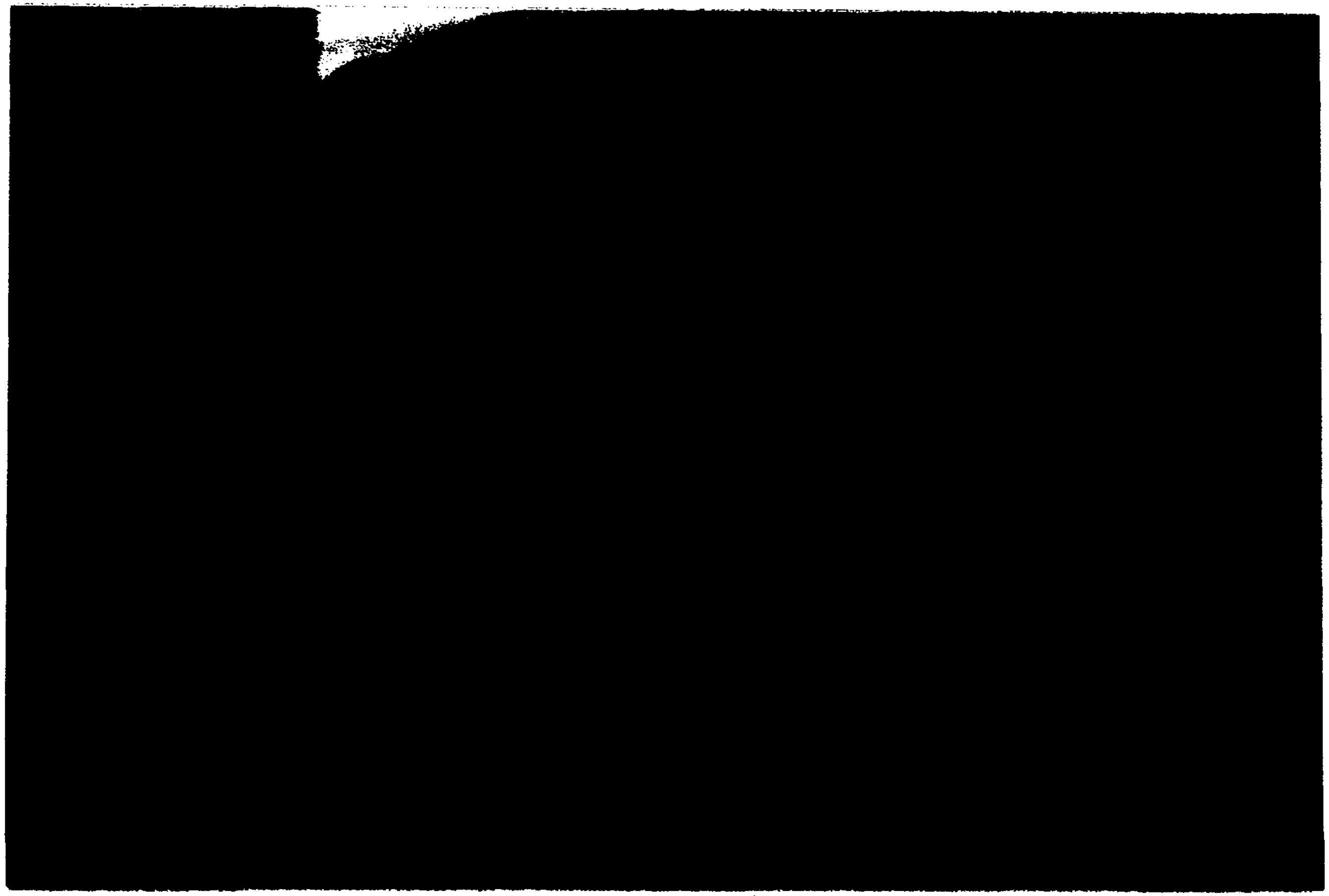

Figure 9. Spring Northwest of Powell Slough Outflow (Courtesy USBR).

deep with an EC of 635 micromhos/cm at 25°C and a temperature of approximately 77°F (25°C). They were filled with a very fine suspended sediment which varied in color from gray at the surface to black at depth. Viers fixed their location at one quarter mile (0.4 kilometers) north of the mouth of Powell Slough--just south of the hole in Figure 9 (Viers, 1964:39).

The spring area southwest of the Provo airport was evidenced during a winter flight by a thinning of the overlying ice (Viers, 1964:36). Insofar as has been determined, this spring has never been located or sampled from a boat.

Bird Island Springs

Bird Island (or Rock Island in the older literature) is composed entirely of tufa deposits, thus indicating considerable spring activity--at least at one time. As one can see from Figure 10, springs are present but none is of any great size. Harding (April 1941:15) reported that on a July, 1937 boat trip to the island no springs could be found rising above the "then elevation of the lake" (-6.25 feet or -1.9 meters below compromise), but he did observe some old spring outlets in the travertine formation. However, Viers (1964:56,61) noted that there is at least one large thermal spring located on the east bank of the north bay (north is at the top of the picture) which has sufficient flow to keep the bay fairly clear of suspended sediments (the flow was not sufficient to keep ice from forming however). The EC and temperature of the water in this area were measured at 14,800 micromhos/cm and 86°F (30°C) respectively. While no actual springs could be located in the west bay, a conductivity of 5,900 and a temperature of 75°F

Figure 10. Winter Photo of Bird Island Showing Evidence of Spring Activity (Courtesy USBR).

(23.9 °C) were measured here--both values much higher than lake readings. The other springs showed little or no evidence of inflow. It is interesting to note that while the pool located between the west and north bays showed no evidence of inflow, it did remain open through the winter.

There are two other springs near, but not necessarily associated with, Bird Island. One of these is reported as "...a deep spring 1/4 mile west of Rock Island..." (Harding, April 1941:18). This location appears to correspond with the deepest part of the lake. The other spring is reportedly located "...about halfway from Bird Island to the west shore...." (Viers, 1964:61). This spring was located by Viers as a hole in the ice on the same flight in which the "Provo airport spring" was spotted.

Lincoln Point Springs

These springs are the second best documented springs associated with Utah Lake. Numerous springs and seeps exist on and around Lincoln Point, but they can be generally grouped into six spring areas. By convention, they have been numbered in order proceding from east to west. Figure 11 is a winter shot of the first four springs taken in 1961. As a base of reference, the old stone building located on the east side of Lincoln Point is shown just above and to the left of spring number 1 and the old swimming pool is slightly above and to the right of spring number 3. Spring number 5 is located on the south shore of the boat harbor and spring 6 is just south of the harbor along the shoreline.

Harding investigated these springs and noted that the much higher concentrations of calcium and magnesium indicates that these

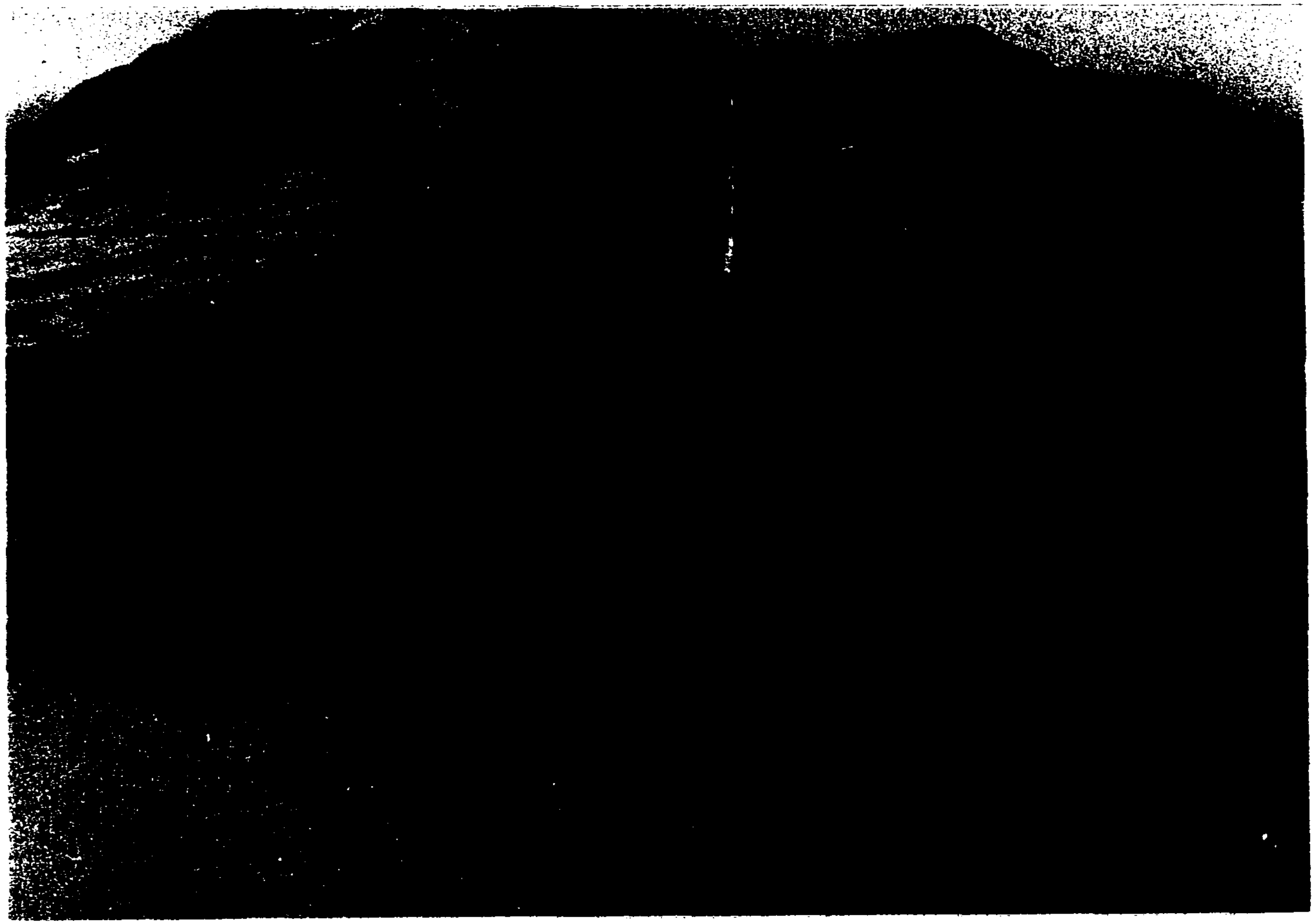

Figure 11. Lincoln Point Springs (Courtesy USBR).

waters move through different formations than the warm springs in the northwestern part of the lake (April 1941:25). In his sampling, however, he made an error in assuming that a sample from one spring was representative of the whole group. As Viers points out (1964:86), the aggregate quality is markedly different than that of the Saratoga springs, but he failed to recognize that constituent concentrations vary significantly between the springs on the east side of Lincoln Point and those on the west side. Table 2 summarizes Viers' (1964:36) flow and temperature measurements and selected quality data from Milligan, et al, (1966:Table 6) for these springs.

TABLE 2

LINCOLN POINT SPRING FLOWS AND QUALITY

Spring number	Average Flow (cfs)	Temperature (°F)	Mean EC @ 25°C (micromhos/cc)	Mean Cl^- (mg/l)
1	1.0	80 (26.7°C)	5588	1348
2*	0.5	90 (32.2°C)	7288	1891
3*		90 (32.2°C)		
4	0.6	90 (32.2°C)	9684	2557
5	---	85 (29.4°C)	---	---
6	0.7	100 (37.8°C)	---	---

*flows from 2 and 3 where channeled together and measured.

The data in Table 6 of Milligan, et al. shows an interesting correlation for Lincoln Point spring number 4 and the Bird Island springs. For instance, the mean TDS concentration in mg/l for spring 4 is 6393 with a standard deviation of 138. For the south Bird Island spring it is 6598 with a standard deviation of 65. Similar correlations are noted between spring 4 and the north Bird Island spring for calcium, magnesium, potassium, and boron.

East Goshen Bay, Goshen Bay and Pelcian Point Springs

These groupings are combined for discussion because previous investigators have found very little evidence of spring activity in any of these areas. Viers (1964) and Fuhriman (1978) observed numerous shoreline seeps in the East Goshen Bay area but none appeared to have significant flow. Brimhall (1976a:10) believes that these warm springs associate with faulting along the west side of West Mountain.

It has been the apparent consensus that subsurface inflows to the Goshen Bay area, if they exist, are so small as to be negligible. Mundorff (1978) feels any such inflows would be the result of irrigation return flow from cultivated areas on the west side of the bay. Harding walked the major part of the southern end of Goshen Bay in September of 1940 (lake elevation was -9.76 feet) and failed to note any evidence of inflow (Harding, May 1941:4). The USBR completed an extensive shoreline mapping project during the low water period of the early 1960's. These highly detailed maps show no evidence of seeps or springs near shore. However, acoustical profiling work by Brimhall, et al. (1976a) did indicate some activity in the deeper water of the bay.

Richardson (1906) is the only one to give much mention to the Pelican Point grouping and even his treatment is somewhat cursory. He simply states that "seep-springs" are abundant from Lehi to Pelican Point on the shoreline near water level and that there are also a few "...2-3 miles beyond Pelican Point where their presence is marked by low, marshy areas..." One of these latter springs was used at that time to irrigate "a few acres" of alfalfa (:56).

"Deep-Water" Springs

During the summer of 1975, Brimhall, Bassett and Merritt (1976a) profiled the bottom sediments of Utah Lake using a sonar-like device. The reflection patterns from this profiler imaged the thickness, distribution and character of the underlying sediments. Figure 12 is an example of the reflection patterns produced. This particular segment happens to be at the eastern end of a transect in Goshen Bay. Note the very obvious "rise" of the sediment layers to meet the shoreline. Figure 13 is a typical undisturbed profile and Figures 14, 15, and 16 represent what Brimhall termed "weak", "moderate" and "strong" spring areas, respectively. Based on these profiles, 38 suspected spring areas were identified. Most of these are depicted (along with all the other spring inflow areas previously discussed) in Figure 17. It is estimated that approximately 20 percent of the lake floor more than 1 kilometer offshore is spiked with springs or seeps (Brimhall, et al. 1976a:17).

Subsurface Inflow Estimates

As was indicated earlier in this chapter, most past inflow estimates have tended toward the conservative side. With the exceptions of Fuhriman, et al. (1975) and Brimhall, et al. (1976a), these estimates have been based on the "missing part" of the water budget, tempered by the knowledge that observations and measurements of known spring inflows indicate that individual flow rates are very small. By using an entirely different approach (i.e., a mass balance type of model

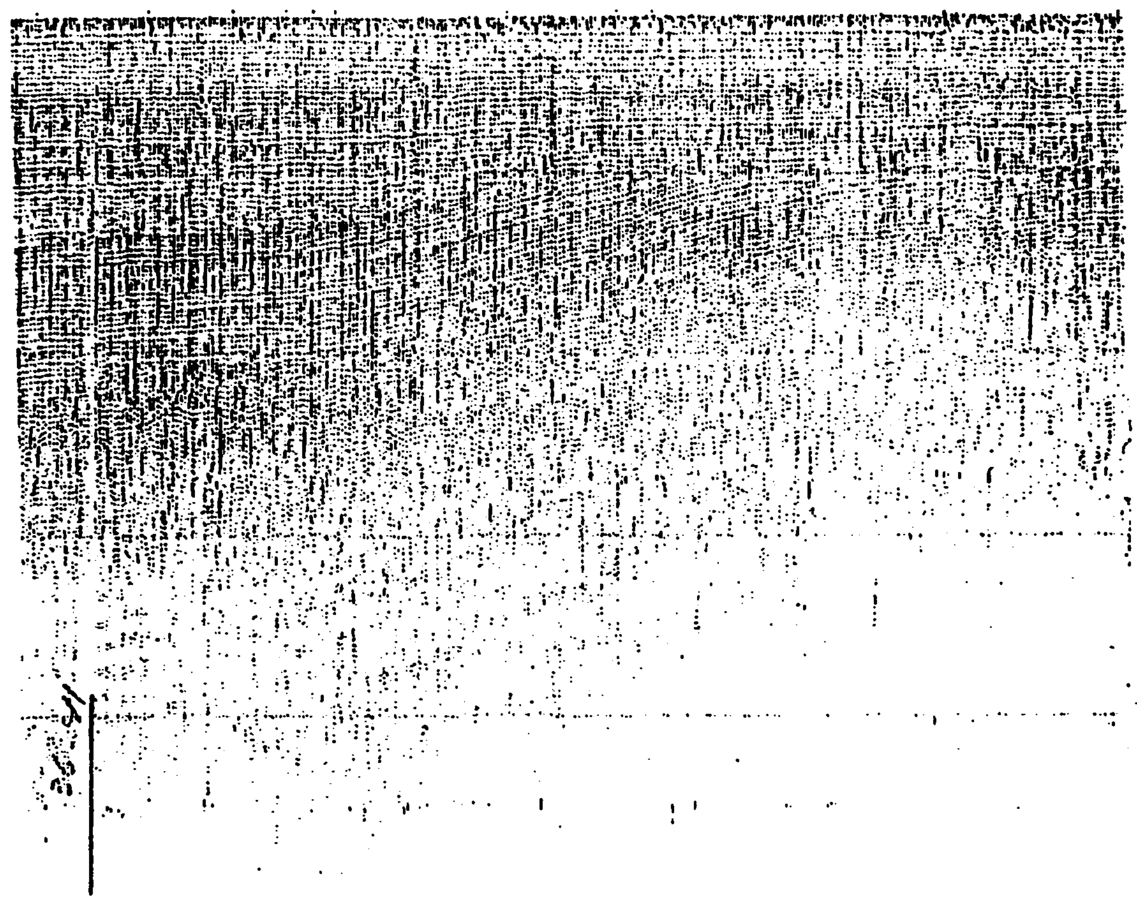

Figure 12. Near Shore Acoustical Profile, East Goshen Bay (Brimhall, et al., 1976a).

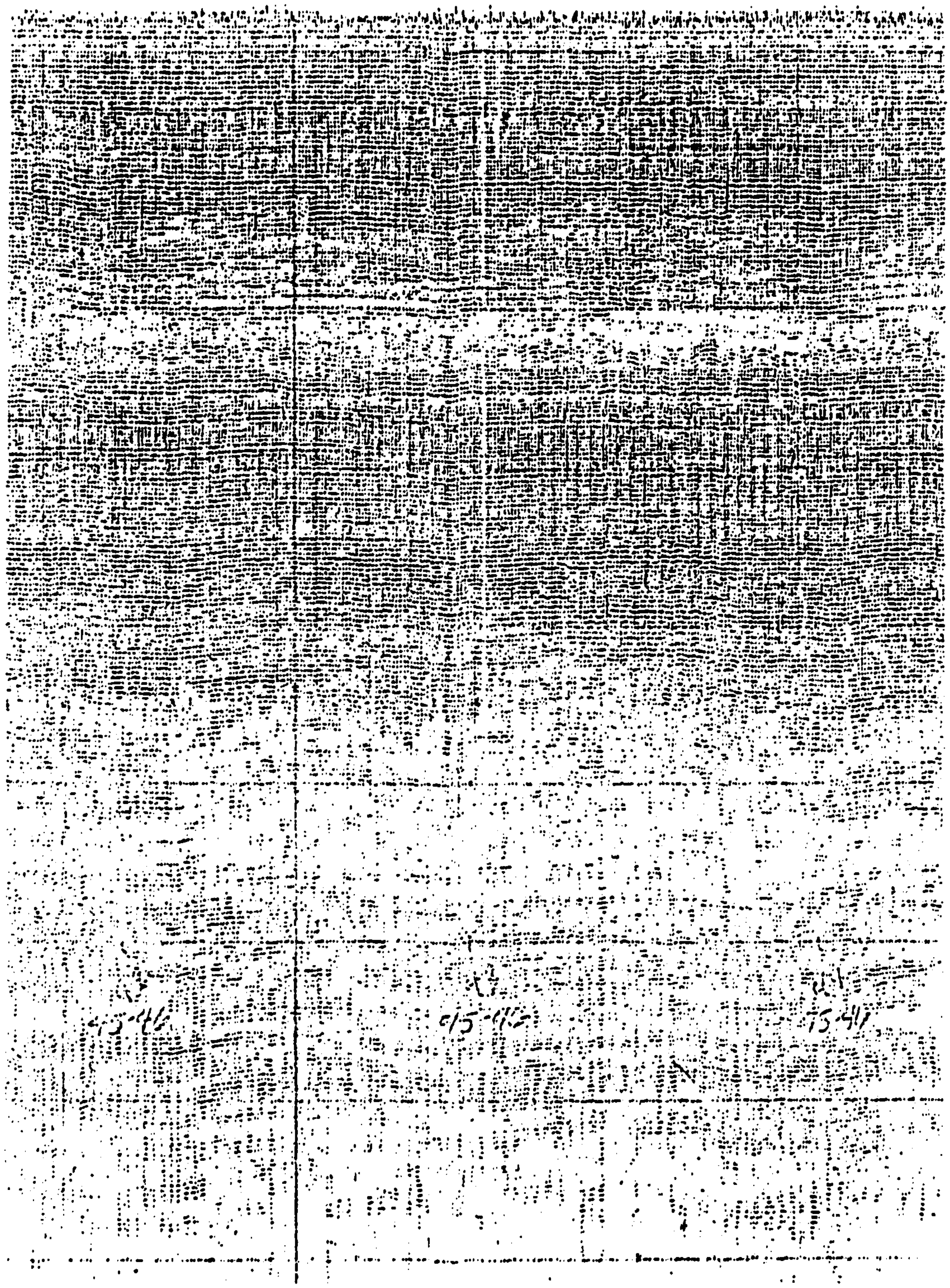

Figure 13. Typical Undisturbed Bottom Profile (Brimhall, et al., 1976a).

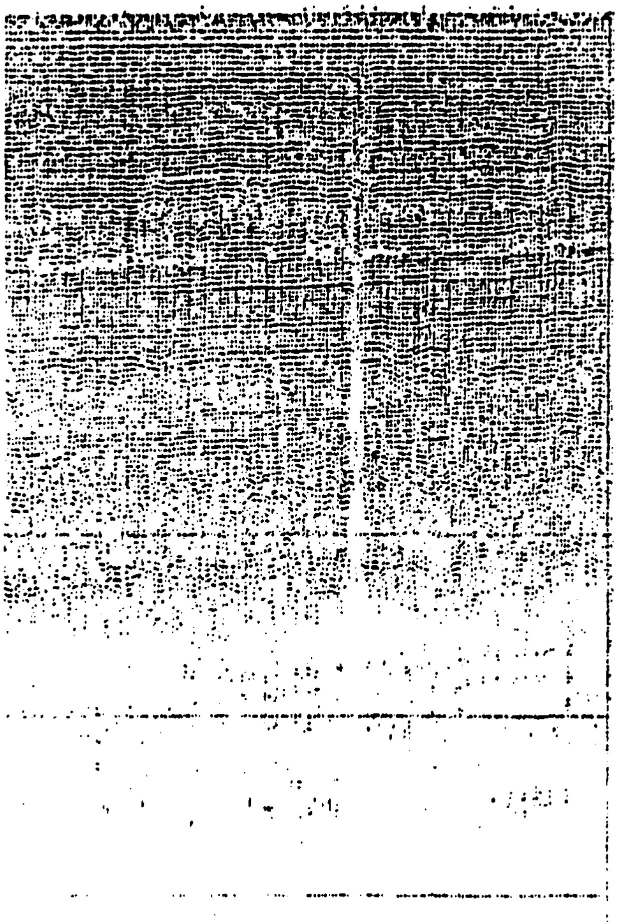

Figure 14. "Weak" Spring Area (Brimhall, et al., 1976a).

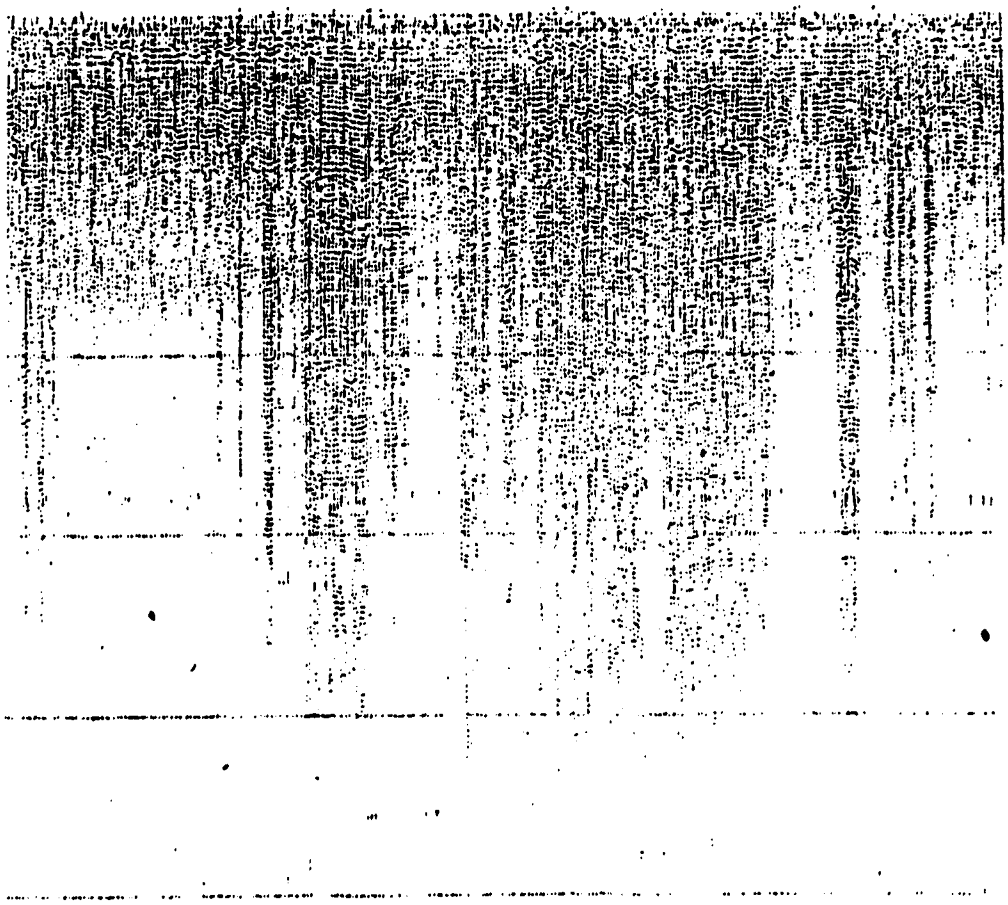

Figure 15. "Moderate" Spring Area (Brimhall, et al., 1976a).

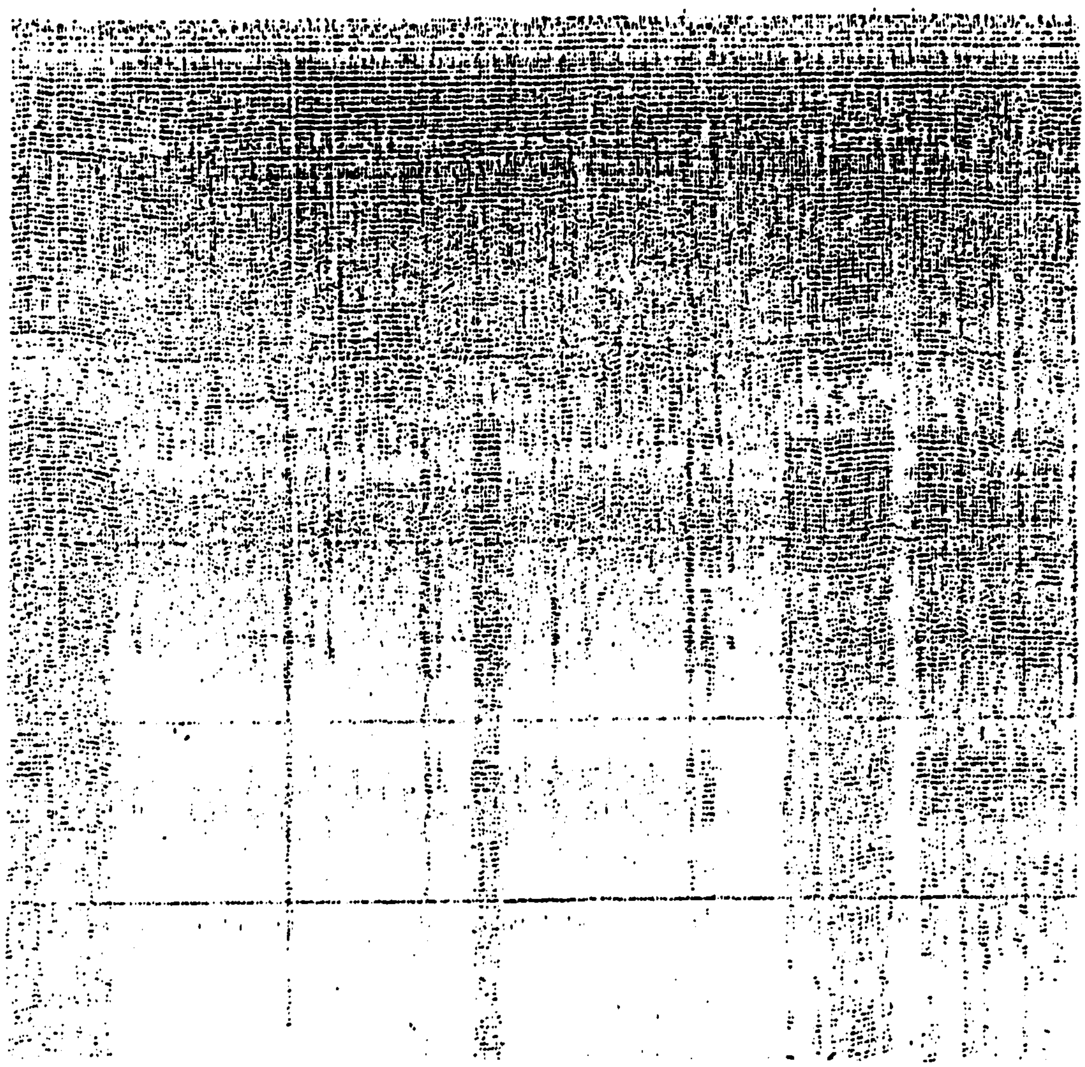

Figure 16. "Strong" Spring Area (Brimahll, et al., 1976a).

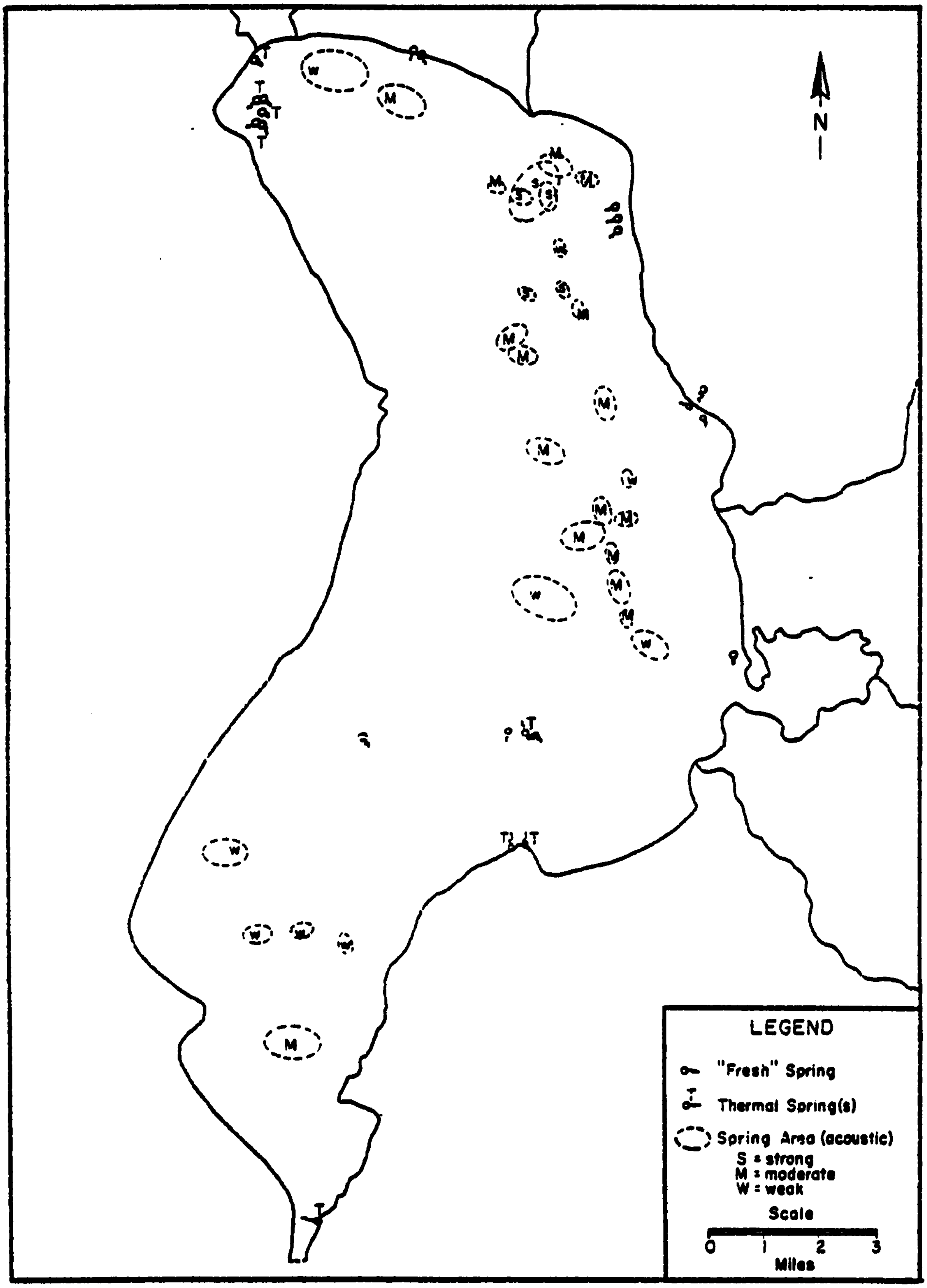

Figure 17. Previously Known Utah Lake Spring Areas.

for both water and salt balances in the lake), Fuhriman's group arrived at a ground water inflow estimate from two to five times that of other investigators. The Brimhall estimate is based on the Fuhriman figures and the acoustical profiling results and does not represent any independent calculations. Table 3 provides a comparison of several of these estimates. Note that an attempt to establish a common base of reference for the earlier estimates has been made by fixing the total average annual inflow at 660,000 acre feet (811,800 m^3) (Viers, 1974:17).

Disparity Among Estimates

The major reason for the disparity between Fuhriman's figures and earlier estimates is that in the traditional water budget approach, evaporation and subsurface inflow are fixed quantities controlled largely by the values of the other parameters. Quality is not considered. Errors associated with such an approach are discussed in the next section. In the salt balance approach, both evaporation and subsurface inflow are treated as variables while the other budget parameters (surface inflow, surface outflow, precipitation, and change in storage) are fairly well fixed--and quality becomes a major factor. The procedure is to adjust the evaporation rates and subsurface inflow volumes until agreement is reached between predicted and measured salt concentrations. The result is an upward revision of both evaporation and subsurface inflow. In discussing this revision with Fuhriman (1978) it was learned that as refinements have been made in the input data (due to more accurate and complete measurement of flows and climatic/weather factors), the trend has been toward a further increase in the subsurface inflow estimates. At the present time, it appears subsurface inflow (based on the salt

TABLE 3

Comparison of Previous Subsurface Inflow Estimates*

Investigator	Estimate in acre feet/year	Remarks
Harding (April 1941)	29-45,000	Investigator considers this estimate to be very liberal
Thomas (Hunt, et al., 1953)	"negligible"	
Viers (1964)	"3%" (20,000)	Investigator admits this is very conservative
Cordova (1965)	30,000	Represents only the discharge in Northern Utah Valley
Riley (1972)	52,800	
Lovelace (1972)	55,000	
Fuhriman, et al. (1975)	96,880	May yet be further revised upward--see following discussion
Brimhall, et al. (1976a)	16% (105,000)	Based on Fuhriman, et al.

*Where precentages are given, figures in parentheses are based on an assumed total average annual inflow of 660,000 acre feet.

model predictions) could be as high as 123,000 acre feet (151,290,000 m^3) per year.

Factors Contributing to Errors in Water Budget Approach

A conventional approach to computing the water budget of Utah Lake prior to Viers was to measure the outflow at the Jordan River outlet, compute the evaporation by multiplying the average surface area of the lake each month by 0.80 times the pan data at Lehi; and then compute the inflow as the algebraic sum of evaporation, measured outflow, and change in lake storage (Hunt, et al., 1953:69). This approach is subject to numerous errors. For example, for every percentile the pan coefficient is different than the actual, an error of from 3000 to 5000 acre feet (3,690,000 to 6,150,000 m^3) results (:71). In addition, sizeable seiches are not uncommon on the lake and stage recorder readings may vary considerably from one end of the lake to another. At compromise elevation a one inch (2.54 cm) difference in water level represents a change in storage of nearly 8000 acre feet (9,840,000 m^3) (Fuhriman, et al., 1975:23-24). Another error results from neglecting evapotranspiration losses due to marginal flooding during seiches and the consumptive use of phreatophytes along the shoreline and in the shallow areas of the lake.

As more complete data became available, attempts were made to incorporate inflow measurements and evapotranspiration estimates into the computations. However, some of these parameters cannot be directly measured and some flows may be overlooked. Small errors quickly compound and have a cummulative effect totally out of proportion with their individual sizes. For instance, Loveless (1972:41) points out that if ground-water is assigned the residual value in the water budget results, a five percent error in measured inflow will result in a 30 percent error in ground-water flow. Similarly, a five percent error in evaporation or outflow results in a 20 percent error in ground-water. While the salt balance model is still subject to some of these same errors, the accounting of quality in addition to quantity represents a significant refinement in budgeting the hydrologic cycle of the lake.

Chemical Quality Summary

Overall water quality has been a major item of interest in nearly every hydrologic study performed on Utah Lake. The high total dissolved solids (TDS) content has been the source of greatest curiosity--particularly in light of the relatively low TDS concentrations in the measureable inflows. The high concentrations have generally been attributed to the influence of the Lincoln Point and Bird Island springs, highly mineralized inflow from Goshen Valley, salt transport via wind and rain, and the residues from evaporation (Viers, 1964). As a result of the work by Fuhriman, et al., it is now known that evaporation has the greatest single effect, followed closely by mineralized spring inflows.

Data relating to the chemical quality of Utah Lake waters is presented in Table 4. Figure 18 is a companion to Table 4 in that the locations of the various sample sites are shown. Values listed in Table 4 for lake samples are the mean values for several samples taken at different times over an eight year period (1970-1978) at the particular location by Brigham Young University Environmental Analysis

TABLE 4

SUMMARY DATA ON THE CHEMICAL QUALITY OF UTAH LAKE WATERS

Sample Location	EC @ 25 C (micromhos/cc)	TDS (mg/ℓ)	Ca (mg/ℓ)	Mg (mg/ℓ)	Na (mg/ℓ)	K (mg/ℓ)	CO_3 (mg/ℓ)	HCO_3 (mg/ℓ)	Cl (mg/ℓ)	SO_4 (mg/ℓ)
1	2308	1572	189	55	223	24.5	4.5	341	355	399
2	2230	1483	183	52	217	25.9	12.4	289	345	425
3	---	947	93	44	112	21.3	---	131	182	271
4	---	572	70	31	45	24.0	---	193	69	155
5	912	554	69	27	29	7.9	---	289	87	120
6	11,417	7224	340	128	2035	175.2	14.1	687	3330	711
7e	5592	3505	218	80	881	97.9	12.6	479	1248	574
7w	9684	6393	406	136	1598	183.2	6.2	616	2556	1086
UL-11	1340	884	49	52	159	17.3	7.3	216	197	228
UL-13	1350	873	47	54	160	17.8	7.2	221	199	228
PB-11	1160	852	49	51	156	19.0	4.7	208	164	217
UL-24	1390	895	48	54	163	17.5	7.3	218	203	235
UL-15	1490	885	49	57	164	18.5	9.1	230	226	229
GB-3	2040	1206	50	70	260	24.6	6.4	243	311	312

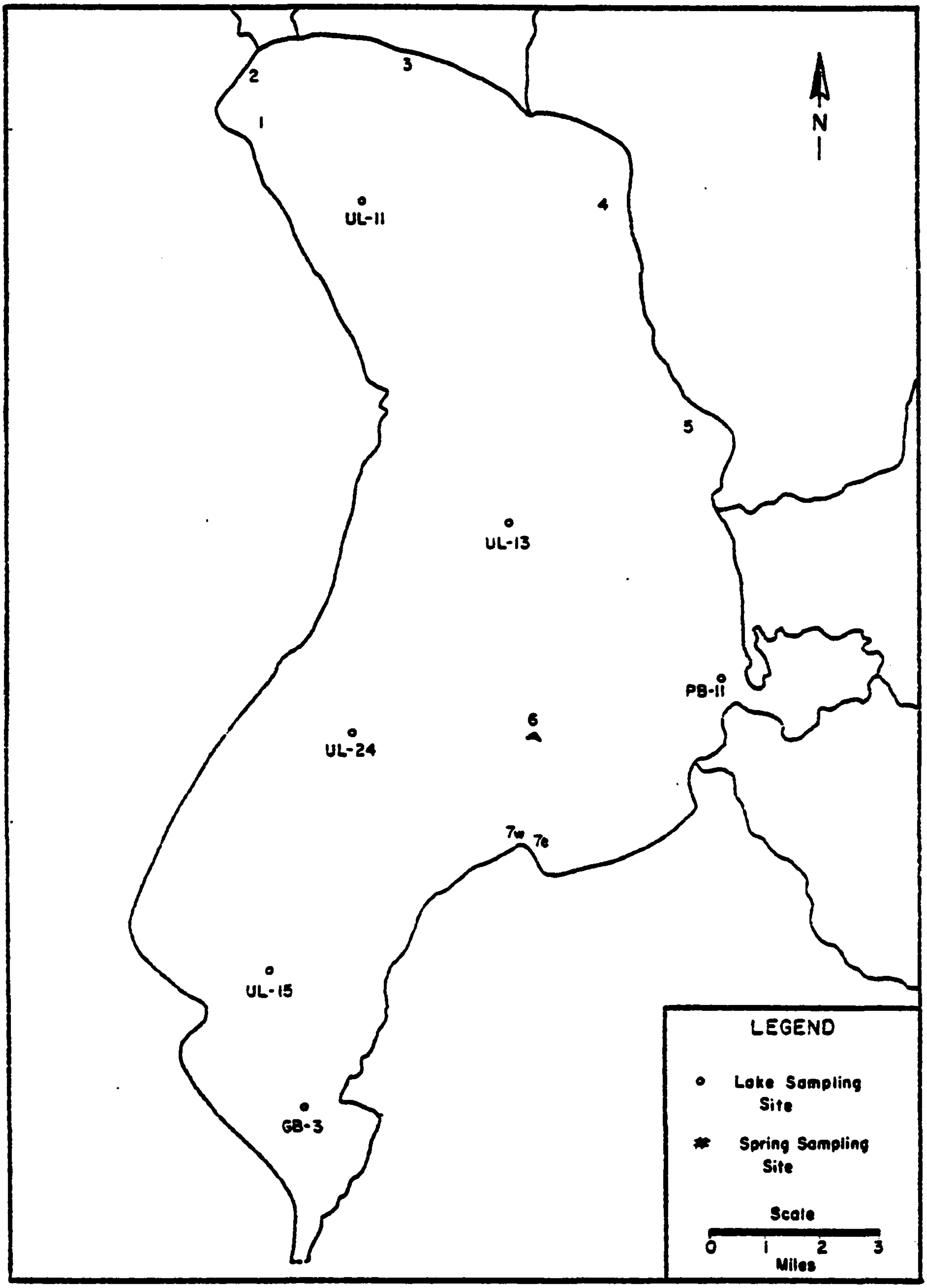

Figure 18. Chemical Quality Sampling Sites.

Laboratory. The data on spring inflows comes from Viers (1964) and Milligan, et al. (1966).

General Trends

From the data it would appear that on the whole, the main body of the lake is of fairly uniform quality. As one moves further south in Goshen Bay, however, the quality begins to decrease markedly as TDS, Mg, Na, K, Cl, and SO_4 concentrations show a definite increase. The slight variation in quality in the vicinity of PB-11 may well be due to the influence of the spring which Viers noted in that area as well as the outflow from Provo Bay.

Statistical Distributions

In reviewing the work done by Jensen (1972) with respect to computer-assisted statistical trend mapping of various quality constituents, some extremely interesting patterns were noted in the southern portion of Utah Lake. These maps were based on data collected during June and October of 1970. Through the courtesy of the BYU Department of Geography, the "SYMAP" deck used by Jensen was secured and selected "mappings" were reproduced. The maps for sodium, magnesium, potassium, and chloride are included in this text as Figures 19 through 22 respectively. The particularly noteworthy aspect of the first three maps is the similarity of the patterns along the southwestern shoreline of the lake. The interesting anomaly in the chloride map is the seemingly inexplicable "island" of lower chloride concentration in the middle of Goshen Bay. The smaller "island within the island" has an even lower level of chloride. If the reader will refer back to the three preceeding maps, he will note this same island exists for each of the other ions. Jensen makes

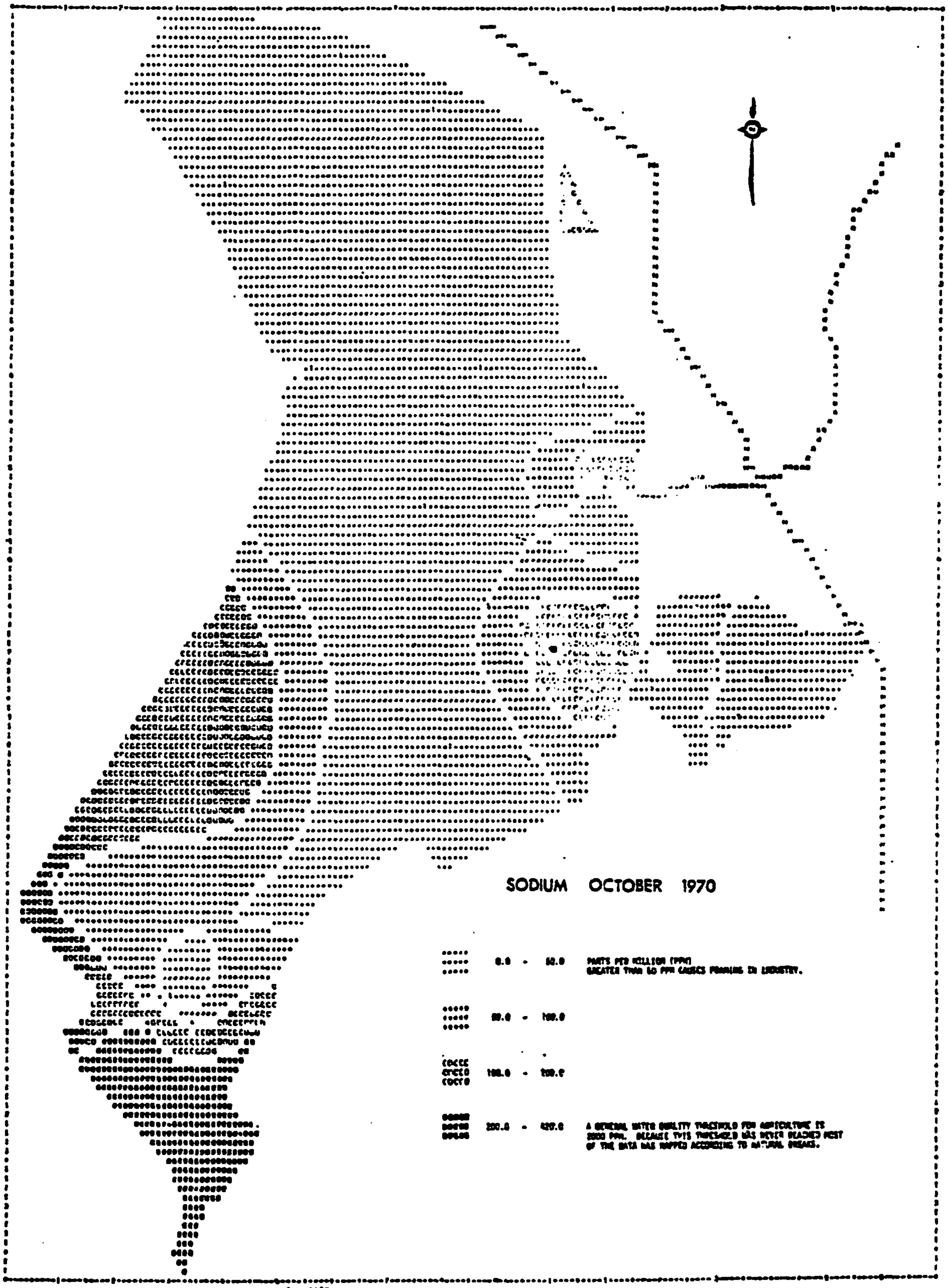

Figure 19. Sodium Distribution October 1970 (Jensen, 1972).

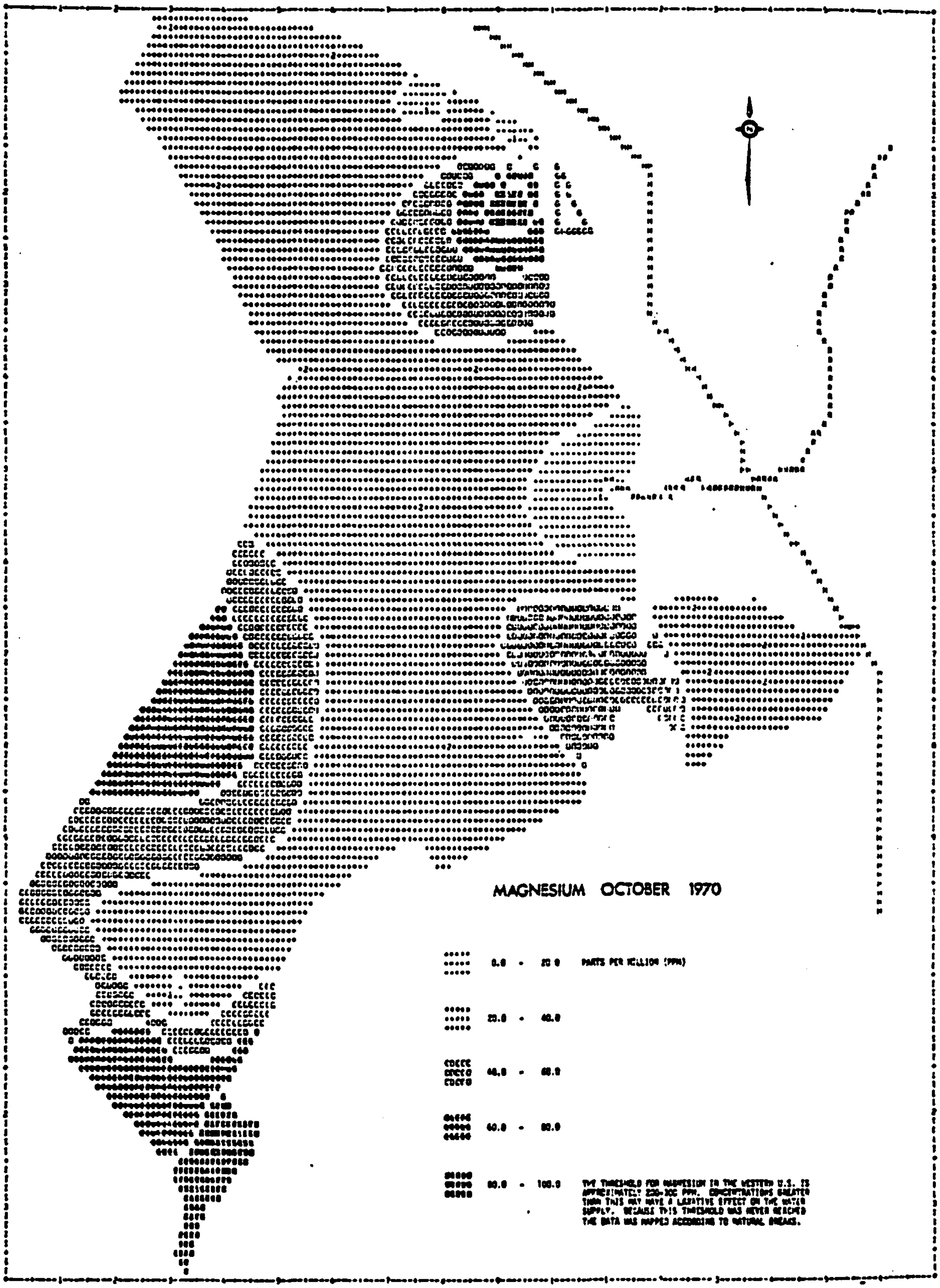

Figure 20. Magnesium Distribution October 1970 (Jensen, 1972).

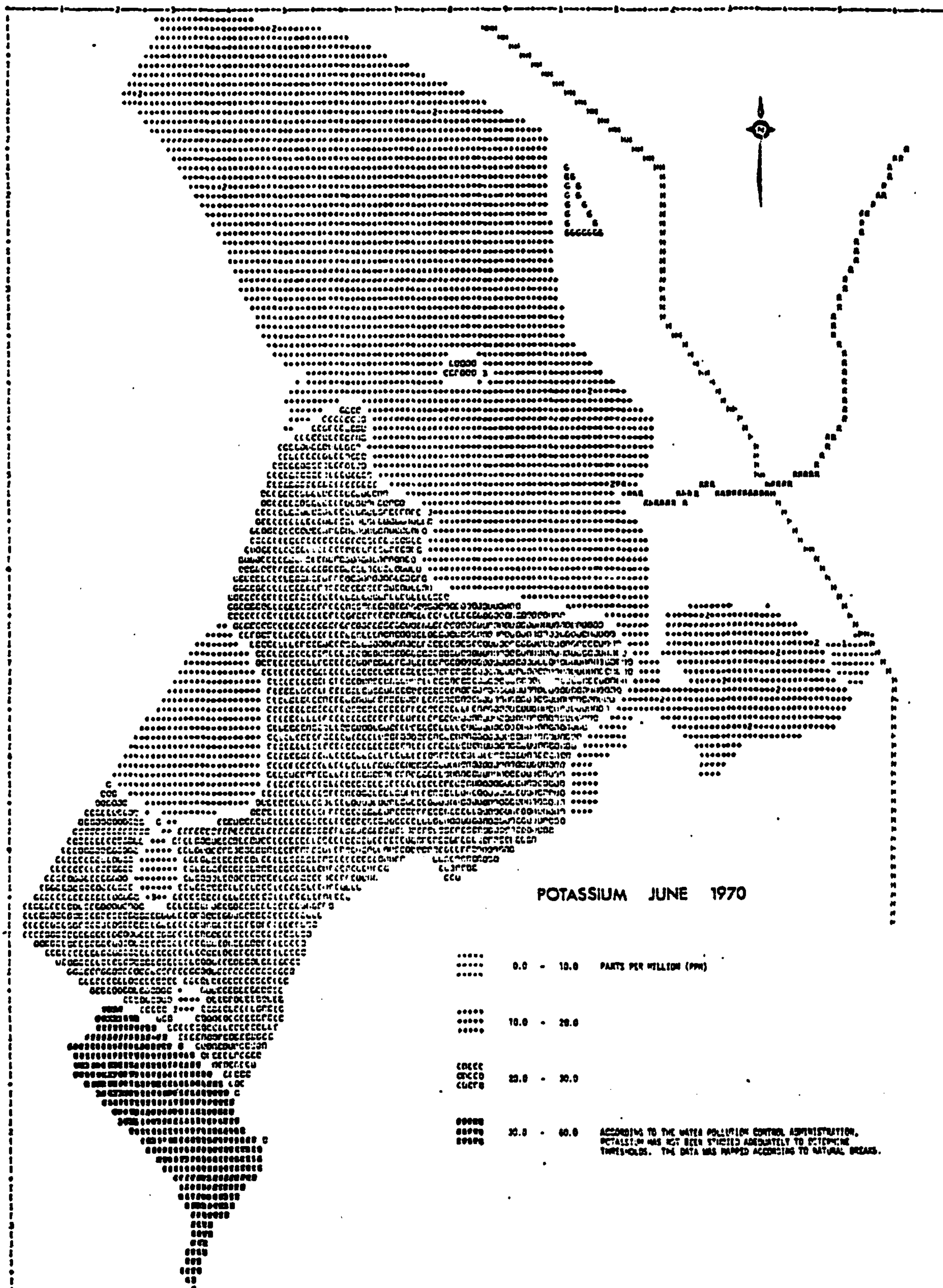

Figure 21. Potassium Distribution June 1970 (Jensen, 1972).

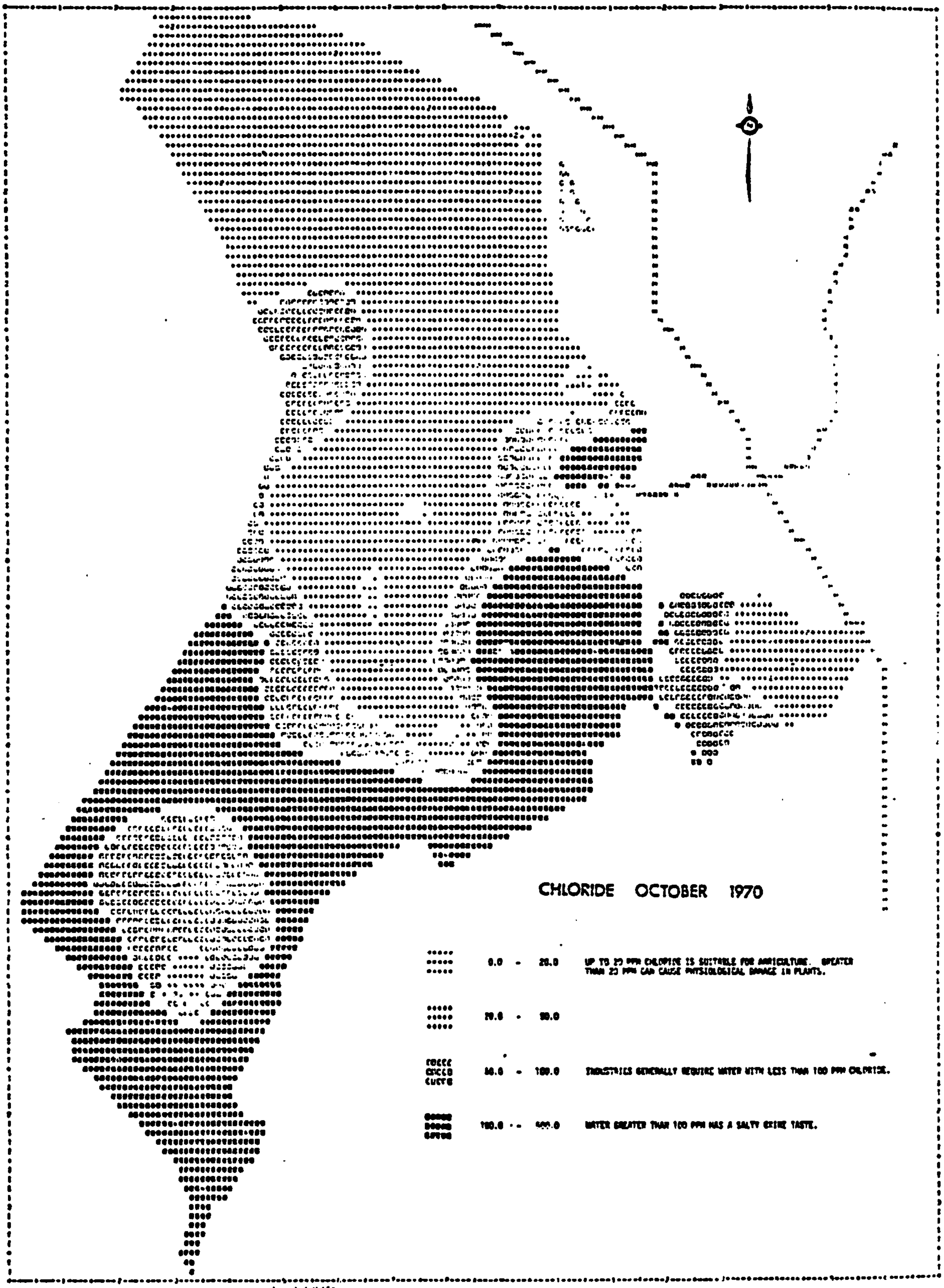

Figure 22. Chloride Distribution June 1970 (Jensen, 1972).

no attempt to explain these patterns as they have no real bearing on the objectives of his study. However, the author feels that these are definite indications of ground-water inflow in mid-Goshen Bay and along the western shoreline just north of the mid-bay.

CHAPTER 3

DESIGN OF INVESTIGATION

Because of the number and interdependence of the variables, unknowns and indeterminables associated with any geohydrologic study, subsurface investigations must be tailored to the area and employ a variety of analytical "tools". In every case, the value of the information must be weighed against the cost of obtaining it. Oftentimes, time and budget constraints prove to be overriding factors in designing the investigation. This study is no exception. While findings may have a significant impact on the diking proposal, the aforementioned contraints dictated that the information be obtained as rapidly and economically as possible.

Following a thorough review of the previous investigators' findings as well as the tools and technology available, the author decided upon the following research format:

1. Perform a detailed review and evaluation of literature addressing the geology and hydrogeology of the Utah Lake Basin insofar as it is known in order to obtain as complete an understanding of the subsurface environment as possible.

2. Inasmuch as Utah Lake is a remnant of the old Lake Bonneville, review and study literature dealing with the ground-water situation in some of the "sister basins" for possible clues as to common characteristics.

3. Through the use of thermal imagery (infrared), attempt to identify thermal gradients over the lake surface.

4. Using the thermal imagery as a guide, complete an aerial reconnaissance of the lake in an attempt to pinpoint inflow locations.

5. Once suspected inflow areas are identified, obtain representative samples and establish piezometric profiles.

6. Formulate conclusions and recommendations in accordance with the stated problem objectives.

Mathematical modeling of the Utah Lake Basin water budget and the use of dyes and tracers were also given serious consideration. The modeling approach was discarded primarily because of the lack of accurate data, the complex interrelationships previously mentioned, and the absence of clearly defined boundary conditions. Use of dyes and tracers was considered impractical because of distances involved between convenient injection points and suspected inflow areas. Not only would it be extremely difficult to predict the arrival time, the chances of the concentrations remaining at detectable levels would be small--particularly in light of the tremendous dilution potential in the inflow area of the lake.

Geology and Hydrogeology

Difficulty is encountered comprehending the nature of the problem and reaching valid conclusions until one understands and appreciates the nature of the Utah Lake Basin geology. Hence, any worthwhile investigation of subsurface flow begins with a strong geologic and hydrogeologic foundation. Inasmuch as the surface rocks in most of Utah Lake Basin consists of sedimentary valley fill, the stratigraphy and geomorphology of the basin provide the best clues as to ground-water occurrence and movement; however, the structural geology may have considerable impact on the routing of such flows. The primary sources of geologic and hydrogeologic data include previous geologic and ground-water studies conducted in the area, well drillers' logs, compiled well data, results of geologic coring, and various observable phenomenon. Information from each of these sources was compared and correlated to obtain a single basin-wide picture rather than a series of localized pictures of the subsurface environment.

Sister Basins

Lake Bonneville was a huge lake which, at one time, covered a large part of the state of Utah and even extended into parts of Nevada and Idaho. While terrain and climate may have varied considerably over such a broad area, conditions were likely quite homogeneous within specific smaller regions. Hence similar depositional patterns might be found in "sister basins" abutting the Wasatch Range. Geographical proximity and structural similarity exist in these basins, and it seems reasonable to assume correlation exists in relation to pre-Lake Bonneville sediments. Based on these suppostions, hydrogeologic environments should have many common features. A review of the findings and phenomena in some of these other basins for clues and/or support of hypotheses relative to the subsurface flows in the Utah Lake Basin could prove most beneficial.

Thermal Imagery

Refinements made in airborne thermal sensors during the Vietnam Conflict have resulted in the emergence of thermal imagery as one of the most beneficial tools available to the environmental researcher. Because of vast differences in the unclassified state-of-the-art since 1968 when the last low altitude thermal scan was made over Utah Lake, the author felt that the results of a new aerial thermal survey could prove invaluable--especially in view of the shallowness of the lake.

Airborne thermal imagery differs somewhat from infrared photography. With photography, infrared-sensitive film is used in a conventional camera consistent with the film size. For the most part, images obtained in this manner lack sufficient detail and clarity to be used in any study requiring high resolution and detailed levels of detection. Thermal imagery, on the other hand, employs an extremely sensitive scanning "radiometer" device mounted on the underside of the airborne platform (aircraft). When activiated, this sensor continuously "sweeps" the area below and electronically transmits reflected radiation data to a processor unit which converts this data to a photographic image. Since a scanning process is used, the image is reproduced on a continuous roll of film as opposed to single frames. Temperature variations are depicted by variations in contrast. On the image negatives, areas of higher temperature appear as areas of darker contrast.

In order to obtain the best thermal imagery results, flights should be made during the early morning hours just prior to sunrise, to prevent interference from reflected solar radiation; following a prolonged period of calm wind conditions, to allow thermal gradients to stabilize within the lake; and at a time when temperatures are as close as possible to maximum density temperature (4°C). Under these conditions any inflows should rise quickly to the surface as they will be warmer and hence "ligher" than the main lake water. In addition, at the time the mission is flown, weather conditions should be such as to preclude turbulence and cloud obscuration. The flight altitudes should be low enough to give maximum temperature resolution with minimum image distortion.

Aerial Reconnaissance

Although considerable effort has been made to identify inflow areas visually via aerial reconnaissance by other researchers (notably Viers and Fuhriman), none of these efforts represent a correlated and systematic search scheme. That is not to imply they were not planned or advantageously employed, but rather these efforts did not fully utilize the potential of aerial observation. These earlier flights did provide an invaluable information base for additional flights, however.

The objective of reconnoitering the lake was not to confirm the existence of previously identified inflows, but to possibly identify points and/or areas rendered favorable by the results of geologic studies and thermal imagery flights. In order to accomplish such an objective, special conditions are required:

1. The lake must be calm and the water relatively "settled".
2. Algal growth must be at a minimum.
3. The "lighting" must be right, i.e., water surface glare must be at a minimum.
4. If ice is present, it must be transparent enough to allow for the identification of variations in underlying water colorations.

5. More than one flight over each of the areas should be made (preferably under slightly different conditions) for positive identification and location.

6. Once an inflow location has been identified, provisions must be made to allow for immediate surface marking so that such points may be reached by boat for sampling and further study.

Samples and Piezometric Profiles

Temporary installation of piezometers provides a degree of refinement to ground-water investigationsin that pressures, water levels and hydraulic gradients may be determined. In addition, undiluted ground-water samples may possibly be extracted and results of the analyses used to more accurately assess inflow quality. Where possible, piezometers should be installed directly in, or as close as possible to, positively identified "springs". Additional efforts should also be made to establish a line of at least two more piezometers in a direction from the inflow point toward the suspected source.

In suspected inflow areas where positive thermal or visual identification cannot be made due to low volume and/or highly diffuse inflow, piezometric data may provide the only tangible evidence to support a postulated influx. In such cases, a line should be established parallel to the suspected direction of flow and piezometers placed so as to minimize effects of any local influences.

CHAPTER 4

GEOLOGY AND HYDROGEOLOGY OF UTAH LAKE BASIN

The importance of a comprehensive understanding of the geologic and hydrogeologic character of the Utah Lake Basin cannot be overemphasized. Such an understanding forms the basic framework for the entire investigation. This chapter is devoted to establishing this framework. The geologic discussion will include history, basin fill, structure of the Lake Mountains and Mosida Hills, and lake bottom geology. The hydrogeologic portion will deal with aquifers, piezometric contours, sources of recharge, and a discussion of the ultimate destination of the Basin's ground-waters.

Basin Formation

According to Gilbert (1890), the Utah Lake Basin was probably formed as a result of two major geological forces: the formation of the Basin and Range Province during which Utah, Goshen and Cedar Valleys were formed and the formation of Lake Bonneville of which Utah Lake is a remnant. The folding of mountain structures was the result of the Laramide Orogeny.

More specifically, Hunt, et al. (1953) points out that evidence strongly indicates that Utah Valley was formed as a result of block faulting, or the raising of adjacent mountain blocks relative to valley blocks. The same is considered true for Goshen and Cedar Valleys. Thus these valleys are basically structural grabens which have evolved over many years. From all indications, the faulting which initiated the valley development may be continuing as vigorously today as in the past (Hunt, et al. 1953:40). Brimhall, et al. (1976b:4) suggest that a "dynamic equilibrium" seems to have been established over the last 15 million years between the uplifting/downdropping and the erosion/infilling processes.

The exact beginnings of this faulting activity have yet to be determined, but it is generally accepted that the basin began to develop as a structural entity about mid-Tertiary time and had obtained appreciable size by late Tertiary time. By early Pleistocene, the proportions we recognize today had been obtained. A simplified geologic map of the area is shown in Figure 23.

Basin Fill

Sediments comprising the valley fill in the basin exist in fairly distinct layers, each associating with a particular geologic period. These layers are at their thinnest in the northern end of the basin and gradually thicken as one moves in a southeasterly direction. For the most part, the valley sediments appear to have been derived from the rocks of the surrounding mountains.

Depth of Fill

Measurements obtained by the U.S. Geological Survey in 1947 using an airborne magntometer indicated that the fill in Utah Valley was very uniform (no anomalies to indicate buried hills containing dense rocks) to a depth "...of at least a few thousand feet..." (Hunt, et al., 1953:37-38). Later, Cook and Berg (1961) reported that gravimetric tests over the basin implied a depth of several thousand feet. Based

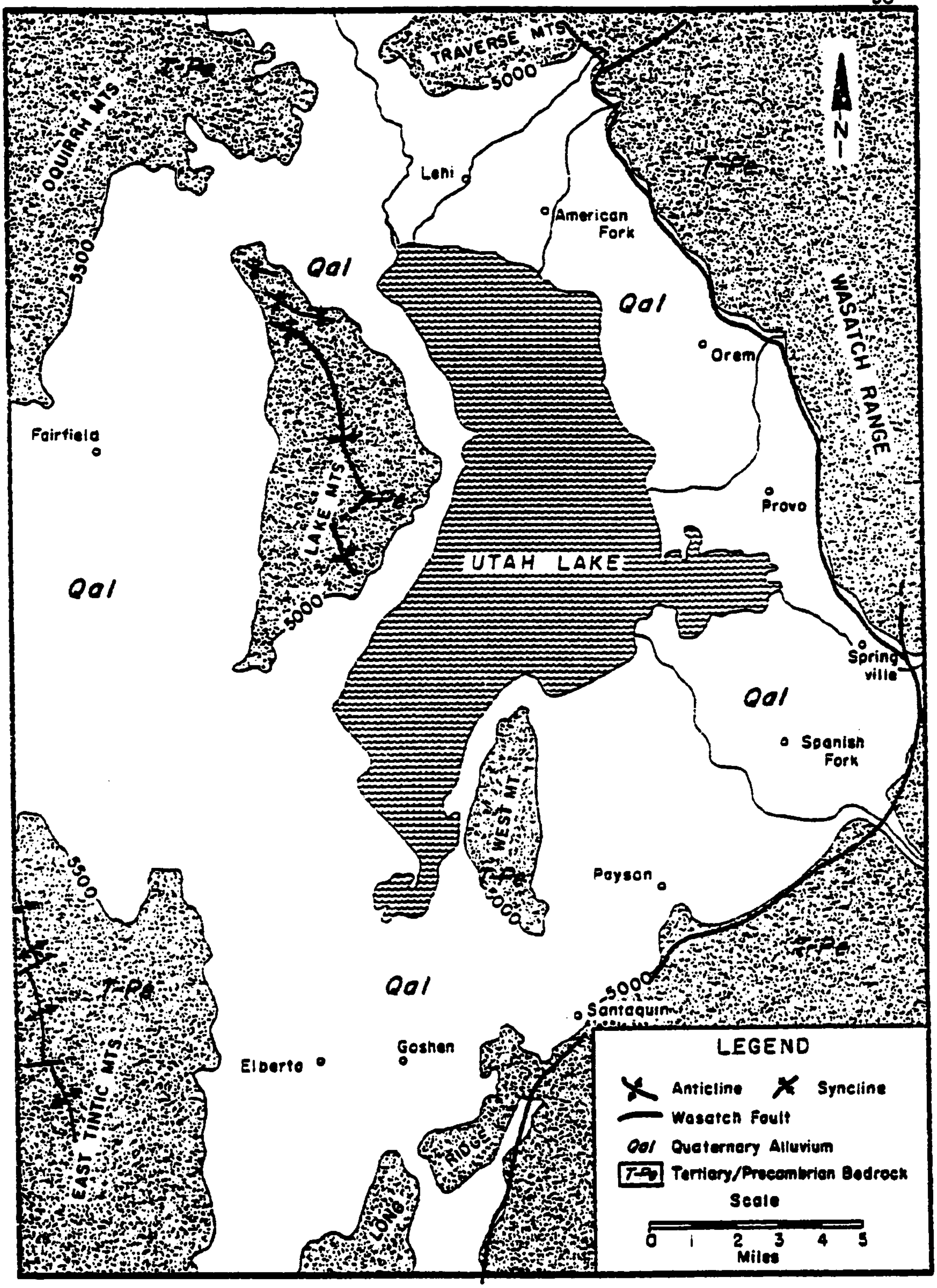

Figure 23. Simplified Geology of Utah Lake Basin (Adapted from Brimhall, et al., 1976b).

on the results of this gravity survey, it has been assumed until only very recently that the depth of fill approached a probable limit of some 8000 to 10,000 feet (2400 to 3000 meters). However, information from the drilling of a wildcat well about one mile (1.6 kilometers) west of the city of Spanish Fork by the Gulf Oil Company during the fall of 1977 proved that limit very conservative. While much of the information is still confidential, a company spokesman did say that drilling was abandoned without reaching bedrock at a depth of 13,000 feet (3962 meters). He went on to say that their geologists now estimate that Paleozoic formations may not be reached for another 5000 to 7000 feet (1500 to 2100 meters) (Mann, 1978).

Pre-Lake Bonneville Sediments

Working upward from the older, deeper sediments, the first identifiable formation is the Salt Lake Formation. This is a considerable thickness of well stratified volcanic and other debris which appears to have been deposited in quiescent water, such as in lake or playa conditions, sometime in late Tertiary time. Reworked ash, probably washed in from pyroclastic deposits which fell on surrounding highlands, and conglomerates, from the erosion of bedrock and lava formations, are interstratified with this volcanic debris. Since the valley was pretty well formed by this time and since there is no evidence of any shorelines above the Bonneville shoreline, it is assumed that this lake(s) and/or playa(s) corresponded roughly to the present valley areas and never exceeded the size of Lake Bonneville (Hunt, et al., 1953). Based on well logs, the depth to the top of these Tertiary deposits varies from approximately 175 to 200 feet (50 to 60 meters) in the north end of Utah Valley to 450 to 500 feet (135 to 150 meters) in the south end.

As the period of vulcanism waned, the last of these Tertiary lakes receded and perhaps even disappeared; and pre-Lake Bonneville Pleistocene time was ushered in. This phase of sedimentation history appears to be characterized by periods when huge alluvial fans extended far into the valleys. These, in turn, were separated by at least three periods when lakes, presumably glacial, were formed. The fanglomerate deposits most likely were the result of mudflows and other flood deposits (Hunt, et al., 1953). Depth to these layers varies from less than 50 feet (15 meters) near Lehi in the north to nearly 300 feet (90 meters) south of Elberta.

Lake Bonneville Sedimentation

Conclusion of the Pleistocene time was marked by the formation of Lake Bonneville. At its maximum size, the lake covered an area of some 20,000 square miles (50,800 square kilometers), see Figure 24, and obtained a maximum depth of about 1000 feet (305 meters) (Bissell, 1968).

During its multiple-life span, Lake Bonneville experienced at least three major substages (Figure 25): the Alpine, Bonneville, and Provo. Of the three, the Alpine substage contributed the most sediment to the Lake Bonneville group. These Alpine sediments are characterized by vast quantities of fine-grained materials, with over half being silt size or finer. It was during the Bonneville substage that the lake rose to its maximum elevation, eventually breaching Red Rock Pass near Preston, Idaho, and flowing into the Snake River drainage.

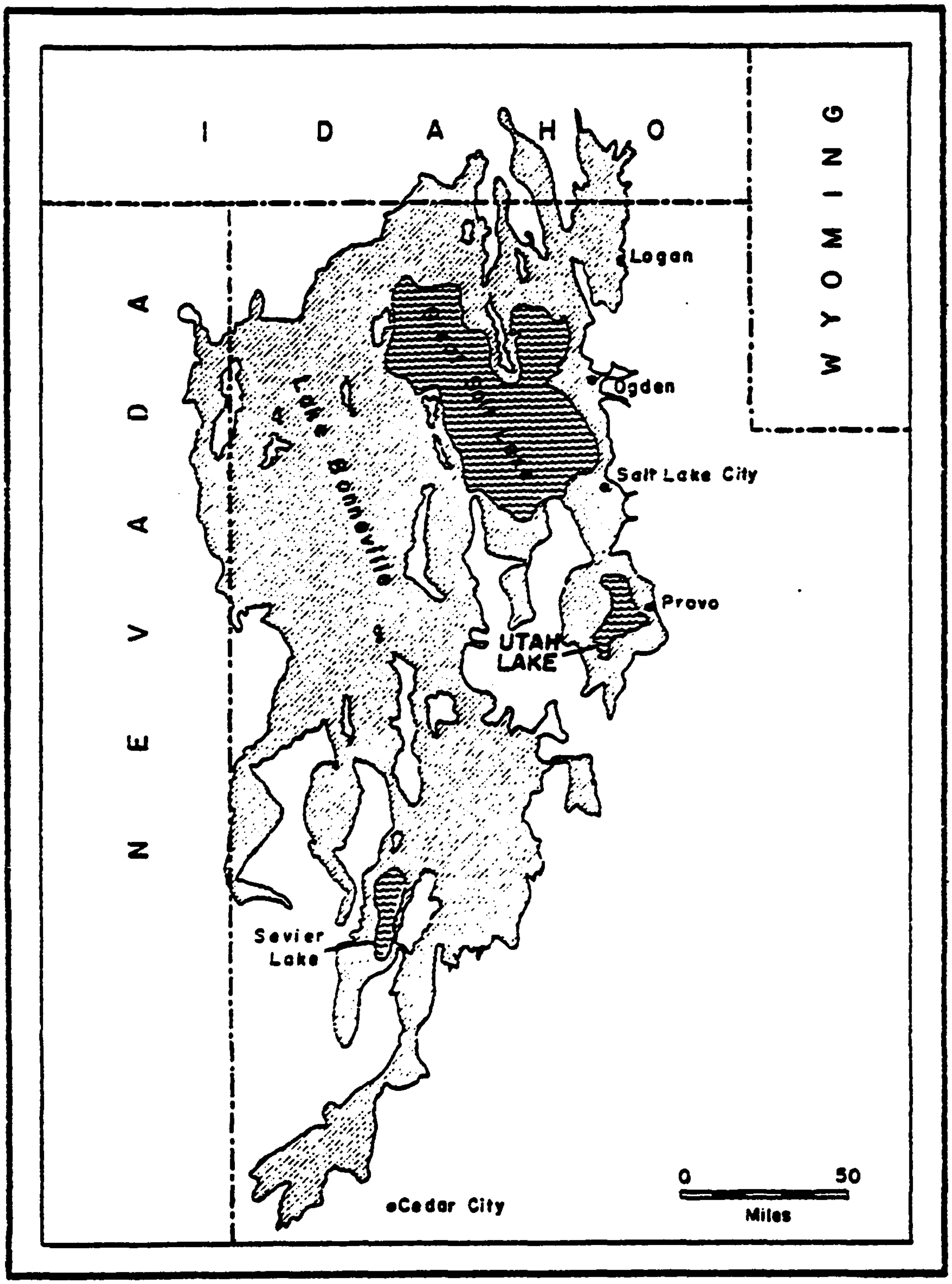

Figure 24. Lake Bonneville at its Maximum Size (Adapted from Bissell, 1968).

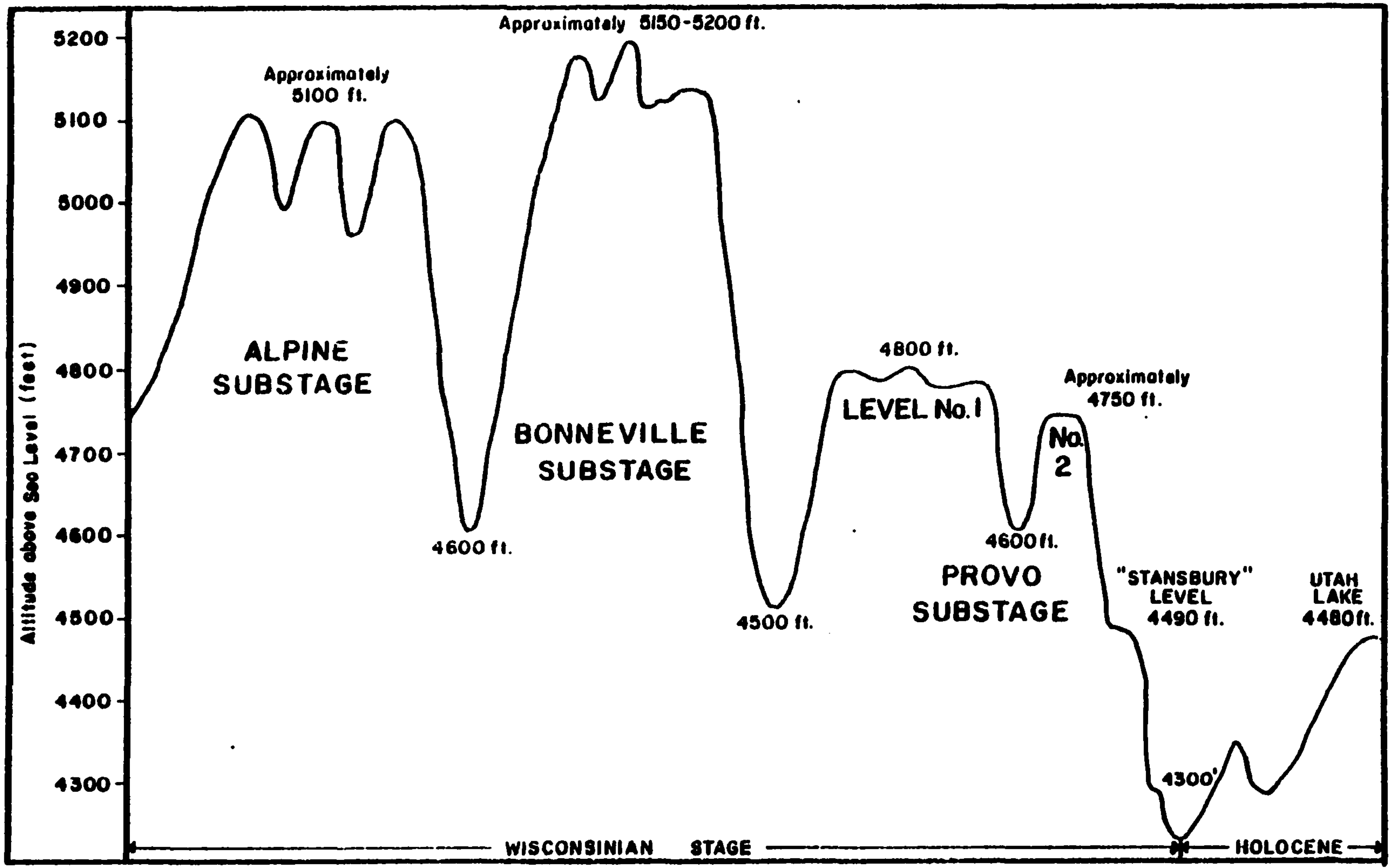

Figure 25. Major Lake Bonneville Substages (Adapted from Bissell, 1968).

However, when compared to the Alpine deposits, the volume of Bonneville sediments is insignificant--indicating the Bonneville substage was relatively short lived (Hunt, et al., 1953:40).

Once Lake Bonneville overflowed Red Rock Pass into the Snake River Valley, there was a rapid and permanent drop in the water level (nearly 300 feet or 90 meters in Utah Valley) and the Provo substage was initiated (Gilbert, 1890:260). During this stage, large lake deltas were built at the mouths of the principal streams draining the Wasatch Range. Types and proportions of coarse and fine-grained deposits of that period are very similar to that being transported into the valley today and are markedly different than those of the Alpine formation deposits previously described (Hunt, et al., 1953:41).

From here, Lake Bonneville gradually receded leaving Utah Lake, Salt Lake and Sevier Lake as surviving remnants. Sediments have continued to accumulate in the valley but at such a slow rate as to have had an insignificant impact (Brimhall, et al., 1976b:24).

The thickening of sediment layers from north to south seems to indicate a tilting of the valley grabens to the southeast. This condition is probably caused by a greater movement along the Wasatch Range than along the western side of the basin.

Cedar Valley Fill

While Cedar Valley has a common geologic history and structure, it does differ slightly from Utah and Goshen Valleys to the east. For one thing, the floor of Cedar Valley averages some 300 feet (90 meters) higher than the level of Utah Valley although it does still slope from northwest to southeast as does Utah Valley. Due to its higher elevation, Cedar Valley has not likely accumulated as much depth of fill as the other two valleys in the basin. Cedar Valley fill is composed primarily of alluvial fans; lacustrine clay, silt, sand, and gravel; and eolian sand and silt. Because of the rather sheltered nature of the valley, which would tend to minimize lake currents, and absence of large perennial streams, which could carry coarse debris, the lacustrine deposits tend to be rather impermeable, well sorted beds of silt and clay intermixed with a few permeable beds of shoreline sand and gravel. Few large deposits of sand and gravel are found in the valley interior (Feltis, 1967:10).

Structure of the Lake Mountains and The Mosida Hills

Lake Mountain and the Mosida Hills separate Cedar Valley on the west from Goshen and Utah Valleys on the east. Figure 26 is an enlarged view of this area. Since Feltis (1967:12-13) has suggested that some Cedar Valley ground-water may be leaving the valley "...along the bedding planes and through fractures and solution channels in the rocks...", attention needs to be given to the structure of this area. Feltis' theory is given further discussion in the hydrogeologic section.

Geology of Lake Mountain

Lake Mountain is basically a syncline comprised of faulted and jointed sedimentary formations. Synclinal axes are depicted in Figure 26. The major syncline has been offset approximately one third of a mile (0.54 kilometers) to the west at its southern end, due to tear faulting (Bullock, 1951:25). The geologic sections A-A', B-B' and C-C' depicted in Figure 26 are reproduced in Figure 27. The following

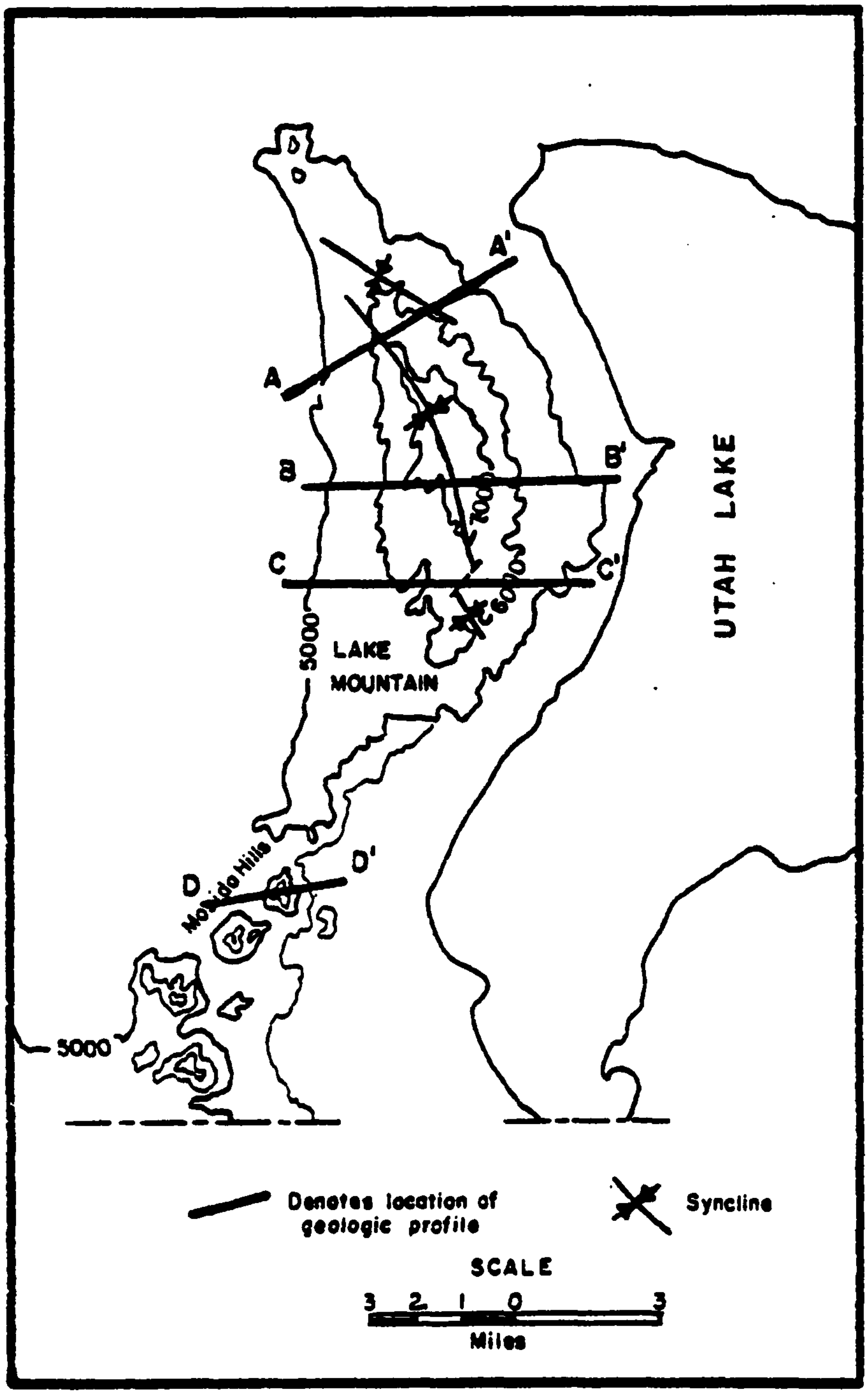

Figure 26. Lake Mountain and the Mosida Hills

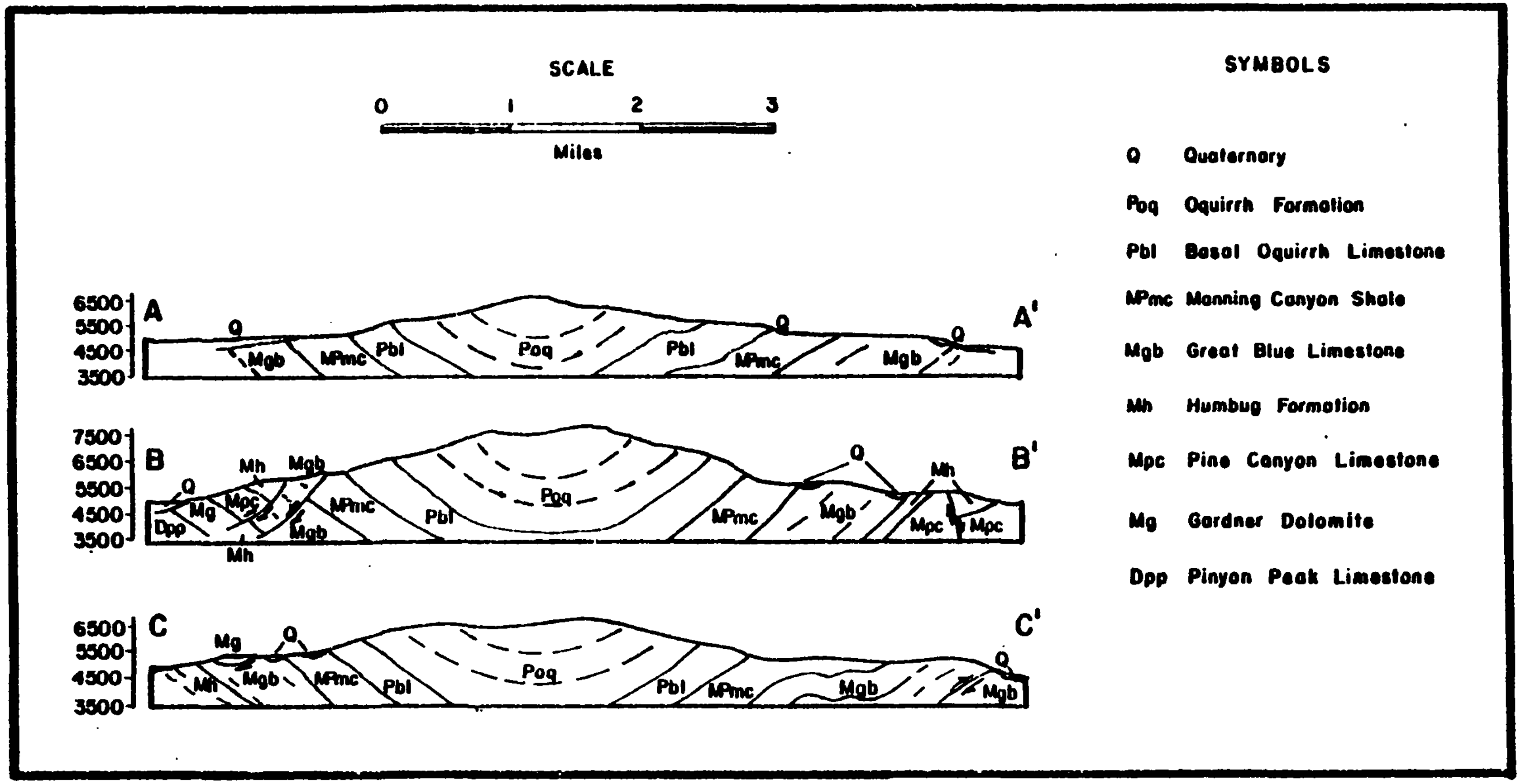

Figure 27. Geologic Sections of Lake Mountain (Adapted from Bullock, 1951).

descriptions of the various constituent formations is based on Bullock's field work (1951:11-16).

The Oquirrh Formation consists of alternating beds of sandstone, limestone and orthoquartzites. Underlying this formation is the Manning Canyon Shale, predominantly a black variegated shale with orthoquartzite beds common in the lower part and limestone beds in the upper. Below this is Great Blue Limestone which is a massive to thin-bedded blue limestone with shale near the base and an abundance of chert in the upper horizons. The Humbug Formation is composed of interbedded sandstone, orthoquartzite, dolomites, and limestone. Pine Canyon Limestone is the next major Formation. It is characterized by alternating layers of chert and limestone. The upper layers tend to be cherty and dolomitic while the lower layers have zones of fine-grained to coarsely crystalline limestone. Beneath the Pine Canyon is Gardner Dolomite. The basal member of this formation consists of sugary dolomites while the upper layers are primarily fossiliferous limestone. The final level of the section is Pinyon Peak Limestone, which grades from limestone to dolomite as one moves northward. There appear to be three distinct layers within this formation: the basal, consisting of medium to coarse-grained dolomites and limestone which tend to weather to a sandy texture; the mid-layer, comprised of irregularly mottled dolomites; and the upper layer of calcareous and sugary dolomite. The water bearing and transmitting capabilities of the constituents of these various formations will be covered in the hydrogeologic section.

Bullock (1951) made two observations which are of particular interest to this study. The first is that the entire Lake Mountain block is tilted southward (apparently happening during the Basin-Range orogeny) (:37). This tilting is emphasized by the southward tilt of the summit as well as the southward drainage of the two major canyons, Mercer and Long Canyons. The second interesting observation is that the synclinal axes, faults, joints, and stratigraphic horizons "...are important controls of drainage lines..." (:39).

Geology of the Mosida Hills

The Mosida Hills lie immediately south of and adjacent to the Lake Mountains, as may be seen in Figure 26. A series of low passes through this area connect Cedar and Goshen Valleys. According to Hoffman (1951), the sedimentary formations as depicted in the geologic section in Figure 28 all have a generally northerly to northwesterly strike and a northeasterly dip averaging 45 to 50 degrees and disappear into Cedar Valley alluvium. Structurally, these hills tend to be characterized by generally north-south anticlines with high angle faults striking normal to the structural trend and by thrust faults.

Geology of the Floor of Utah Lake

During the field season of 1904, a team from the U.S. Reclamation Service performed a series of "washed borings" at various locations in the floor of Utah Lake. While little specific information was obtained, it was determined that the sediments well away from the shore were characterized by a very soft "...very fine, smooth, slick clay, light colored on top, and changing...to a bluish color under the surface...". The clay was somewhat stiffer toward the shore and was mixed with sand. Along the north and east shores they found mostly sand extending some distance out from shore where it merged into clay. In some cases, the sand was quicksand. Along the western shore a strata of hard material

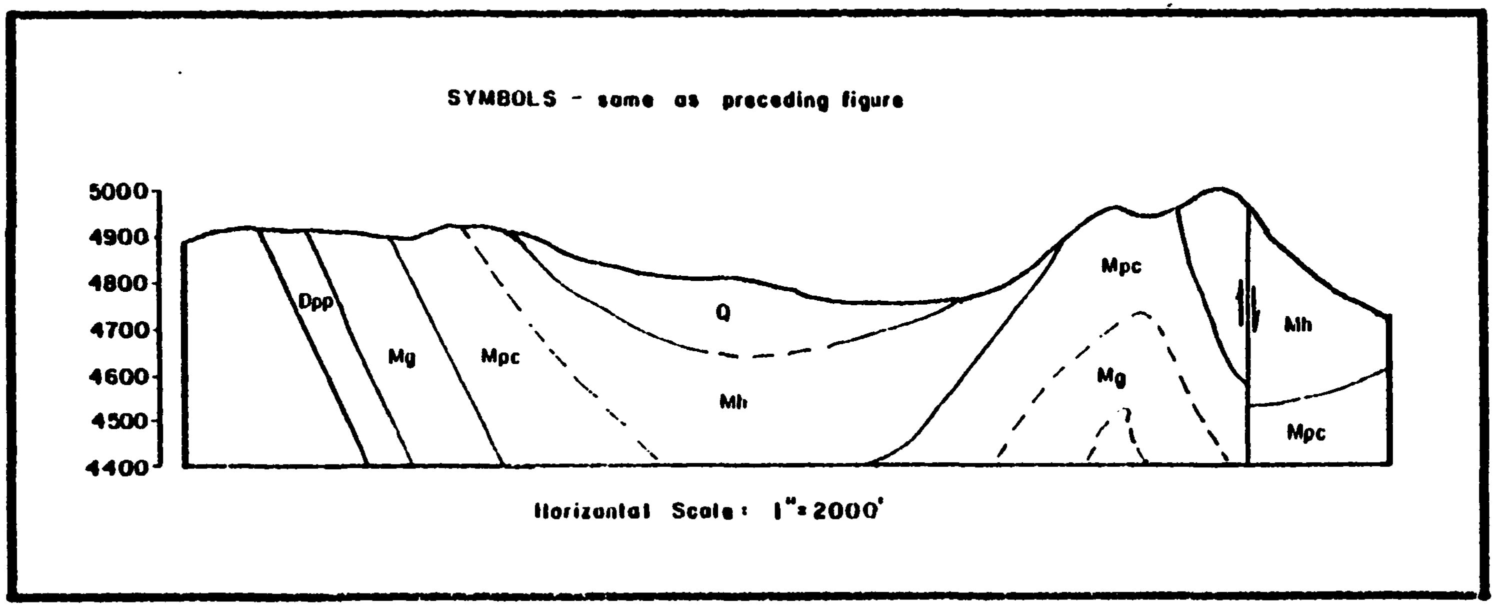

Figure 28. Geologic Section of the Mosida Hills (Adapted from Hoffman, 1951).

(presumed to be hardpan or cemented sand, gravel and boulders) was overlain by "2 or 3 feet" (approximately 0.75 meters) of sandy clay. Equipment limited penetrations to a depth of 108 feet (32.9 meters) (Horton, 1905:490-494).

Later, in 1962, the USBR conducted a reconnaissance study of the proposed Goshen Bay dike. Figure 29 shows both the dike alignment and locations of the 28 bore holes associated with the study. Figure 30 depicts the profile obtained from the borings along the proposed dike axis to a depth of approximately 90 feet (27 meters). The report describes the sediment as consisting of "...low plasticity silts and very lean clays having a very uniform texture and compactness down to a maximum depth of 76 feet..." at the center of the dike (U.S. Bureau of Reclamation, 1963:5). This silt and clay layer thins progressiveley to a thickness of approximately 19 feet (5.8 meters) near the shoreline. The silt is further described as being very homogeneous with the complete uniformity in compactness and physical characteristics suggesting an eolian rather than a fluvial origin (:6).

Under this silt and clay layer is a thin layer of moderate to high plasticity, highly compacted red clay; and under the clay, interbedded and lensed sands and silts ranging from coarse silts to fine to medium clean sands. The boring party found that the cleaner sands were "...full of water showing some artesian pressure...". Large quantities of marsh gas (principly methane and nitrogen gas with some carbon dioxide) under considerable pressure were encountered in the holes designated by "PRG-7" and "PRG-10" at a depth of approximately 75 feet (22.9 meters) below the water surface (:6).

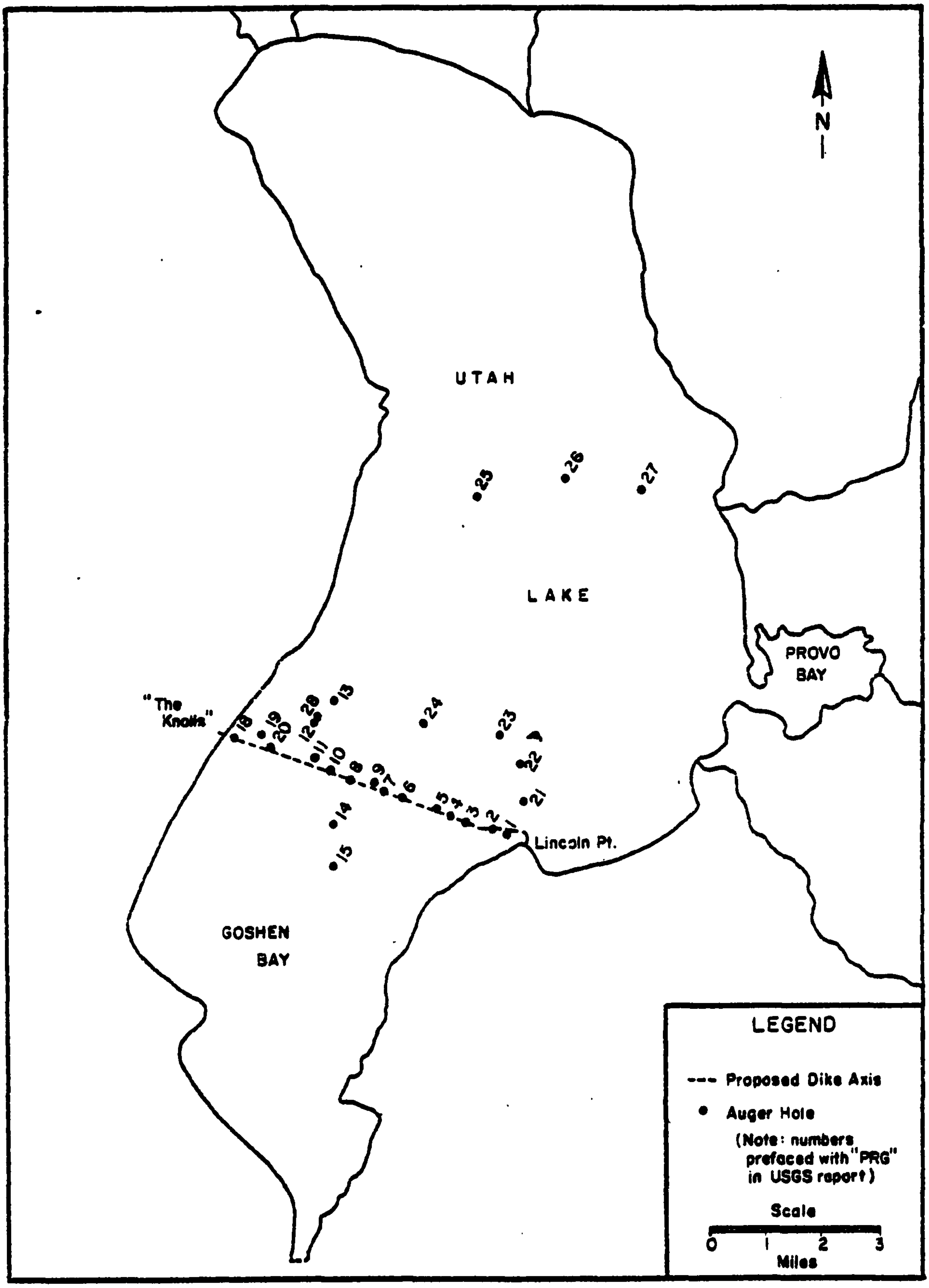

Figure 29. Reconnaissance Borings--Goshen Bay Dike (USBR, 1963).

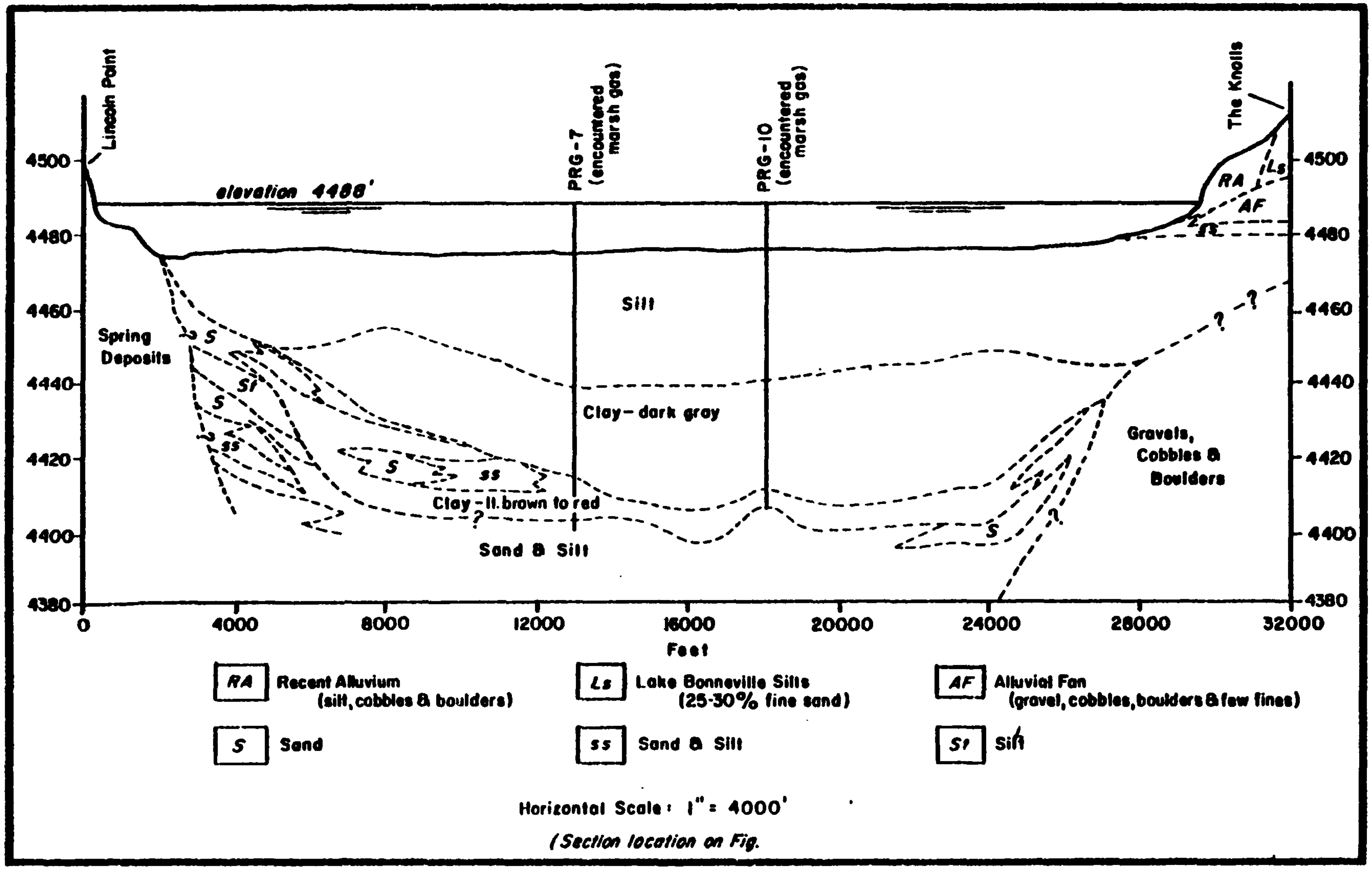

Figure 30. Geologic Profile of Proposed Goshen Bay Dike Axis (USBR, 1963).

The logs of holes 25, 26 and 27 indicate that the same character and layering of sediments is present at mid-lake. The dark gray clay layer of Figure 30 was very obvious in the acoustical profiles done by Brimhall, et al. (1976a) and persisted over the entire lake bed. This is further evidence that it is reasonable to assume that the lake bed has a fairly homogeneous character in its upper layers.

Distribution Patterns and Nature of the Upper Sediments

Sonerholm (1974) and Bingham (1975) have done computer-assisted statistical trend mappings of the mineral and particle size distributions, respectively, in Utah Lake sediments. As would be expected, the coarser grained materials tend to have their highest values along the eastern edge of the lake, corresponding to the major tributary inflows. The very fine grained materials tend to accumulate in the deeper water furtherest from these major inflows. Brimhall and Merritt (1976b:15) note that the predominant mineral in this upper region of sediments is calcite with impurities of magnesium, strontium and others. The next most abundant is quartz and other forms of silica followed by clay minerals of illite, montmorillonite and mixed layers types. The reason for the higher calcite concentrations in the deeper calmer waters is that the calcium coming into the lake via surface and subsurface waters combines with carbonate into tiny silt/clay size particles. These particles are so small as to be kept in suspension by the wave action in shallower water--thus most of the precipitation occurs in deeper waters (:17-20).

Lake Bed Faulting

Acoustical profiling work done by Brimahll, et al. (1976a) has provided a rather detailed picture of recent faulting within the bed of Utah Lake. Observations were possible to a depth of about 25 meters with the equipment used. Figure 31 is adapted from that work. It has long been theorized that a major fault also extends in a rough north-south arc from Lincoln Point, through Bird Island, and on up to Saratoga Springs. This theory is based on the presence of thermal springs at each of these locations (suggesting deep-seated geologic processes) and is supported by the gravimetric work of Cook and Berg (1961).

The Bird Island Fault in Figure 31 is displaced from 6.5 feet (2 meters) to less than 1.5 feet (0.5 meters) while displacements along the East Goshen Bay Fault range from 3.3 feet (1 meter) to less than 1.5 feet (0.5 meters). The East and West Jumbers Point Faults, on the the other hand, show the greatest displacements of any in the lake--from approximately 3 to 16 feet (1 to 5 meters). The Pelican Point Graben represents the lowest structural point in the basin and corresponds quite closely with the lowest topographic point as well (Brimhall, et al., 1976b:27-33).

Travertine Deposits at Lincoln Point and Bird Island

The best description of the nature of the spring deposits at Lincoln Point and Bird Island is found in the USBR reconnaissance report of the proposed Goshen Bay dike. The following quote is taken from that report.

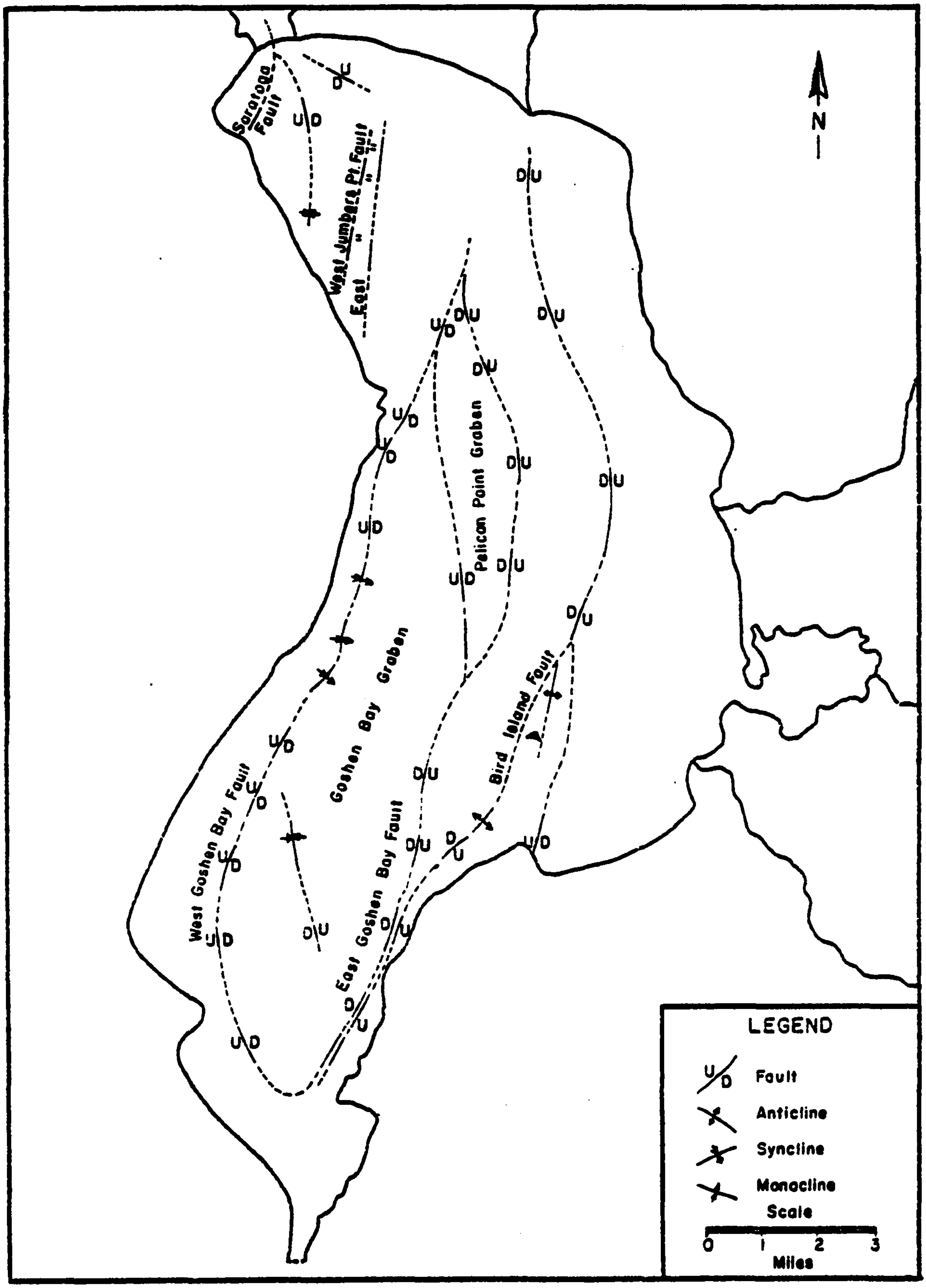

Figure 31. Lake Bed Faulting (Adapted from Brimhall, et al., 1976a).

> The travertine (and tufa) are hot spring deposits composed of calcium carbonate. They vary from very hard rock to very earthy deposits...and extend for about 1 mile around the east side of the point and for about 3 miles along the west side. Bird Island is composed entirely of travertine...the channel ways which the hot waters have followed are probably quite large, perhaps even cavernous. The lime material (travertine) was undoubtedly derived from the solution of the limestone as the hot waters have flowed through. (U.S. Bureau of Reclamation, 1953:4).

Hydrogeology

The occurrence and movement of ground-water within the Utah Lake Basin is directly controlled by the geology just discussed inasmuch as aquifers are co-located with porous strata and movement is controlled by the presence of hydraulic gradients and permeability. In the following discussion the author provides support for this theory--that the hydrogeology of the basin affords considerably more opportunity for subsurface inflow to Utah Lake than has been previously supposed.

Basin Aquifers

The aquifers within the Utah Lake Basin clearly associate with the major sedimentary deposits. The four major fresh water aquifers in the Utah Valley/Goshen Valley area which have been developed to any significant extent are known as: 1) the Water Table aquifer; 2) the Shallow Pleistocene aquifer; 3) the Deep Pleistocene aquifer; and 4) the Tertiary aquifer. The nature of the valley fill in Cedar Valley make positive identification of these same aquifers a bit more difficult, but some correlation does exist through at least Pleistocene.

In general, sand and gravel layers of these major deposits are the principal water-bearing layers. The sand and gravel tends to be more coarse, more permeable, and more extensive near the mountains, becoming progressively finer and less permeable toward the center of the valleys. The geologic processes described in the section on basin fill produced a complex sequence of interbedded and interfingered clay, silt, sand, and gravel. Ground-water moving away from the mountains and toward the valley is confined beneath the clay and silt layers producing artesian pressures in areas of all three valleys. These artesian pressures are prevalent throughout all of northern Utah Valley and southern Utah Valley north of a line through Payson.

Cordova (1970:13-14) points out that in Goshen Valley artesian conditions are confined mainly to the eastern part of the valley between Goshen and Utah Lake and generally flow only occurs below an elevation of 4520 feet (1378 meters). The lack of artesian conditions on the west side of the valley may be attributed to the absence of extensive confining beds. Himebaugh (1977:4-6) presents a fairly good argument that reduced artesian pressures may be the result of head loss as the water moves horizontally from the recharge area.

Feltis (1967:12) reports that artesian conditions exist in Cedar Valley east of the Oquirrh Mountains. Fairfield has flowing wells from aquifers at depths of 100 to 824 feet (30 to 251 meters). Indications are that these aquifers may extend all the way across the valley, but pressures are not sufficient to cause wells to flow in the central and topographically low parts of the valley. He feels this reduction in pressure may possibly be due to the discharge of water into the bedrock on the east edge of the valley. While he theories that artesian conditions may occur at depths greater than 200 feet (61 meters) in the southern part of the valley, they cannot be substantiated with data because no wells in the area penetrate below that level.

Each of the four major aquifers will now be discussed in greater detail. Figures 32 through 41 have been prepared to facilitate this portion of the discussion. Figure 32 shows the locations of the various geologic sections depicted in Figures 33 through 41 These sections are based on selected well logs. See Appendix A for the well numbering system.

Water Table aquifer. This is the uppermost of the aquifers and associated with the Lake Bonneville Group. Water in this aquifer is unconfined, fairly close to the ground surface, except in areas of Cedar Valley, and generally of poorer quality than the deeper aquifers. Throughout most of Utah Valley and Goshen Valley, the water table is within 25 feet (7.6 meters) of the surface. In many low lying areas of southern Utah Valley and Goshen Valley the water table is at or above ground level. This is in sharp contrast to Cedar Valley where the depth to water ranges from 30 feet (9.1 meters) in the northwestern part to 200 feet (61 meters) in the southeast. However the hydraulic gradient is still toward the east and southeast since the floor of Cedar Valley is some 300 feet (91 meters) higher than Utah and Goshen Valleys.

Shallow Pleistocene. The next deeper aquifer is the Shallow Pleistocene. Depths to this aquifer range from about 38 feet (12 meters) near American Fork to some 300 feet (91 meters) near Goshen. Aquifer thickness varies from about 40 feet (12 meters) near Lehi to nearly 200 feet (61 meters) in parts of southern Utah Valley. Artesian conditions prevail from the Payson area northward but appear to be absent or greatly diminished south of that point and in Goshen Valley. The artesian pressures in Cedar Valley associate primarily with the Pleistocene

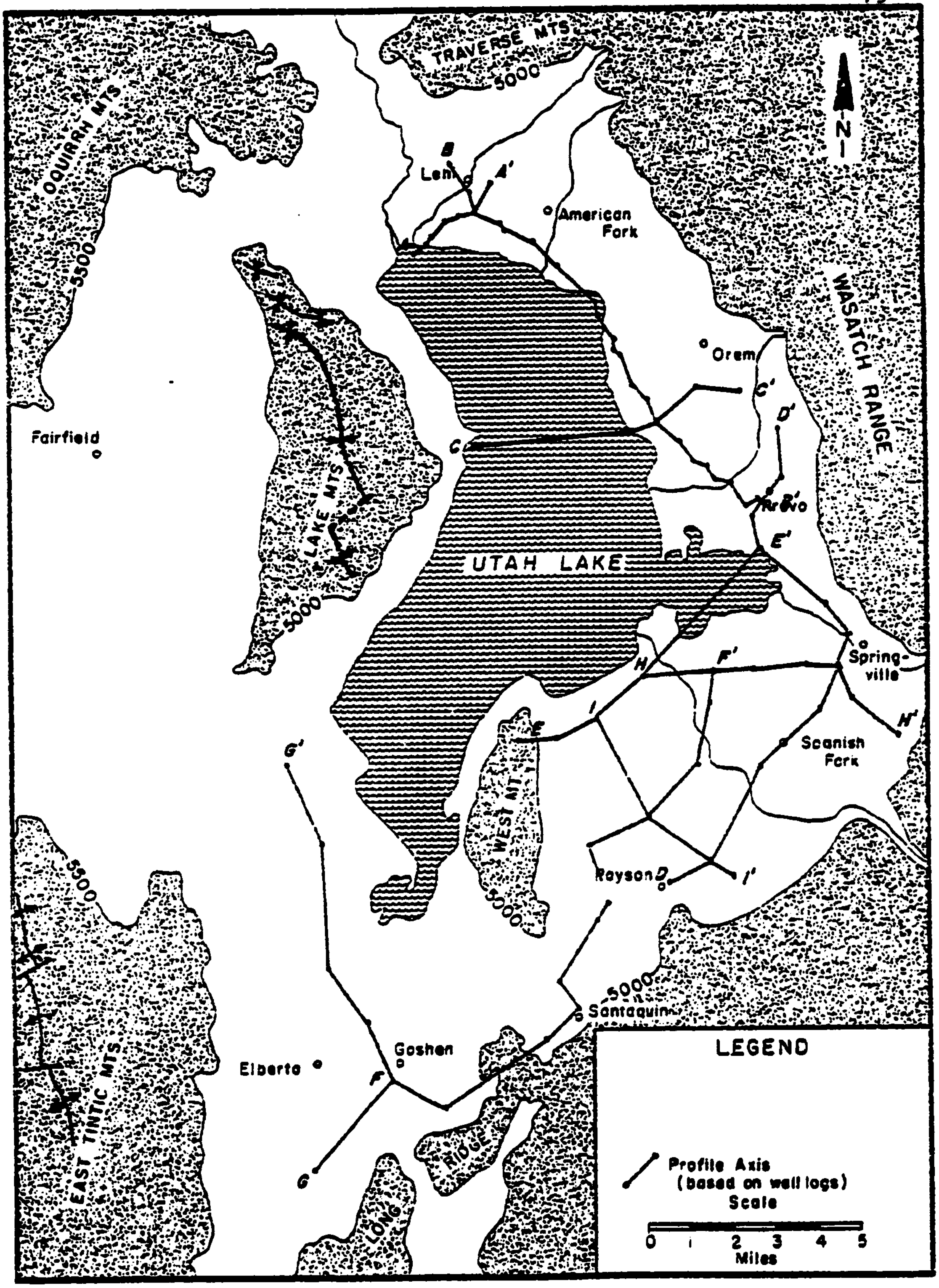

Figure 32. Locations of Geologic Sections for Figures 32-40.

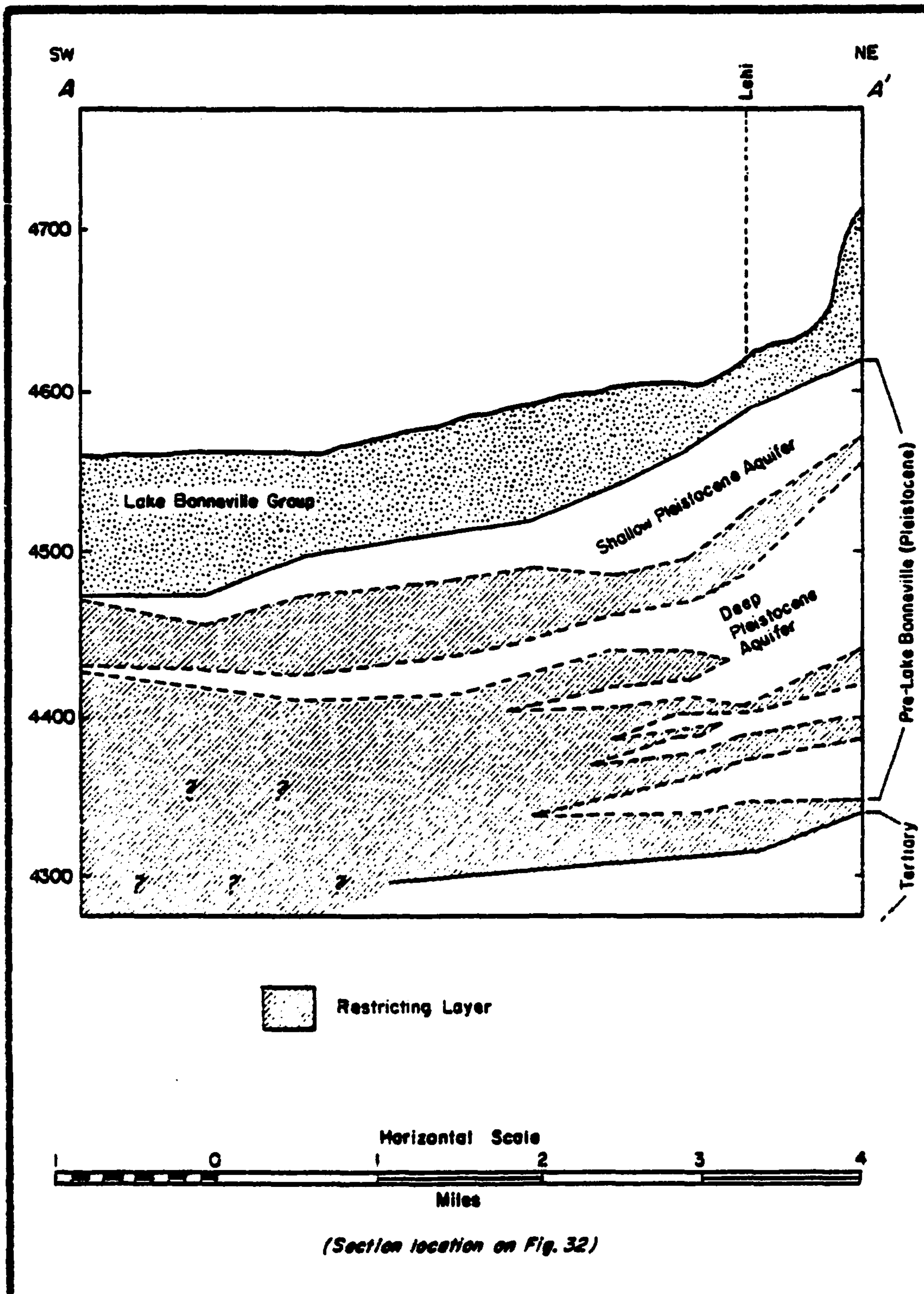

Figure 33. Section A-A': Utah Lake to Highland Bench (Adapted from Hunt, et al., 1953).

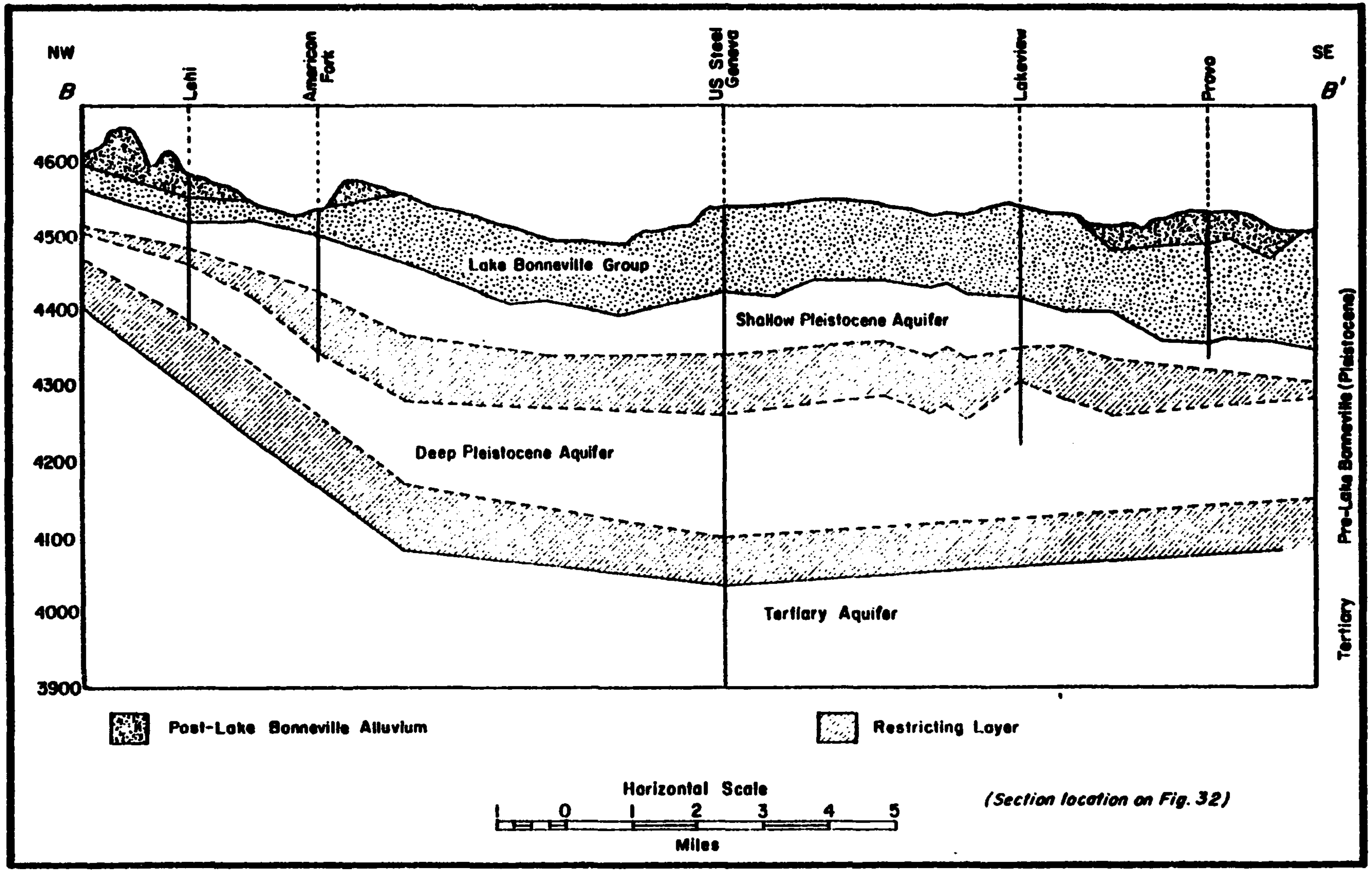

Figure 34. Section B-B': North of Lehi to Provo (Adapted from Hunt, et al, 1953).

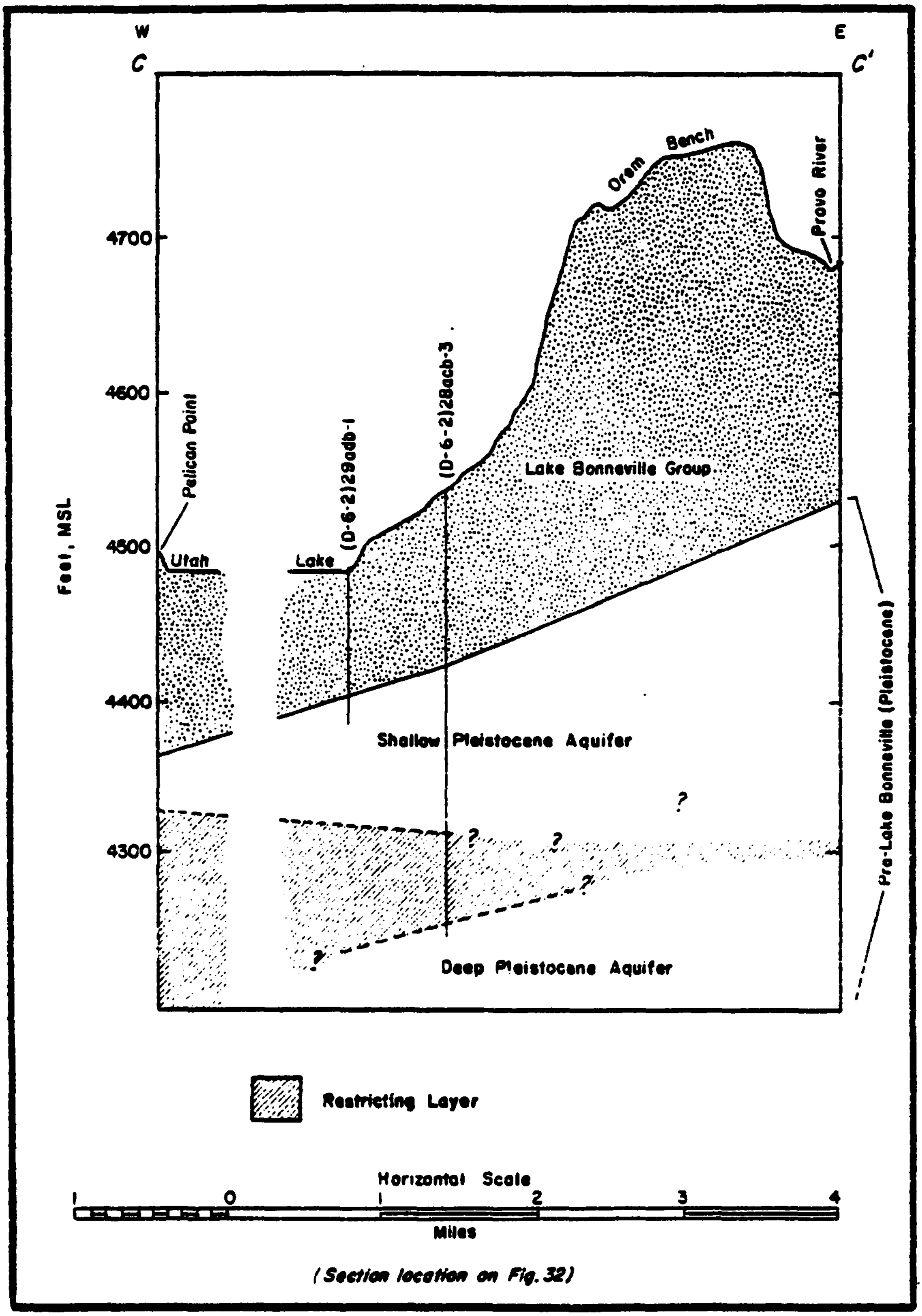

Figure 35. Section C-C': Pelican Point to Orem (Adapted from Hunt, et al., 1953).

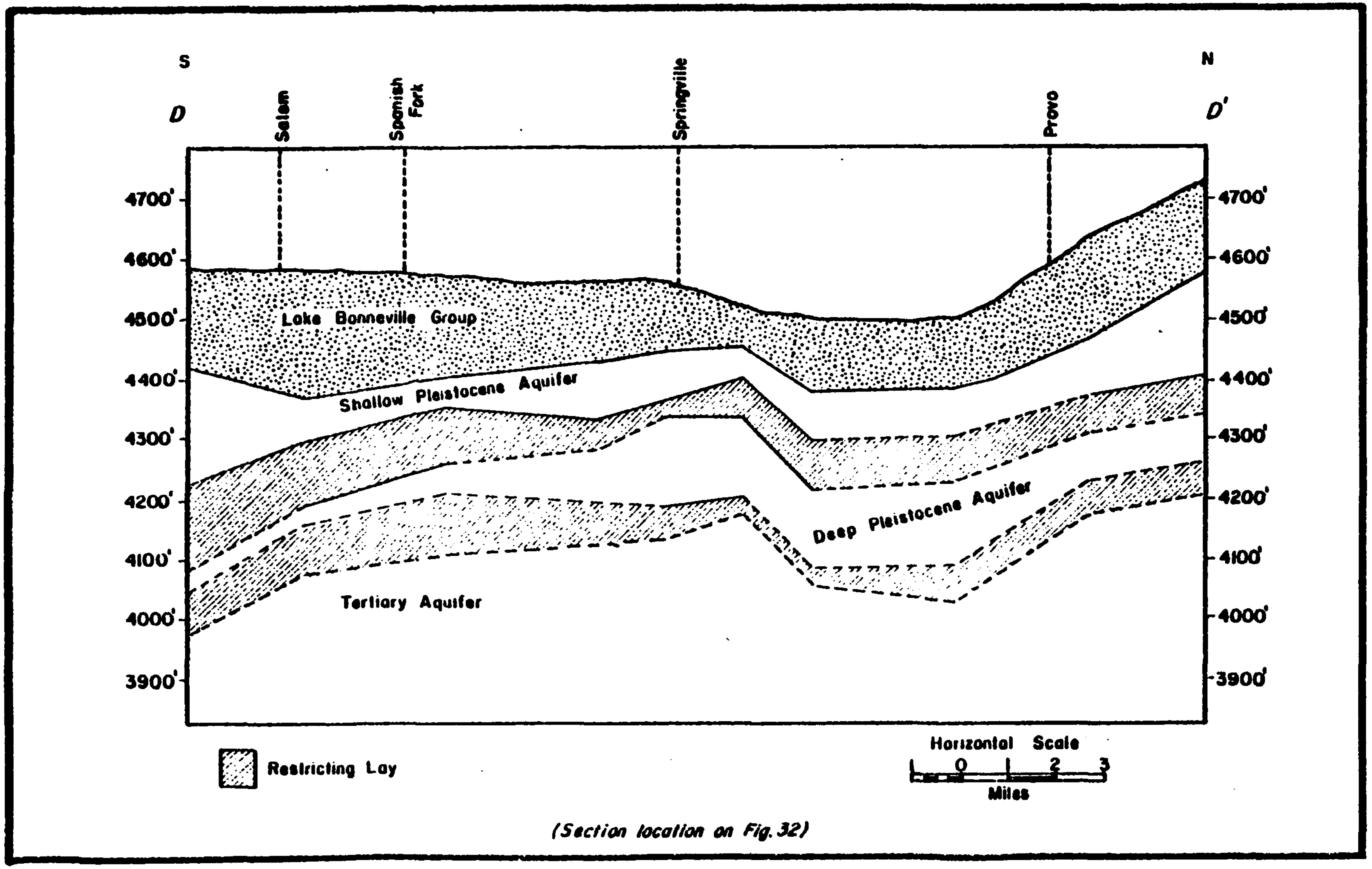

Figure 36. Section D-D': Payson to North Provo (Adapted from Cordova 1970).

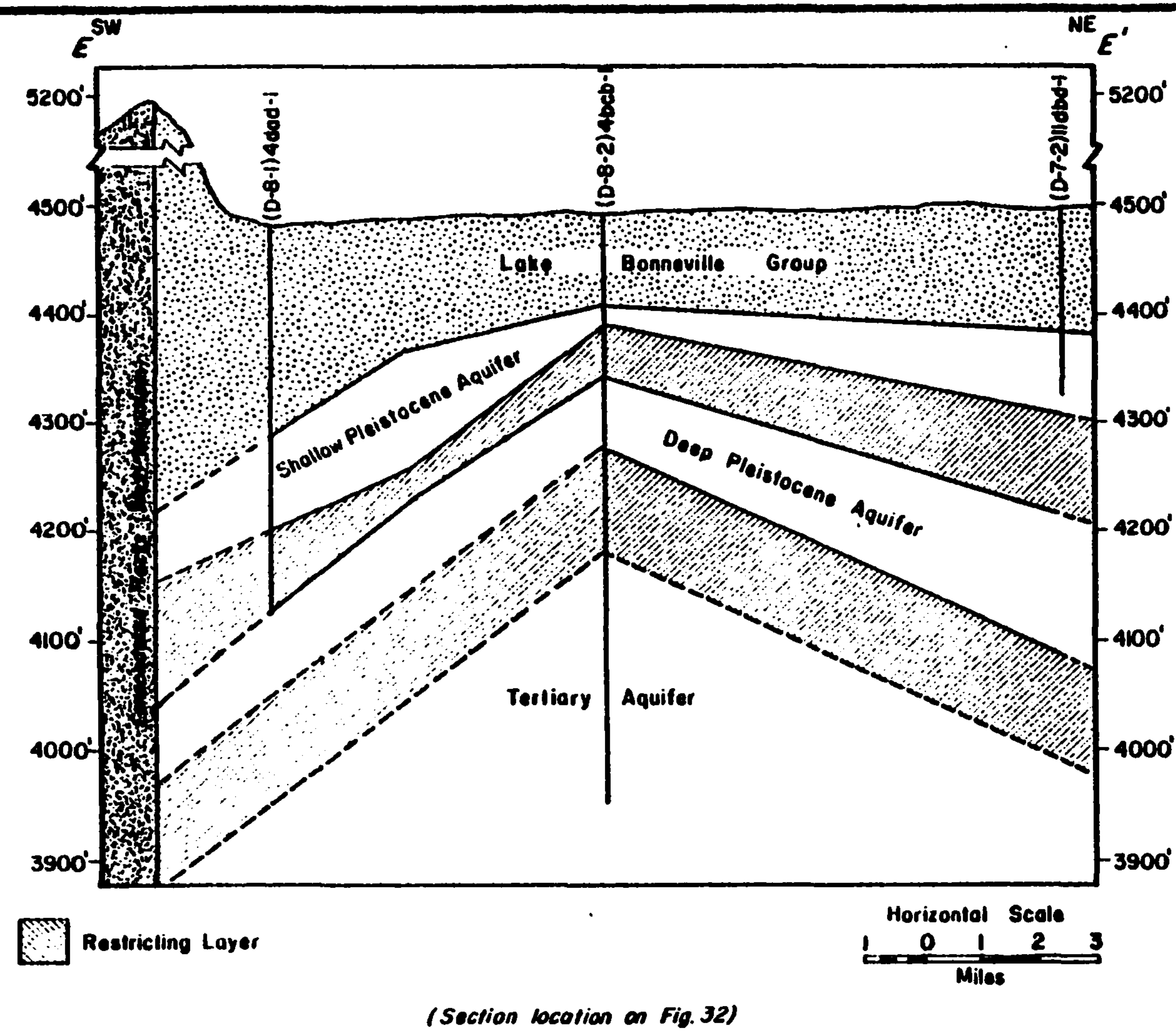

Figure 37. Section E-E': West Mountain to South Provo (Adapted from Cordova, 1970).

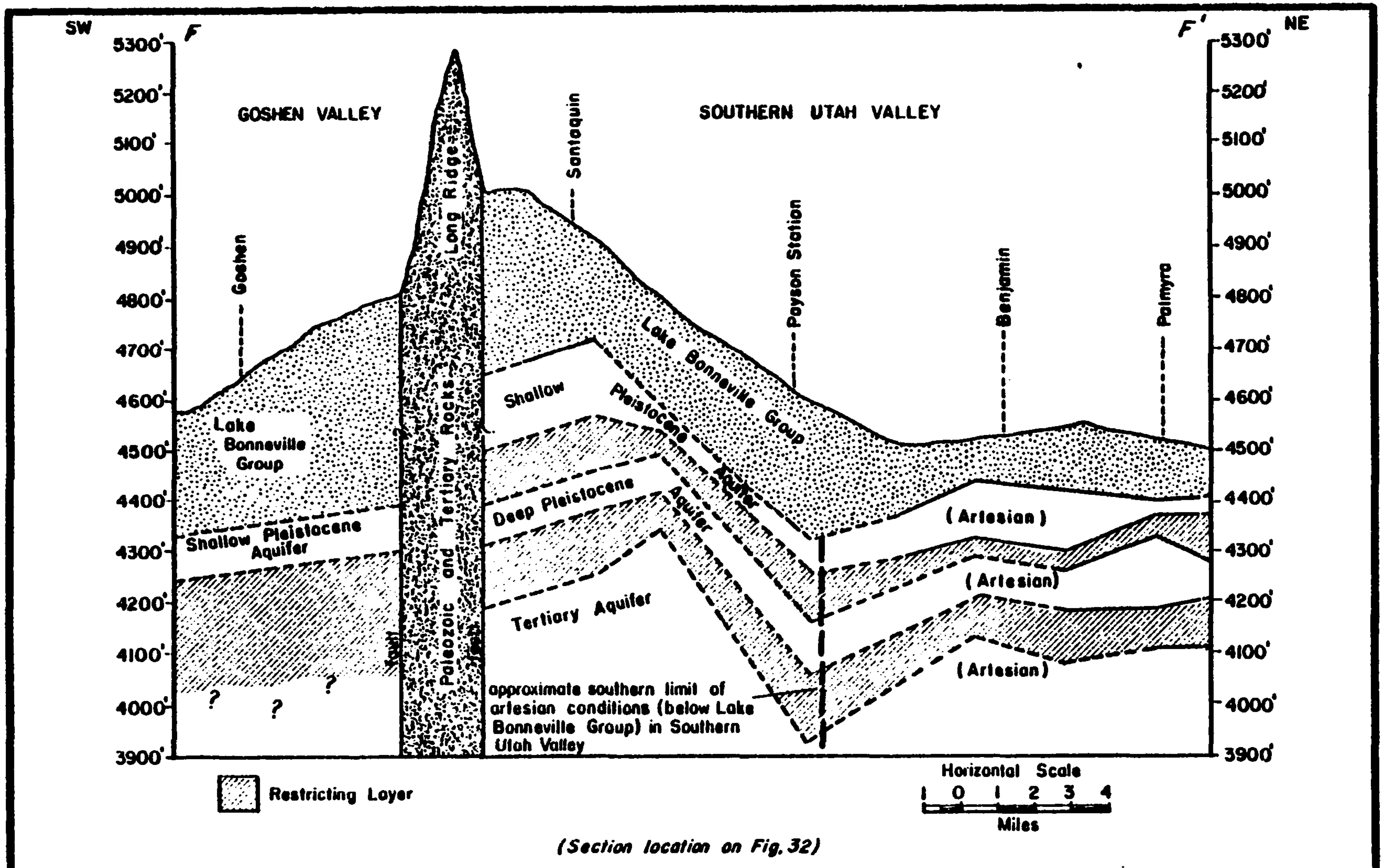

Figure 38. Section F-F': Goshen to Palmra (Adapted from Cordova, 1970).

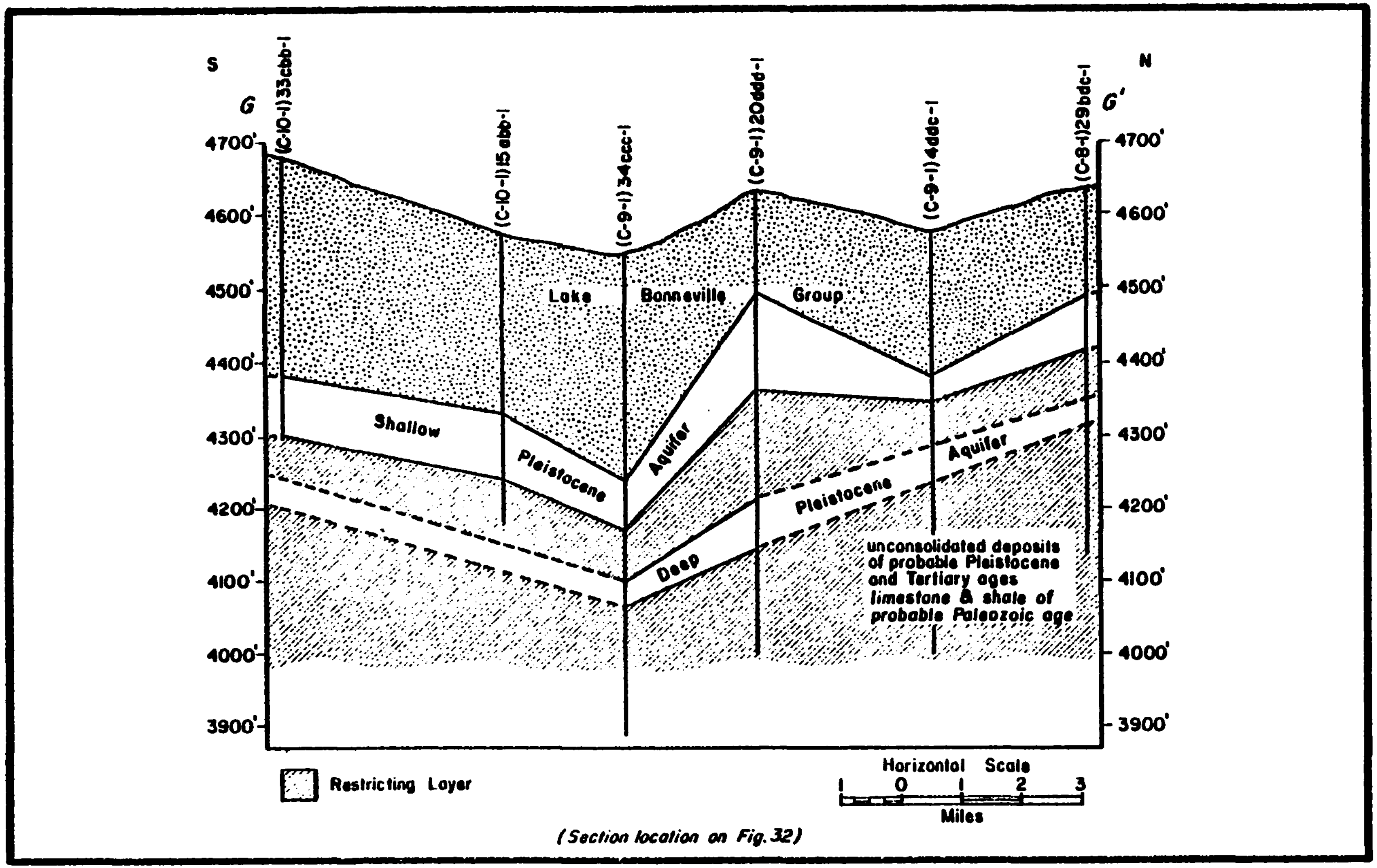

Figure 39. Section G-G': South of Elberta to Mosida (Adapted from Cordova, 1970).

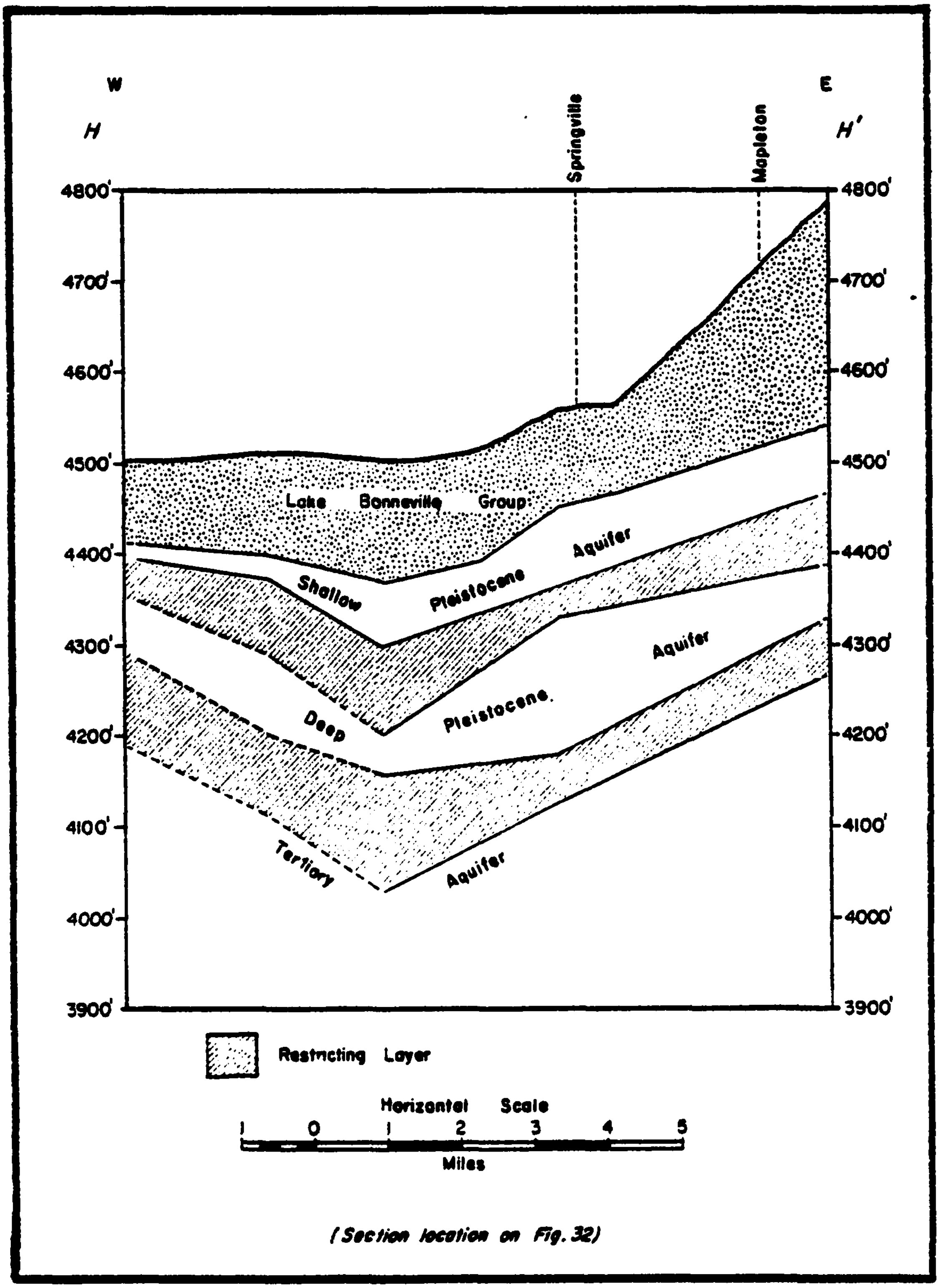

Figure 40. Section H-H': Utah Lake to Mapleton (Adapted from Cordova, 1970).

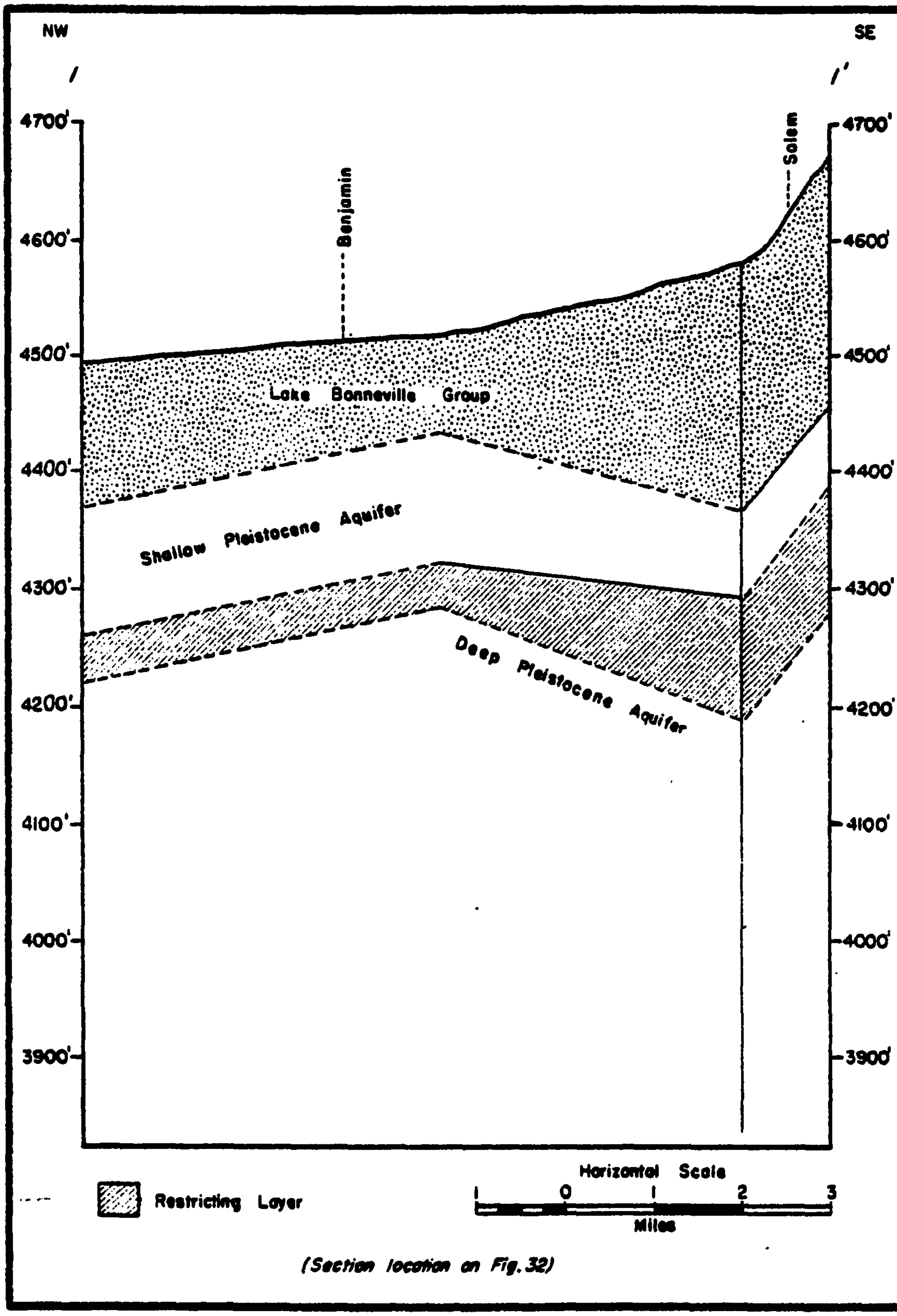

Figure 41. Section I-I': Benjamin Slough to Salem (Adapted from Cordova, 1970).

aquifers, but some of the deep flowing wells along the western side of the valley appear to penetrate Tertiary formations. The quality of the water in the Shallow Pleistocene aquifer is generally of better quality than that of the Water Table aquifer throughout the entire basin. This last characteristic was noted by Hunt, et al. (1953), Cordova (1970), and Feltis (1967); and is readily apparent as one reviews the data contained in Cordova (1969), Subitzky (1962) and Feltis (1967).

Deep Pleistocene. A 50 to 90 foot (15 to 27 meter) thick layer of fine-textured material composed primarily of a calcium carbonate rock flour (Hunt, et al, 1953:83) forms the confining layer between the Shallow Pleistocene and the Deep Pleistocene aquifers. This deeper aquifer has the same areal extent as the Shallow, but the pressure head is from 15 to 20 feet higher. As may be observed in Figures 33 through 41, depth to the Deep Pleistocene varies from about 100 to nearly 400 feet (30 to 122 meters); and the thickness from some 25 to 175 feet (8 to 53 meters). Once again an improvement in quality is noted in moving to a deeper aquifer.

Tertiary. The highest quality ground-water is found in the deepest of the developed aquifers--the Tertiary aquifer. This water-bearing stratum is encountered from 200 to over 500 feet (61 to 152 meters) below the ground surface throughout the basin and the thickness has never been adequately established. Besides the quality being highest in this aquifer, so are the artesian pressures (Hunt, et al., 1953 and Cordova, 1970).

Deep Tertiary aquifers. Until Gulf Oil drilling in late 1977, no one had drilled deep enough to reach the bottom of the Tertiary aquifer so nothing was known relative to water bearing strata below the main Tertiary. Electric logs from the Gulf Oil "Banks No. 1" well show that additional fresh water strata are located between depths of 870 and 900 feet (265 to 274 meters), 1125 and 1140 feet (343 and 348 meters), 1190 and 1225 feet (363 and 373 meters), 1415 and 1455 feet (431 and 44 meters), 151υ and 1570 feet (460 and 478 meters), 1630 and 1645 feet (497 and 501 meters); and 1720 and 1750 feet (524 and 533 meters). At this last level the waters begin to get highly saline, and at 5000 feet (1524 meters) the fill material begins to be characterized by shaly deposits mixed with sand (Mann, 1978).

Coefficients of storage and transmissibility. Considerable work was done by Hunt, Varnes and Thomas (1953), Cordova and Mower (1967), and Feltis (1967) to determine the storage and transmissibility coefficients for northern Utah Valley, southern Utah and Goshen Valleys, and Cedar Valley, respectively. In general, it was noted that the values decreased as one moved from the mountains toward the valleys--an obvious reflection of the corresponding gradation of particle sizes from coarse to fine.

Piezometric Contours

The piezometric contours for the Water Table, Shallow Pleistocene and Deep Pleistocene aquifers are plotted on Figures 42, 43, and 44, respectively. Three important observations may be made upon examining these contours:

1. All aquifers have common sources of recharge.
2. The hydraulic gradients tend toward the lowest topography (Utah Lake) from all directions.

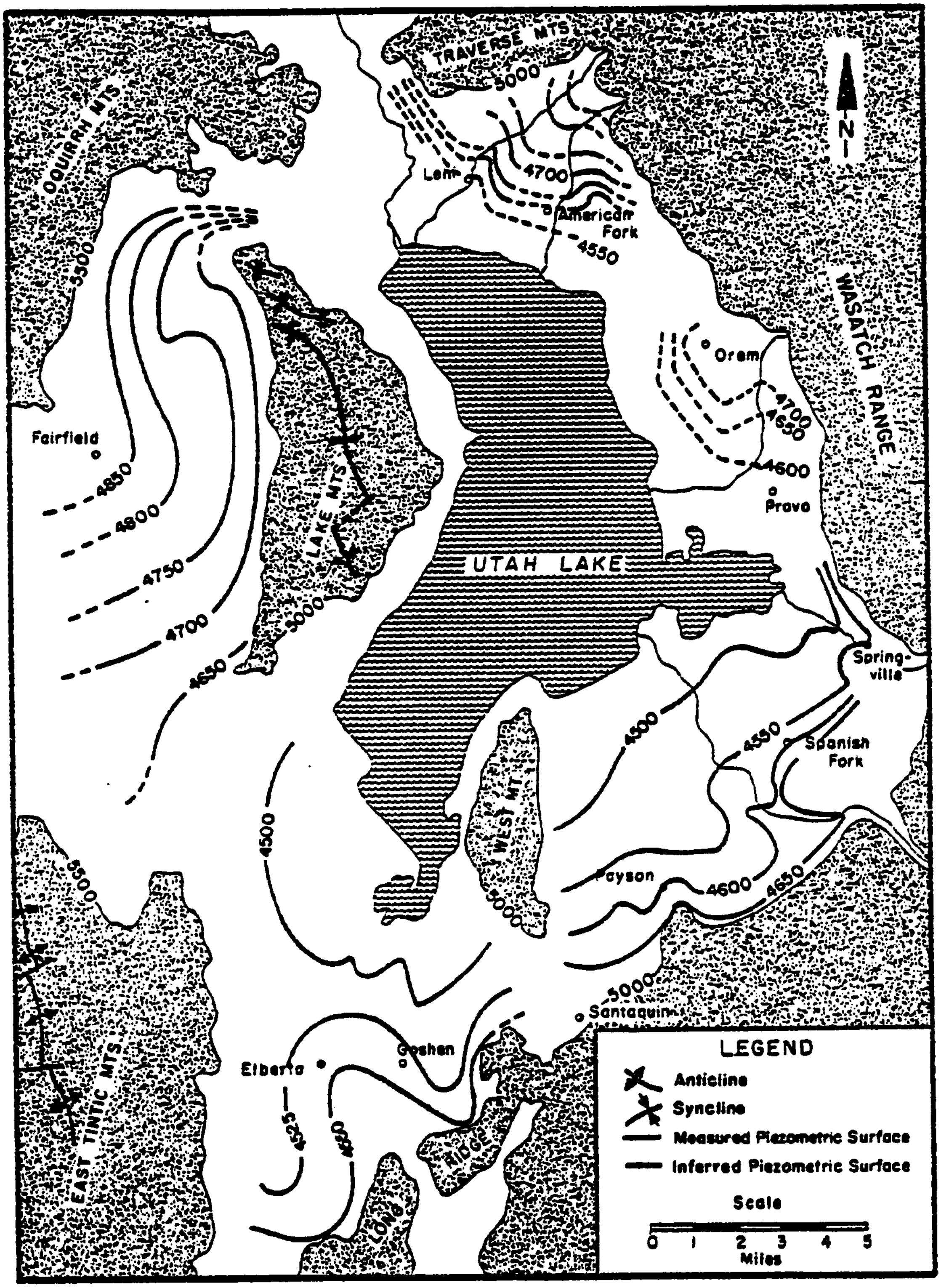

Figure 42. Piezometric Contours for the Water Table Aquifer. (Adapted from Hunt, et al., 1953, Feltis, 1967, and Cordova, 1970).

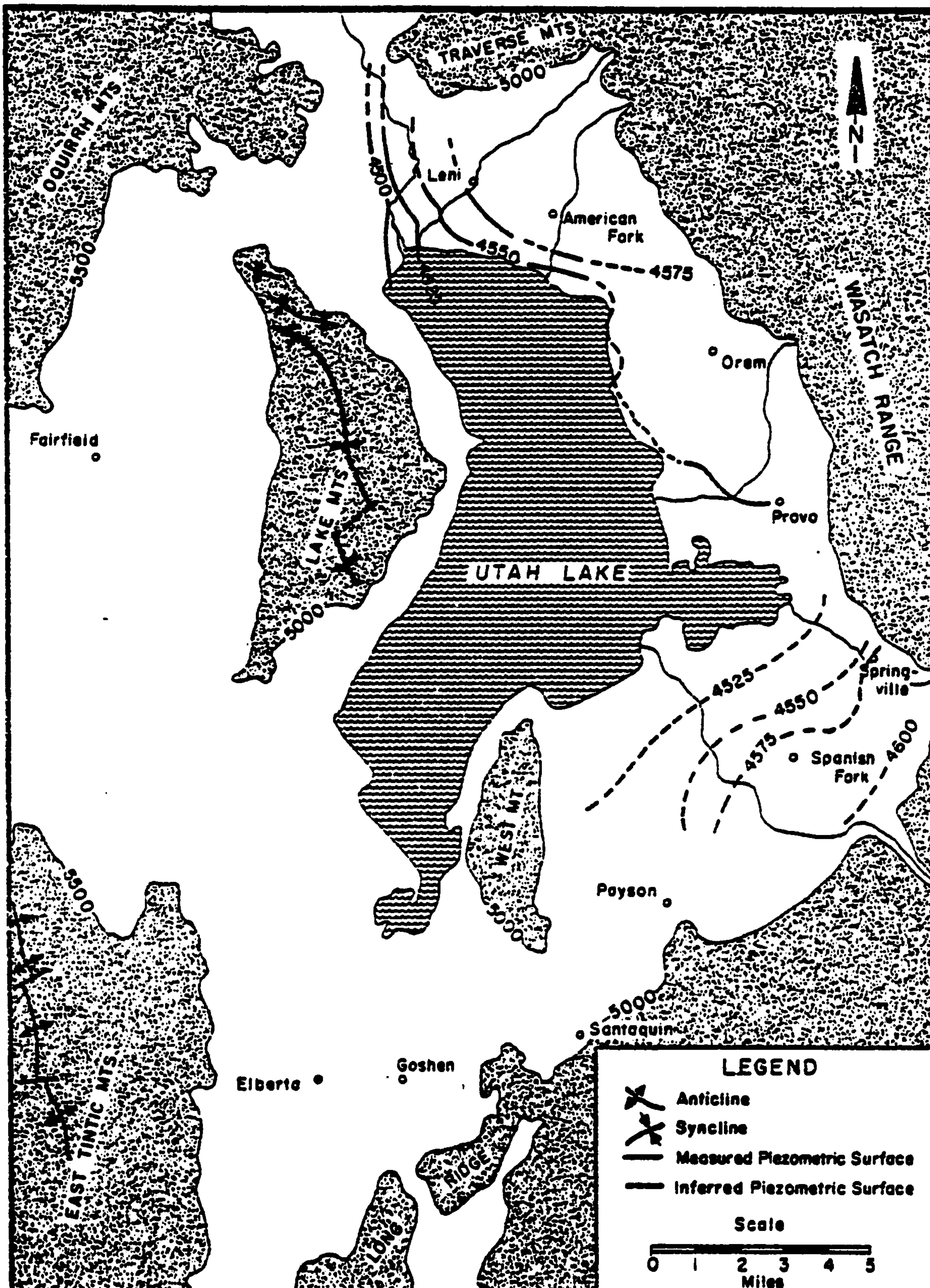

Figure 43. Piezometric Contours for the Shallow Pleistocene Aquifer. (Adapted from Hunt, et al., 1953, and Cordova, 1970).

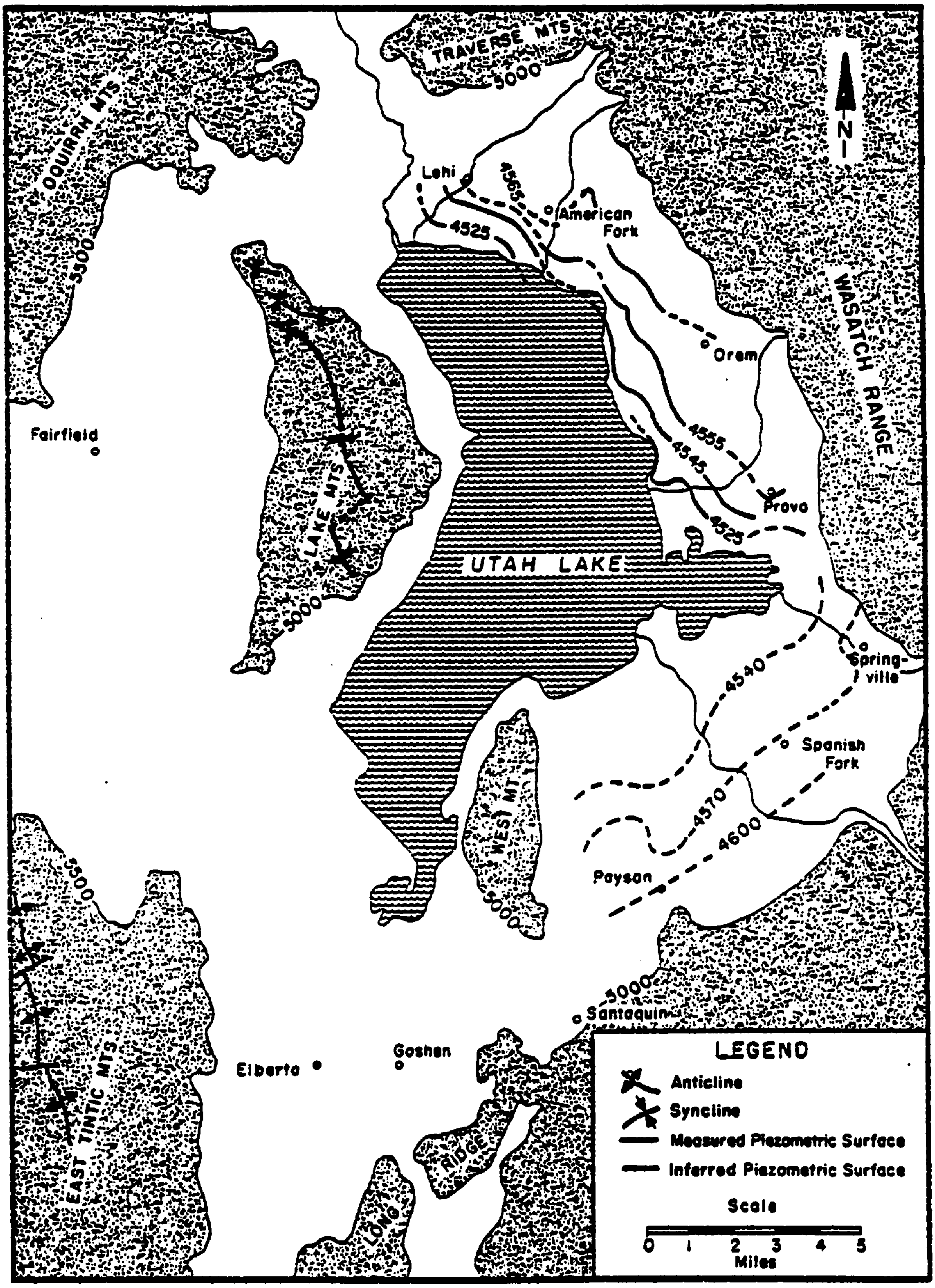

Figure 44. Piezometric Contours for the Deep Pleistocene Aquifer. (Adapted from Hunt, et al., 1953, and Cordova, 1970).

3. The gradient indicated in Cedar Valley implies that water may be flowing around and through the Lake Mountain and Mosida Hills area (Feltis, 1967).

Contours for the deeper aquifers were not plotted in Cedar Valley because of the sparcity of data or in Goshen Valley because all the aquifers appear to be interconnected. Combined data show the same general gradient depicted for the Water Table aquifer. The Tertiary aquifer contours were not plotted because they follow the same general trend as the overlying aquifer contours with perhaps a slightly more westward trend and at pressure heads of 5 to 10 feet higher than the Deep Pleistocene.

Hunt, Varnes and Thomas (1953:82-83) noted that the piezometric surfaces appear to be unaltered by large well withdrawals thus indicating this gradient is a product of natural conditions "...under which there has been discharge from the aquifer in the central and lower part of the valley for a long period of time." Utah Lake occupies this "central and lower" part of the valley.

Sources of Recharge

Figures 42 through 44 indicate that most recharge occurs near the major tributary canyons and along a narrow band around the base of the mountains--the Wasatch Range for Utah Valley and the Oquirrh Mountains for Cedar Valley. Contours in Goshen Valley suggest recharge is from the southeast and from the west to northwest.

Richardson (1906:28) points out that the bulk of the underground water is supplied by seepage from streams and canals (channel losses), but other sources include:

1. Underflow of streams at the canyon mouths,

2. Springs from bedrock,

3. Seepage at the mountain base/aquifer interface, and

4. Infiltration and deep percolation of precipitation and overland flow over the valley floor.

In relation to Richardson's observation, Hunt, Varnes and Thomas determined that only 70 percent of the measured inflow to northern Utah Valley reached the lake as surface flow. This implies that a considerable amount of water becomes recharge water.

Recharges figures reported by Cordova and Subitzky (1965) for northern Utah Valley, Cordova (1970) for southern Utah and Goshen Valleys, and Feltis (1967) for Cedar Valley all represent conservative minimum values. However, it appears that the determination of more accurate estimates would require extensive additional data collection and analysis. Refinements may result from a much more detailed water budget, but the volume of subterranian recharge issuing from fractured bedrock along the mountain base/aquifer interface cannot presently be and may never be accurately determined. However, Mr. Cordova (1978) feels that the amount could be comparatively large considering the bedrock lithology (highly fractured limestone). The sparcity of vegetation along the mountain front even though the area receives considerable precipitation (Figure 45) indicates that the ability of the rock to absorb and transmit water may be substantial. If a "reasonable" 10 to 15 percent error is introduced by disregarding this bedrock discharge, the difference in the volume of recharge would be some 30,000 to 45,000 acre feet (396,000,000 to 553,000,000 m^3) per year in Utah and Goshen Valleys alone. The effect of this additional supply on subsurface

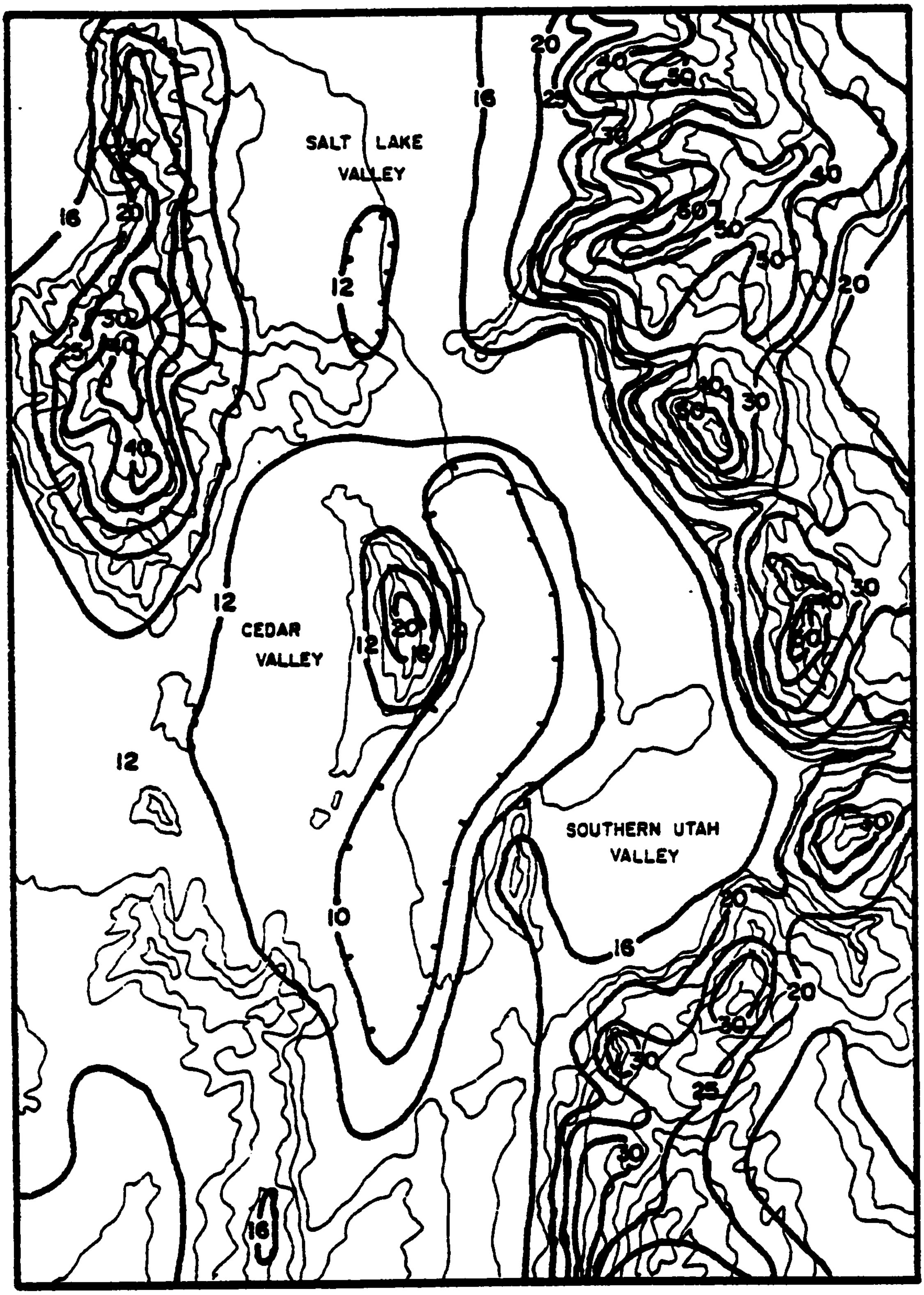

Figure 45. Isohyets Depicting Annual Precipitation in Inches.

inflow estimates to Utah Lake would be a 70 to 80 percent increase over more previous estimates (assuming it all entered the lake).

While the horizontal permeability through the basin fill is much greater than the vertical permeability, the increase in artesian pressures and water quality with increasing depth noted by previous investigators indicates that the confining layers are not totally impervious. Head losses occur as the water seeps upward through the less permeable silt and clay layers. Increased concentrations of dissolved solids probably occur as a result of solution of minerals contained in these silt and clay layers. Cordova and Subitzky (1965:32) noted that the TDS concentrations in Tertiary aquifer waters are strikingly similar to those found in the surface and non-thermal spring waters tributary to the valley, suggesting the probable source of recharge.

With respect to recharge to Goshen Valley, investigators do not agree as to whether most recharge comes from the East Tintic Mountains to the southwest or the Wasatch Range to the southeast. Wasatch Range recharge seems most plausible since:

1. By comparison only limited precipitation falls on the East Tintic Mountains (see Figure 45).

2. Piezometric contours indicate major recharge through Currant Creek Gap.

3. The profile of the water table through Goshen and Genola Gaps (Figure 46) is consistent with such a theory.

Cordova (1970:46) noted that his water table profiles (Figure 46) were based on limited data and were not conclusive proof that water did pass from southern Utah Valley to Goshen Valley via these paths. He explained that West Mountain is possibly a recharge area and water

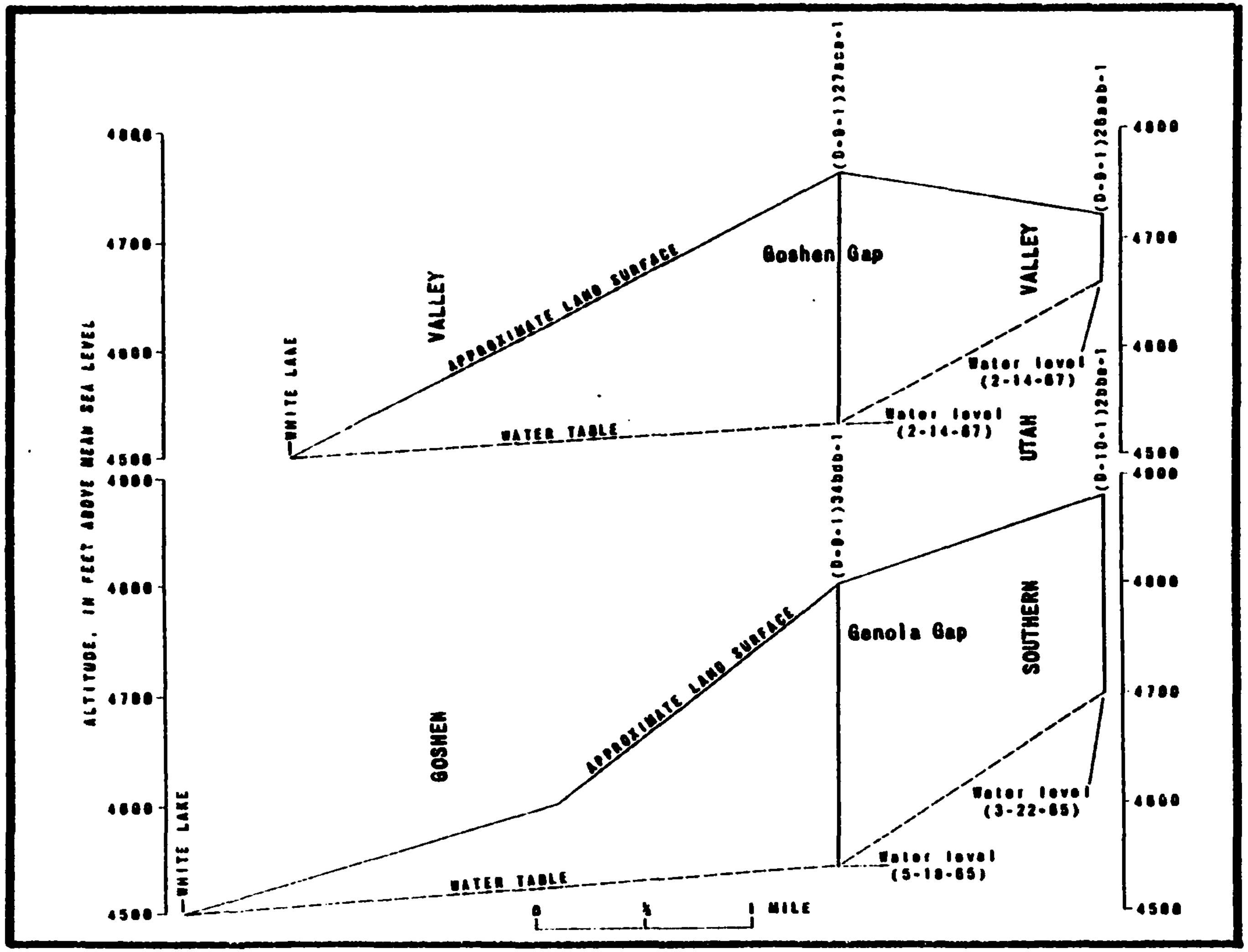

Figure 46. Profiles of the Water Table in the Goshen Gap and Genola Gap Areas (Reproduced, with permission, from Cordova, 1970).

may flow both east and west there. However, when one considers the topography of the Santaquin/Goshen Gap area (slopes westward as well as northward) and the lithology of the Goshen/Genola Gap region (fractured limestone), it is possible that the hydraulic gradient could carry some water through to Goshen Valley. Such a flow would be relatively small compared to that coming through Currant Creek Gap, however.

Destination of Basin Ground-Water

As ground-water flows through aquifers, it is subject to several losses. These losses include well discharges, spring discharges, evapotranspiration, and even simple evaporation where the water table is at or above the ground surface. The remaining water continues its flow until pressures are equalized and the hydraulic gradient is reduced to zero. This "zero point" occurs within Utah Lake for most of the subsurface flows. However, ground-water in Cedar Valley may discharge elsewhere, and some limited north Utah Valley ground-water may flow out through the Jordan Narrows. Such being the case, further discussion of these two topics is warranted.

Cedar Valley water. According to Feltis (1967:13) water leaves Cedar Valley in four areas (see Figure 42): the low pass on the north end of Lake Mountain, through Lake Mountain-Mosida Hills area, through the bedrock of the East Tintic Mountains, and toward Rush Valley to the west of Cedar Valley. He conducted aquifer tests through mid-Cedar Valley (north-south) and then calculated the horizontal discharge through the valley fill. Using transmissibility data, he arrived at a figure of approximately 10,000 acre feet (12.3×10^6 m^3) per year, whereas his water budget calculations indicated closer to 19,000 acre feet (23.4×10^6 m^3) per year flowing outward from the Oquirrhs (:18-19). While these two values differ substantially, their relative order of magnitude is the same. Since the calculated recharge for the valley was only 24,000 acre feet (29.52×10^6 m^3) per year, a significant loss is indicated.

If some of this "lost" water does exit Cedar Valley via natural pathways in Lake Mountain, then it must also exit Lake Mountain at some point or points. A very careful evaluation of the Lake Mountain geology shows that ground-water accumulating in Lake Mountain would have a much greater tendency to flow to the south than east or west due to the natural drainage line alignment. A more detailed piezometric study would be required to confirm or disprove this observation.

Lake Mountain and the Mosida Hills are composed primarily of limestone and dolomite. These sedimentary rocks have excellent water-bearing properties. As earth movements produce fractures and crevices, water enters these openings and slowly dissolves the rocks. These openings may eventually become sizeable solution channels through which large quantities of water may pass (Briggs and Fidler, 1975:30). The nature of the rock, the alignment of the synclinal axes, and the strike and dip of the bedding planes in Lake Mountain and the Mosida Hills, support Feltis' theory that some Cedar Valley water leaves the valley "...along the bedding planes and through fractures and solution channels..." in the rocks (Feltis, 1967:13). Until this study, however, no one was able to identify any major discharges into the west side of Utah Lake. Hence some critics have tended to discount the idea that much water flows through these mountains.

Northern Utah Valley water. The natural surface drainage from Utah Valley is northward via the Jordan River through the Jordan Narrows. At least some ground-water also follows this path (Hunt, et al., 1953 and Cordova and Subitzky, 1965). Piezometric contours for this area, particularly for the artesian aquifers, support the possibility of a northward component of the hydraulic gradient. However, owing to the tremendous volume of recharge available in the Utah Lake Basin, the narrowness and shallowness of this northern escape route, and the more west-to-southwest than north alignment of flow direction, as indicated by the contours, it appears that a minor proportion of subsurface water is lost to the north.

Sister Basins

One of the most intriguing aspects of the basin hydrogeology is the upward migration of water through the overlying confining layers, as this is most likely the key to discharges into Utah Lake. In an effort to learn more about such discharges, the hydrogeology of the Weber Delta District and Cache Valley were investigated for a similar phenomenon. The condition was found to exist in both places.

Cache Valley

Cache Valley is located approximately 100 miles (161 kilometers) to the north of Utah Lake Basin, just south of the Idaho border. Red Rock Pass forms its northern limit. The pre-lake Bonneville sediments here are very thin compared to the Utah Lake Basin. Owing to the difference in elevation between the two areas, it is most likely that there was drainage from Cache Valley during most of Pleistocene time, thus accounting for the thinness of these sediments. As a result, most of the valley fill is largely made up of Lake Bonneville sediments of the Alpine, Bonneville and Provo formations. Well logs indicate two main aquifers in the valley, one within and one beneath the Lake Bonneville group, separated by confining layers of silt and clay. Artesian conditions are prevalant over a large part of the valley (Williams, 1962:131-152). In short, conditions are not identical but are nonetheless very similar to the Utah Lake Basin.

In 1926, O.W. Israelsen and W.W. McLaughlin conducted a piezometric investigation in the valley to test their hypothesis that the clay layer overlying the aquifer(s) was not totally impervious (Israelsen, et al., 1942:11-15). Piezometers were simultaneously installed at different depths and the water levels were measured in each. It was found that the deeper the piezometer, the greater the pressure head. This effectively proved their theory that water under artesian pressure did migrate upward through the clay layer, experiencing an overall decrease in head along the way. Preliminary calculations made from their measurements indicated that "...200 to 250 gallons per minute per square mile..." flow upward "...from the water-bearing gravels..." in the valley.

Weber Delta District

This ground-water district is located about 70 miles (113 kilometers) north of Utah Lake and is bounded on the east by the Wasatch Range and the west by the Great Salt Lake. The setting, geology, and hydrogeology are all very similar to the Utah Lake Basin.

A hydrologic investigation revealed that 20,000 acre feet (24.6 x 10^6 m^3) of discharge per year could not be accounted for (Feth, et al., 1966:56-57). The authors assumed that some part of this discharge was via direct leakage into the Great Salt Lake, but efforts to identify any sizeable or measureable springs within the lake wre fruitless. A previous study by Peck (1954) indicated about a four year carryover effect on changes in lake volume in response to fluctuations in precipitation in drainage areas tributary to the lake. This carryover was attributed to discharge from deep artesian aquifers beneath the lake. Using Peck's data, Feth's team made a rough calculation of the hypothetical ground-water contribution coming from the Weber District based on an assumption that 20 percent of the periphery was believed to contribute most of the underflow and came up with a figure of the same order of magnitude as the 20,000 acre feet of unidentified discharge. Thus, even though discharge points could not be identified or measured, the hypothesis appeared sound.

In 1968 a test well was drilled on the causeway connecting Syracuse, Utah, to Antelope Island. The 127 foot (39 meter) well was located about 0.75 miles (1.2 kilometers) northeast of the northern tip of the island and produced an artesian fresh water flow of 10 gpm (6.31×10^{-4} m^3/s) from a depth of 97 feet (30 meters). One year later, a second well as drilled about 400 yards (370 meters) west of the first well to a depth of 481 feet (147 meters) in which two artesian aquifers were encountered. The first was from a depth of 150 to 170 feet (46 to 52 meters) and produced an artesian head of approximately 30 feet (9 meters) above the causeway. The second one was located between 423 and 475 feet (129 and 145 meters) and produced a flow of 280 gpm (1.77×10^{-2} m^3/s) with a static head 54 feet (16 meters) above the causeway (Bolke and Waddell, 1972:5-6). The chemical analysis of the water from the first artesian level indicated a sodium bicarbonate type with 330 mg/l TDS. Water from the second level was a sodium chloride type at 661 to 738 mg/l TDS (:17). When the analysis of the deep aquifer water was compared with the analyses of three springs on the north end of Antelope Island, it was found that similarities existed for several constituents. Sodium chloride waters are also found in the East Shore (Weber District) area aquifers (:18).

CHAPTER 5

INVESTIGATIONS

As expected, the geology and hydrogeology of the basin point to significant subsurface flow to Utah Lake. The strong hydraulic gradient toward the lake suggests a considerable water discharge into the lake, including the west side of the lake and Goshen Bay, although previous investigators have viewed such west side and Goshen Bay inflow as negligible--particularly in the area behind the proposed dike. However, in order to substantiate such a claim, it would be necessary to first locate the areas where this inflow would occur and then provide conclusive evidence that the water was indeed there. The format of the investigation described in Chapter 3 was designed to accomplish these two objectives. This chapter presents the results of various investigations undertaken.

Thermal Imagery

The use of aerial thermal imagery to detect spring inflows is not without precedent. Perhaps the most successful example of such an application was the study of fresh-water springs of Hawaii by the U.S. Geological Survey (USGS) in 1963 (Fischer, et al., 1966). It had been previously determined that a sizeable portion of the estimated 10 billion gallons per day (45.5 million m^3) average rainfall over the island of Hawaii was discharging as sea level ground-water flow along rocky shores exposed to waves where detection and measurement were extremely difficult to impossible. By using infrared the researchers were able to postively identify some 219 individual spring discharges.

Preliminary USAF Flights

The author contacted the U.S. Air Force (USAF) to arrange for a series of thermal scans to be make of Utah Lake during the fall of 1977. The more sensitive equipment was not available for the project, but arrangements were made with the Idaho Air National Guard (ANG) (flying RF-4C aircraft out of Boise, Idaho) to make preliminary scans in conjunction with regularly scheduled training fights. Federal Aviation Regulations, the inability to control the date or time of the flights, and the sensitivity of the thermal sensors (similar to that used by the USGS in 1963) posed definite limitations. However, in spite of the restrictions, results of these initial flights were very encouraging. The most striking contrast obtained on any of these flights is shown in Figure 47, in which the thermal effect of the inflow from the "Big Spring" area near Saratoga is very evident.

Another "successful" scan was flown on the morning of 13 November 1977. This run was made from an altitude of 5000 feet (1524 meters) above the surface of the lake. The major thermal areas (including "Big Spring") were clearly recognizeable and distinct thermal gradients were evident in several areas of the lake. These areas included the north end of the lake extending outward from the shore in a rough arc from the Saratoga area to the American Fork Boat Harbor; moving outward from the Provo Bay outlet; radiating outward from Lincoln Point; and in a narrow band along the west shore line just south of the west abutment of the proposed Goshen Bay dike (see Figure 48). The radial pattern

Figure 47. Thermal Image of the "Big Spring" Area (Courtesy Idaho ANG, USAF).

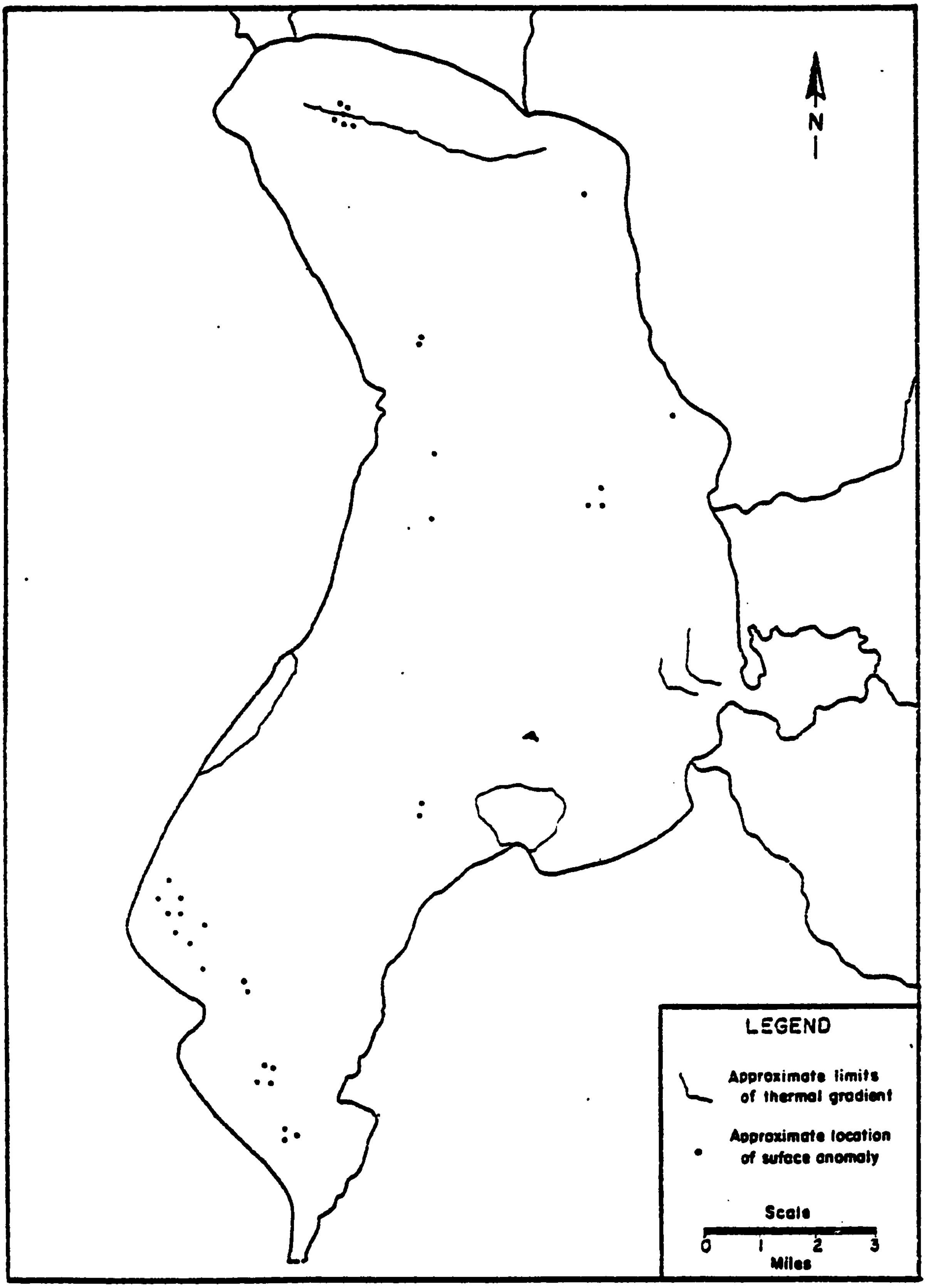

Figure 48. Indications of the 13 November 1977 ANG Thermal Scan.

emanating from Lincoln Point is easily explained by the thermal springs on the point. Similarly, the pattern off the Provo Bay outlet is most likely the result of the warmer municipal wastewater discharges into the Bay. Considering that overnight low temperatures for the two week period preceding the flight were in the mid-20's to low 30's and daytime averages in the upper 40's (Fahrenheit scale), the discharge of 60 to 70 degree water from the fresh-water springs in the north shore area could produce the gradient detected there. If such were the case, then the narrow band of warmer water along the northwestern shore of Goshen Bay could also indicate a seepage area. A "hot spot" was detected at the southern extremity of this band very close to shore, possibly denoting a small spring.

Besides showing the gradients just described, the film depicted some peculiar anomalies occurring in irregular patterns over the lake surface. They appear on the film as extremely small (less than 1 mm across) spots with ragged edges. Their appearance resembles the sort of pattern one would find when ice has not completely formed, yet the contrast indicates these small areas are colder than the surrounding surface. The lowest recorded Provo temperature during the 48-hour period immediately preceding this flight was 33°F (0.6°C). If temperatures were lower over the lake than over the populated areas during this period of time, it is possible that a thin ice cover could have formed and been present during the early morning hours. In that case, it would also be possible that reflected radiation from the ice could give a false indication that the temperature was warmer over the ice than over the open water. Unfortunately prior notice of the flight was not received so ground reference temperatures and observations were not obtained and the anomalies remain somewhat a mystery.

USFS Results

The film from the preliminary scans was shown to to the personnel of the Central Utah Project Office, USBR, and it was decided that the refinement of imagery detail would be worth the extra cost of a survey with more sensitive scanning equipment. It was determined that the U.S. Forest Service (USFS) based a Beechcraft King Air out of Boise, Idaho, which was equipped with a special thermal scanning unit used in forest fire detection. The necessary inter-governmental agency coordination was accomplished and arrangements were made to have the flight crew and equipment available on a 24 hour notice.

13 December 1977. Conditions were approaching near optimum on 12 December 1977 (lake approaching maximum density, several days of calm winds and clear skies, etc.) so the USFS was notified and the crew arrived that afternoon. The following morning (13 December) the crew flew a complete scan of the lake from an altitude of 3500 feet (1067 meter) above ground level (AGL). The sensitivity at this altitude was two degrees Centigrade. The entire scan was accomplished prior to sunrise in order to preclude interference from reflected solar radiation. Water temperature readings were obtained from the Saratoga Boat Harbor, the American Fork Boat Harbor, the Provo Boat Harbor, and Lincoln Point. Temperatures were 39°F (3.9°C), 38°F (3.3°C), 37.5°F (3.1°C), and 38.5°F (3.6°C) respectively. A light breeze blowing out of the northwest caused a slight rippling of the water surface and is felt to be the cause of the relatively low temperture reading (considering the thermal

sources present) at Lincoln Point. Since maximum density occurs at approximately 39°F (4°C) and the lake had been calm for several days, conditions were ideal for subsurface inflow to rise to the surface. The breeze was the only disadvantage in that it could cause some mixing and horizontal displacement of thermal gradients. Figures 50 through 58 are positive prints of the images produced within the areas shown in Figure 49. The contrast and resolution of the prints is not as sharp as in the negatives, but considerable detail may still be noted. The reader must keep in mind that these are not photographs but images produced by infrared radiation in the 8 to 14 micron wavelength band. Contrast changes represent temperature differentials with lighter shades representing warmer temperatures and darker shades representing cooler temperatures. The "tick-marks" along the film edge are nautical mileage markers.

In Figure 50, the shoreline seeps and thermal spring areas near Saratoga are quite visible. The influence of the group of the six major thermal springs in the "Northwest Grouping" is noted by the relative "brightness" of this corner. The fact that individual springs did not show up is probably due to mixing action caused by the breeze. The same gradient "arc" across the north end of the lake noted in the 13 November USAF film is again evident here, indicating a source of "warmer" water from the north end of the lake. Figure 51 is basically an eastern extention of Figure 50 and the light area extending out and down from the shoreline south of the U.S. Steel cooling pond is evidence of the numerous fresh-water shoreline seeps and springs in that area. Figure 52 shows more of the same sort of influence.

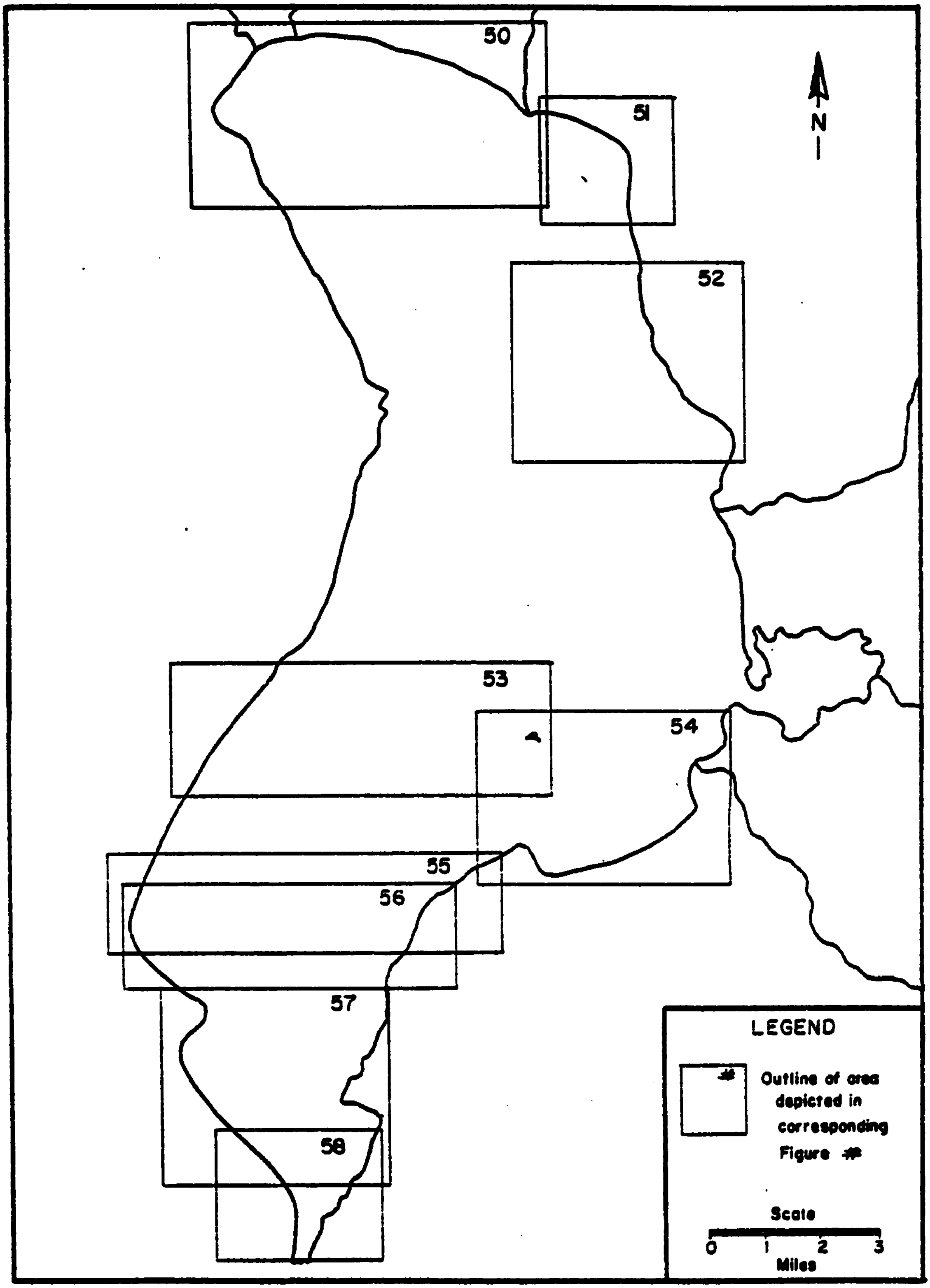

Figure 49. Areas Depicted in Figures 50 through 58.

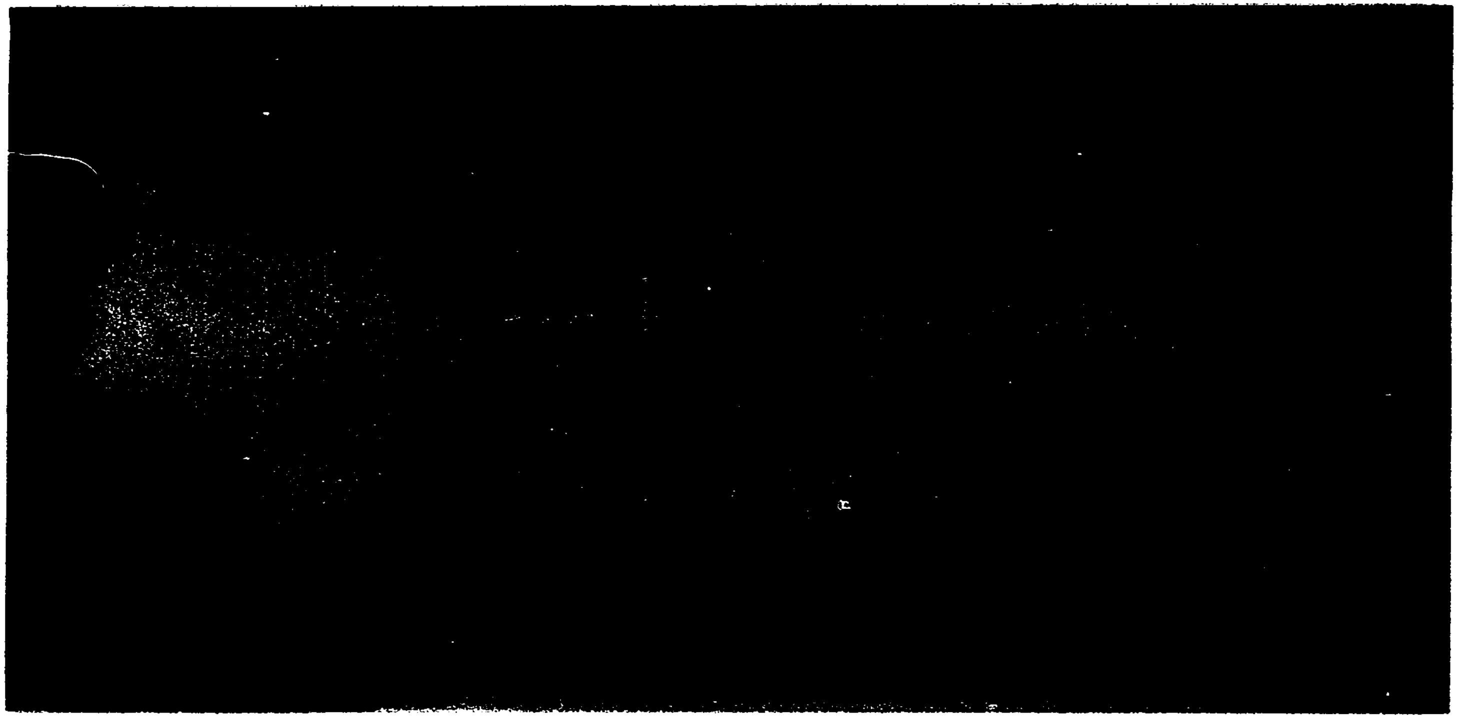

Figure 50. Thermal Image of the North End of Utah Lake (USFS).

Figure 51. Thermal Image of Geneva Area (USFS).

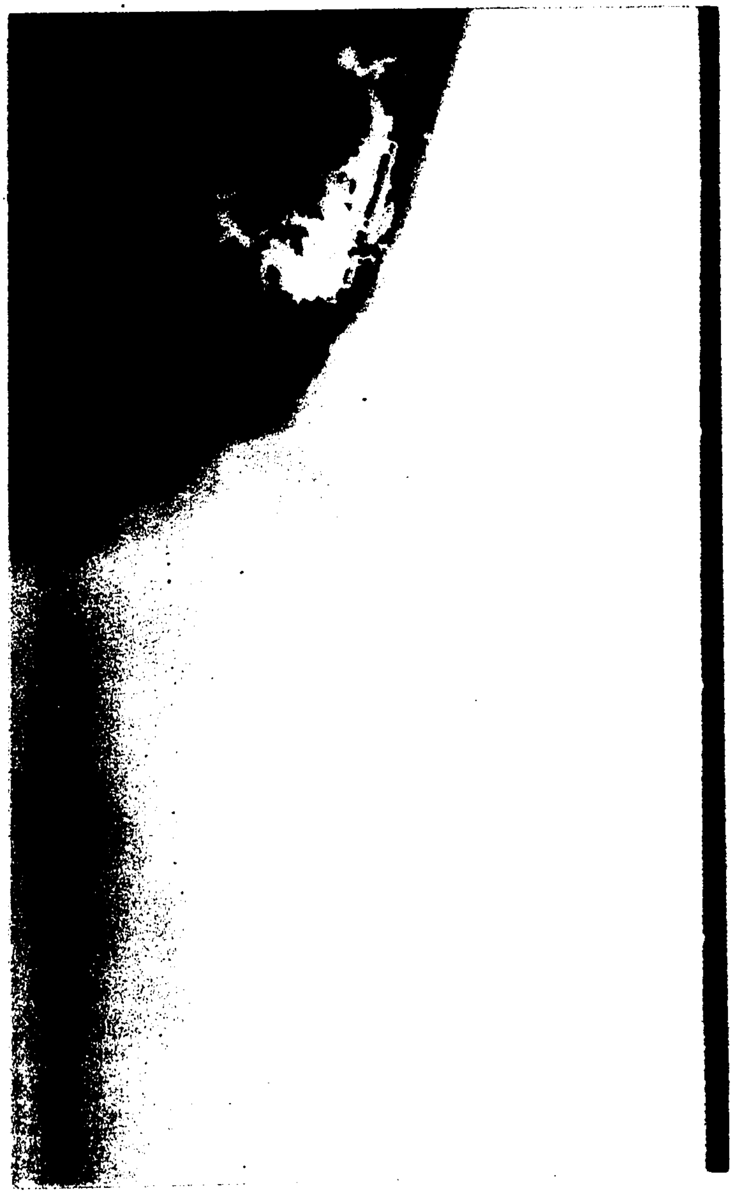

Figure 52. Thermal IMage of Powell Slough Area (USFS).

In Figure 53 the areas to the west of Bird Island and north of Lincoln Point appear lighter than the surrounding water, indicating the influence of the thermal springs in these areas. The area along the western shore of the lake also appears lighter than the surrounding water and the lightest contrast is found closest to shore. The width of the light area tends to increase toward the souuth. This band of light contrast along the west shoreline may be traced through Figures 54, 55 and 56.

The Lincoln Point springs and their influence are quite obvious in Figure 54. Two other observations may be made concerning this particular image. The first is that Viers' (1964) spring number six does not show up while all the others do. This is most likely due to submergence. The other interesting observation is that warmer inflows are indicated in two other areas close to shore about two thirds to three fourths of the way from Lincoln Point to the mouth of the Spanish Fork River.

Figures 55 through 58 show that warmer zones exist along the east shore line of Goshen Bay (most likely due to the seeps noted by previous investigators). They also indicate that a warmer area exists in the large bay just east of the old Mosida townsite. Another area is located about one mile (1.6 kilometers) south of the bay and to the east of the Church Farm Pump Channel. These areas correlate closely with several of the "anomaly" sites on the 13 November film (see Figure 48). Figure 58 is included primarily to show the springs and seeps in the extreme southeastern Goshen Bay area.

14 December 1977. Gradients depicted over the main body of the lake in the 13 December film were pretty much as had been expected, but the indications along the western shoreline south of Pelican Point

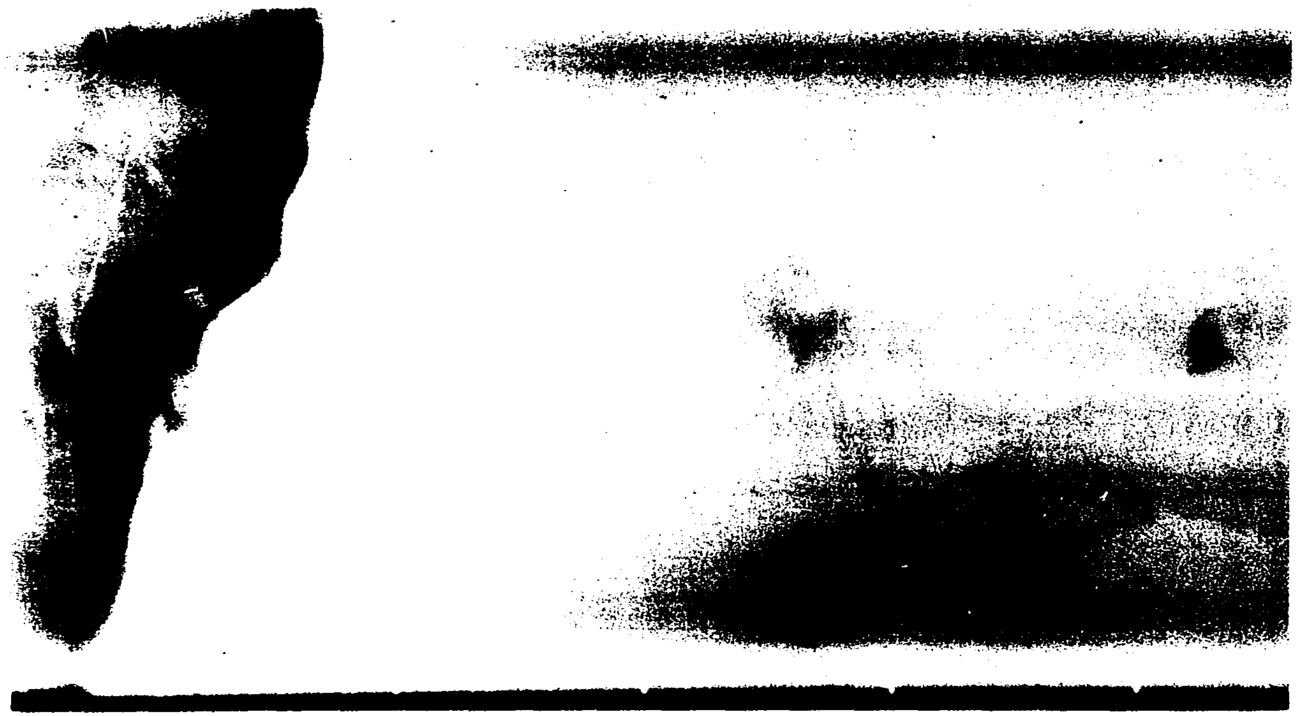

Figure 53. Thermal Image of Area Between West Shore and Bird Island (USFS).

Figure 54. Thermal Image of Lincoln Point Area (USFS).

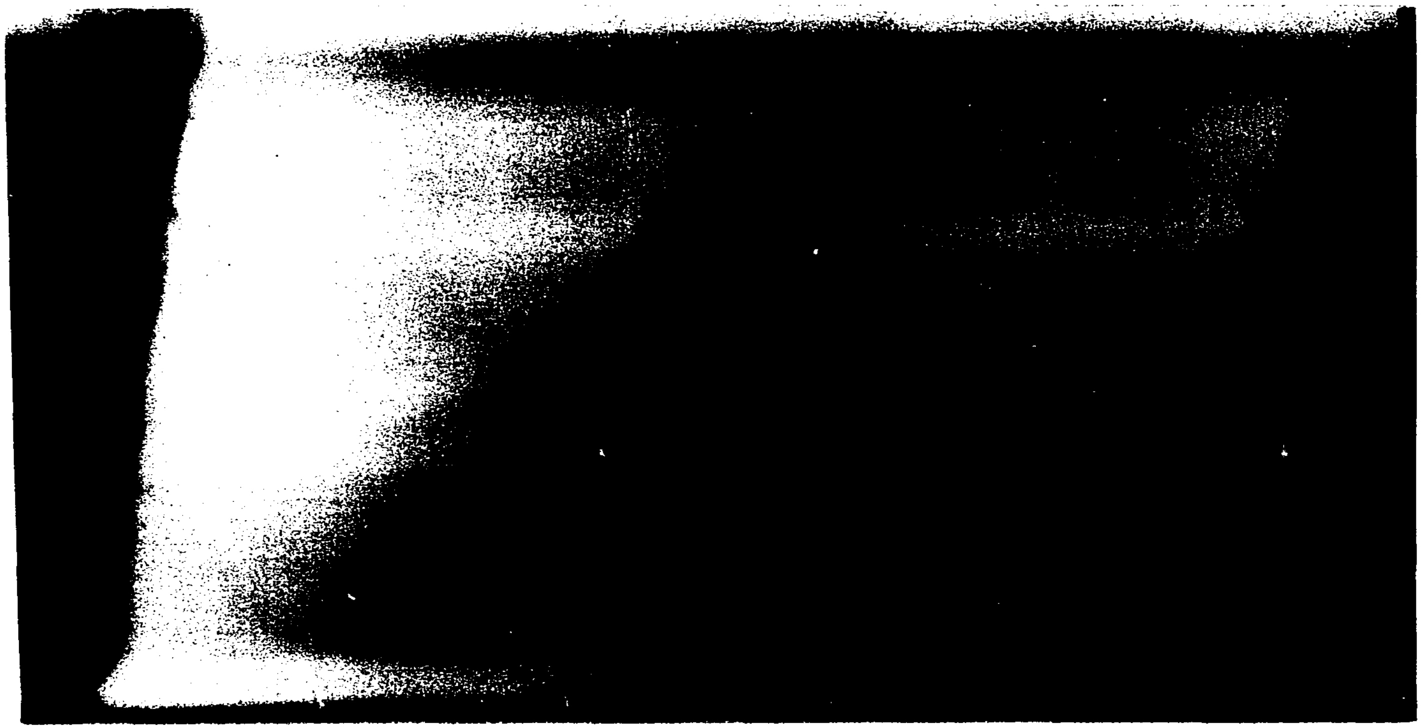

Figure 55. Thermal Image of Northern Portion of Goshen Bay (USFS).

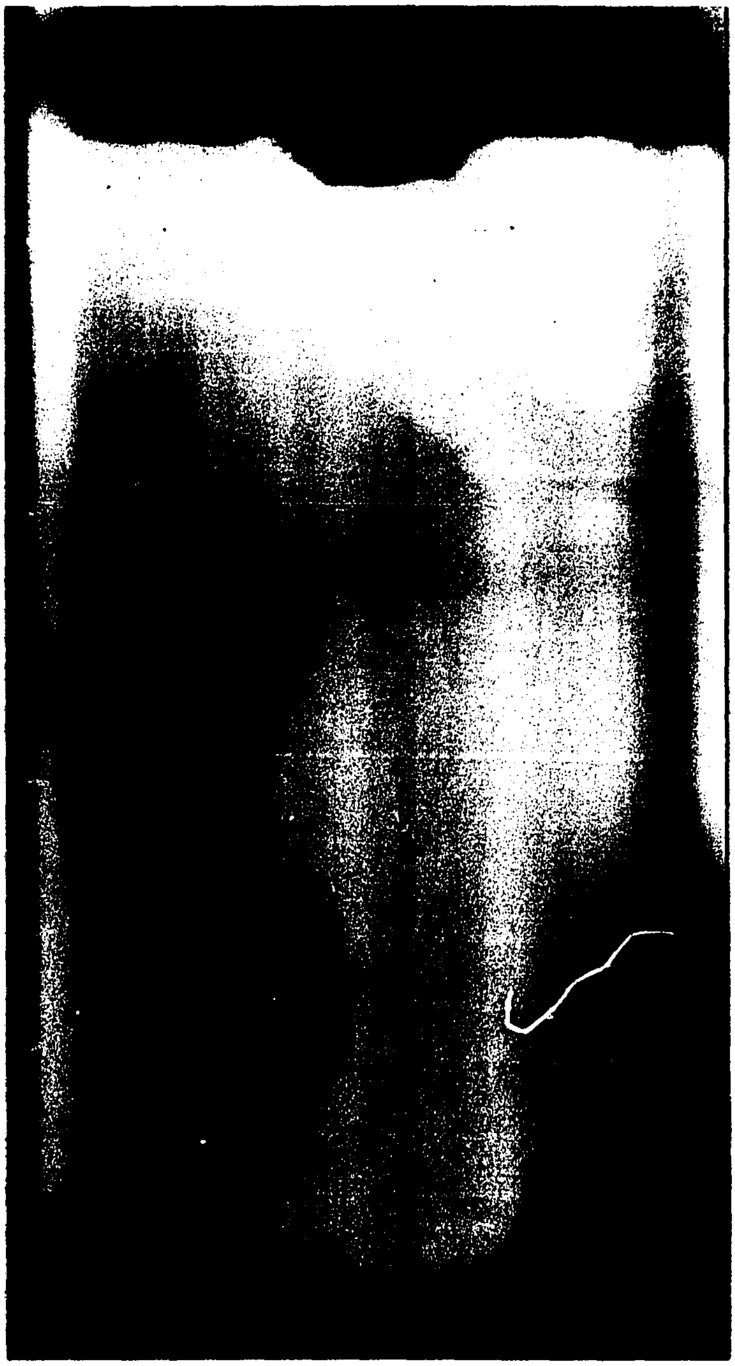

Figure 56. Thermal Image of Mid-Goshen Bay (USFS).

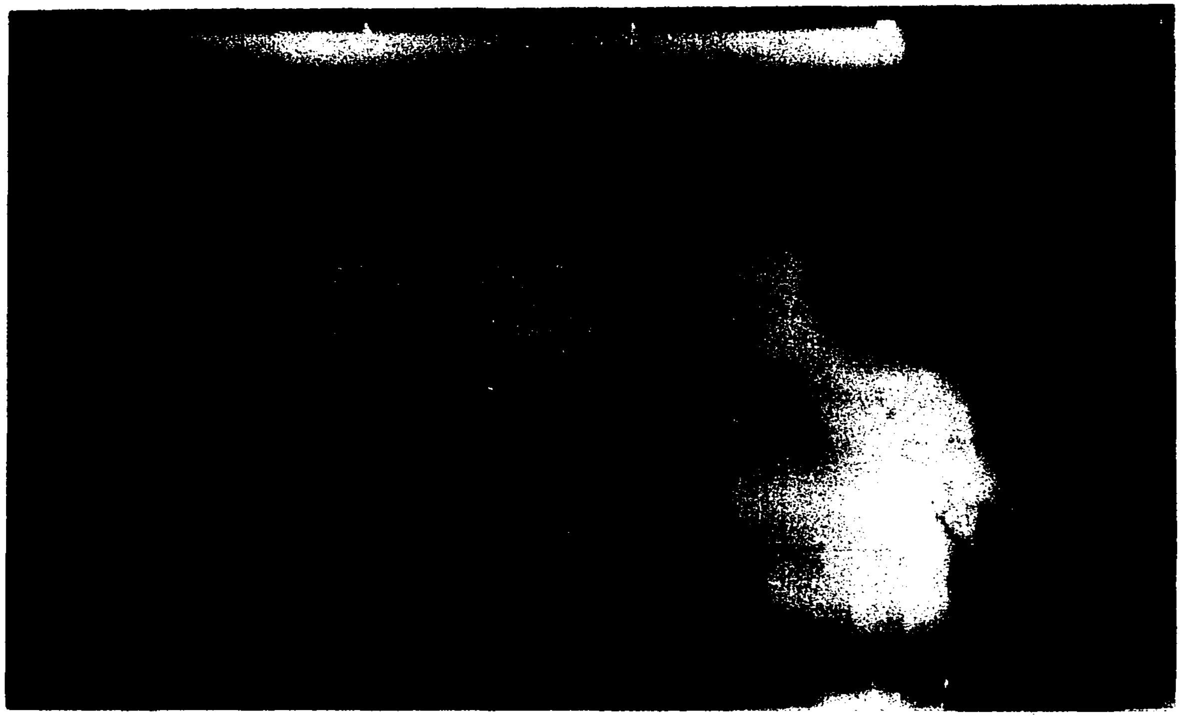

Figure 57. Thermal Image of Southern Goshen Bay (USFS).

Figure 58. Thermal Image of South Tip of Goshen Bay (USFS).

and in Goshen Bay aroused enough curiosity to retain the crew for one more day in an attempt to get concentrated coverage of the Goshen Bay area.

The next day a thorough scan was made of the areas in question. On this flight the altitude was reduced to 750 feet (229 meters) AGL where equipment sensitivity dropped to less than one degree Centigrade and the scan width decreased from approximately 2.5 miles (4 kilometers) to less than 1300 feet (396 meters). However, this increased sensitivity caused difficulties in film interpretation due to overlapping tracks and minor surface disturbances.

Both rolls of film are currently maintained in the CUP Office, USBR, Provo, Uath, and are available for inspection and further study by interested parties. The author has donated the film from the USAF flights to the Department of Civil Engineering at Brigham Young University.

Aerial Reconnaissance

The next phase of investigation was a concentrated effort to identify visually the areas where inflow might be occurring. A preliminary flight was made on 14 January 1978 to reconnoiter the lake shore line and to determine what the optimum conditions might be for spotting subsurface inflows in the lake. Ice was just beginning to form and there were many large open leads. While the water was by no means clear, it appeared well settled and had taken on a dark hue as opposed to its normal summertime chalky greenish-brown. The author was able to spot numerous small sand boils rising from the lake bottom within a mile (1.6 kilometers) or so from the shore. Most of these were less than 10 feet (3 meters) across and all had the appearance of billowy clouds of gray to brown suspended sediment. An unusually large number of these sand boils seemed to be concentrated along the east and north shorelines in a somewhat random pattern. By the time the Goshen Bay area was reached the lighting conditions had deteriorated and the flight was terminated.

A period of unsettled weather moved in following this first flight and it was not until 31 January that another flight could be made. Dr. LaVere B. Merritt of BYU Civil Engineering Department accompanied the author this time. The leads in the ice had pretty well closed up but the ice itself was extremely thin and transparent and the sand boils spotted on the previous flight could be seen through the ice. In some cases there were very small holes in the ice directly over the sand boils.

Only two or three small boils had been spotted between Saratoga and Pelican Point, but at Pelican Point the trend began to change. Two plumes, the largest being approximately 8 feet (2 meters) across, were spotted in a tight group approximately 500 feet (152 meters) to the north and east of the tip of the point. Another plume was spotted near the center of the south cove formed by the point, and another about 100 feet (30 meters) offshore approximately one half mile (0.8 kilometers) south of the old pumping plant.

Nothing else of interest was sighted until arriving at the area just south of "The Knolls" where an irregularity in the ice aroused some curiosity. The irregularity was a large open water area of a rough triangular shape. The "base" of the triangle was formed by two to three miles (3 to 5 kilometers) of beach and the "apex" was roughly two miles (3 kilometers) out from the beach in a southeasterly direction.

Other small open areas had been spotted at various places on the lake but none of these were of comparable size.

The flight continued southward to the large cove just east of the old Mosida townsite midway along the western side of Goshen Bay, which the author has dubbed "North Mosida Cove" (see Figure 59) for ease of discussion. The largest single concentration of sand boils spotted anywhere in the lake was found here. Between 15 and 20 plumes ranging in size from 3 feet (1 meter) to 6 feet (2 meters) across were located within the confines of this cove.

Continuing around "Mosida Point", two large plumes were spotted about 1200 yards (1097 meters) out from the tip of the point (see Figure 59). These were within 30 yards (27 meters) of each other and the largest of the two appeared to be 10 to 15 feet (3 to 5 meters) across. Two more groups of small boils were located south of this area in "South Mosida Cove" and about midway across the southern end of Goshen Bay. The boils in these two areas resembled those in "North Mosida Cove" but were not quite as numerous or closely spaced.

From this point, the flight turned northward and a grouping of three large plumes was located just north of a line between "Mosida Point" and the large metal sheep barn on the east shore of Goshen Bay. The group was located in fairly deep water approximately one mile (.16 kilometers) out from the east shore (Figure 59) and the largest of the plumes appeared to be 15 to 20 feet (5 to 6 meters) across.

On the return flight to the airport, a pass was made over the area between Lincoln Point and the mouth of the Spanish Fork River. Two more sand boils were spotted here in shallow water about 100 yards (91 meters) off shore. They were located approximately 1.5 and 2.5

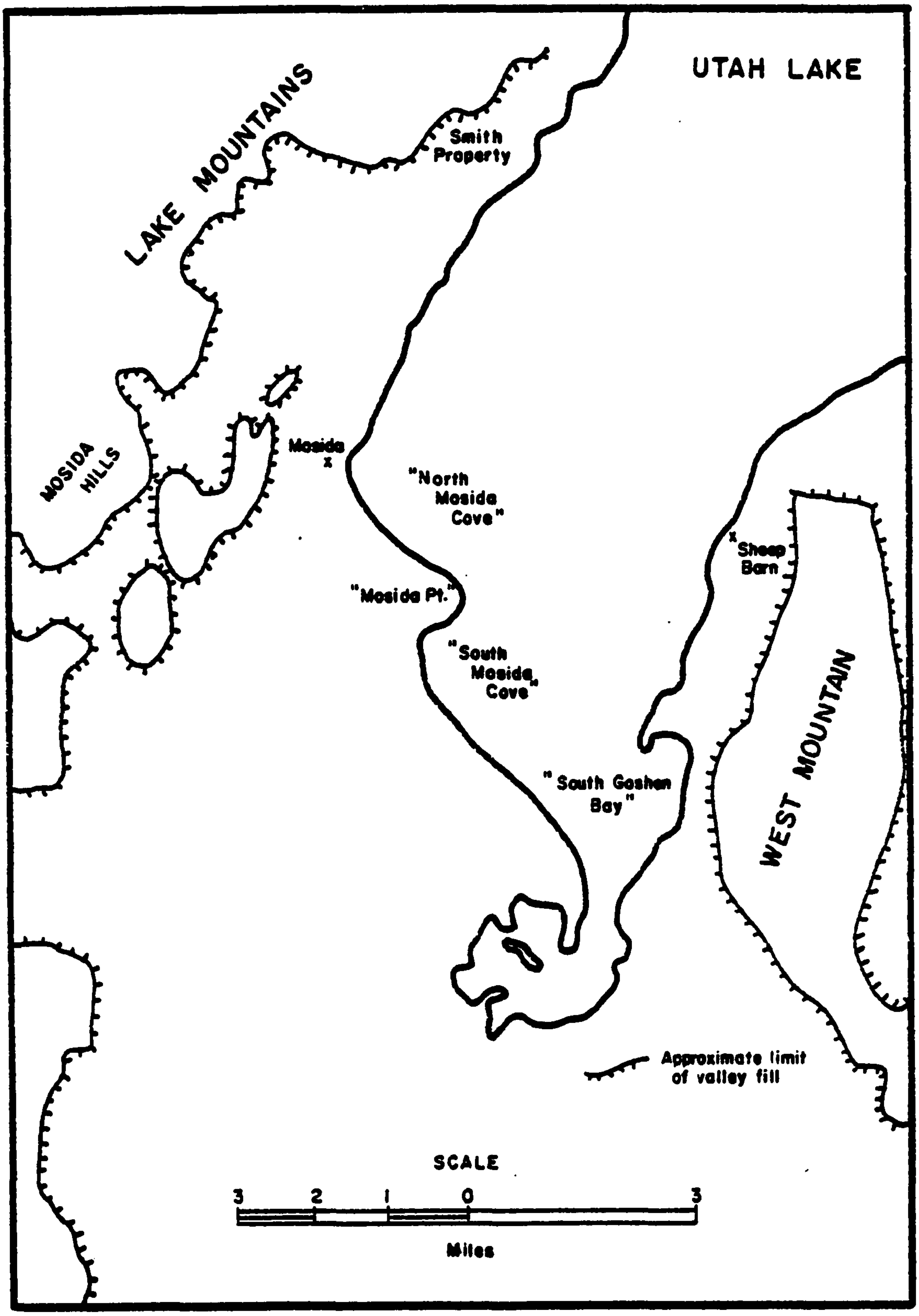

Figure 59. Geographic Points in Goshen Bay.

miles (2.4 and 4.0 kilometers) east of Lincoln Point, respectively, and compared in size to those found along the northern and eastern shores of the lake.

On 23 February 1978, buoys were dropped from a helicopter on the plumes off Mosida Point, those off the sheep barns on the east side of Goshen Bay, and the plume 1.5 miles (2.4 kilometers) east of Lincoln Point. Pictures were also taken on this flight and two of them are included as Figures 60 and 61. Figure 60 is a photo of the large plumes off "Mosida Point" with the orange float visible at the lower left edge of the main plume. Figure 61 is one of the small sand boils in shallow water in "North Mosida Cove" and is included to illustrate the effect of even a slight breeze on the turbidity of the lake water. The boil is barely visible slightly left of center and one third of the distance down from the top of the picture. Figure 61 also illustrates why these sand boils had escaped previous detection and why it would be impossible to spot them from a boat.

Numerous sand boils around the eastern and northern shores indicate that inflow is occurring over a very broad area in this end of the lake. The plumes along the west side of the lake and in Goshen Bay identify very definite subsurface inflows in an area previously thought void of such ground-water. The open area in the ice south of The Knolls corresponded very closely with the patterns shown in the trend maps for Na, Mg and K discussed at the end of Chapter 2, and with the thermal imagery indications for that area. The "islands" discussed in connection with Jensen's (1972) trend maps correspond with the location of the large plumes off "Mosdia Point". Many of

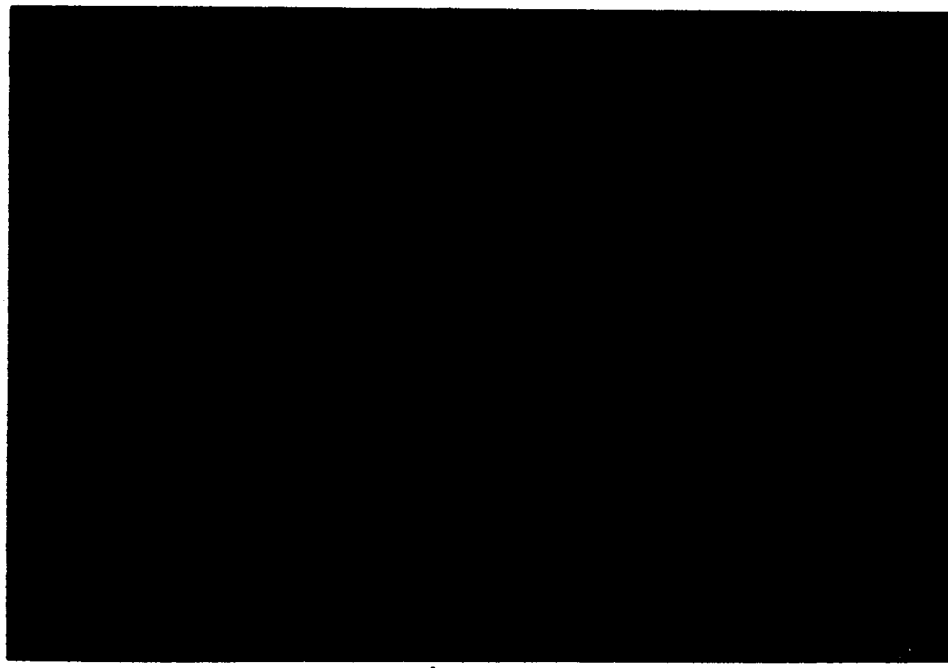

Figure 60. Large Plumes off "Mosida Point".

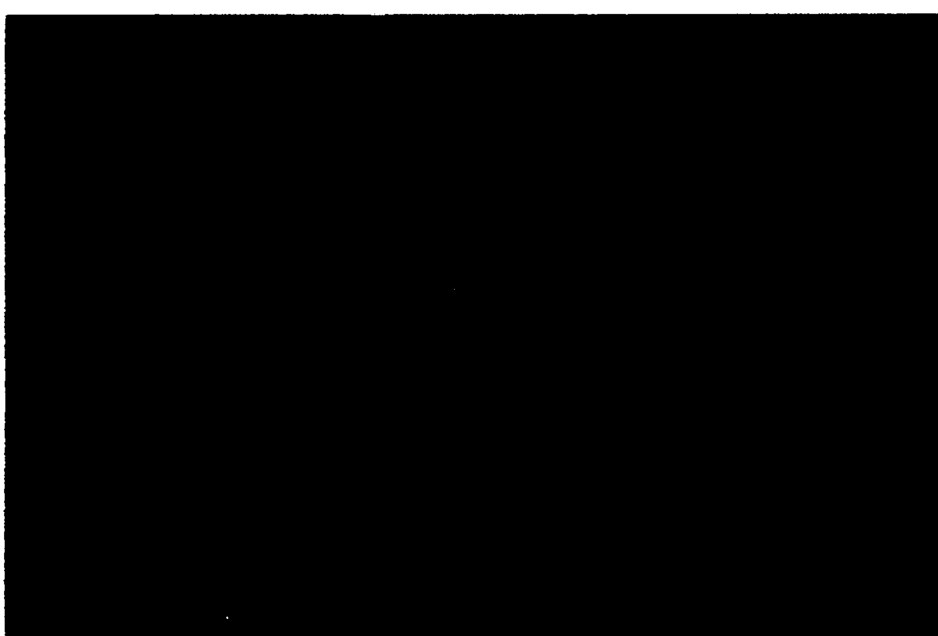

Figure 61. Effect of Lake Bottom Agitation on the Visibility of the Sand Boils.

the "anomalies" mentioned on the 13 November USAF film (infrared) correspond closely with many of the sand boil locations.

Samples and Piezometric Profiles

Due to time constraints, there was only one opportunity to install piezometers and collect data and samples. In order to predetermine the best locations and alignment for these initial piezometers it was first necessary to identify those areas considered to be the more probable "source areas". Since most major inflows occur from the Mosida area north and tend to be located in the western half of Goshen Bay, it was decided to concentrate the "source area" search in the northwestern part of Goshen Valley. Inflow from a southerly direction was not totally ruled out, but the topography and piezometric profiles for Goshen Valley indicate that subsurface inflow from that direction would have a greater likelihood of discharging further south than the Mosida area.

Mosida Inflows

Irrigation activity was the first possibility investigated to test the theory of inflows to Goshen Bay being the result of irrgation return flow. The author concluded this was probably not a significant source for two reasons. The first is that sprinkler irrigation, which is a highly efficient application method, is used throughout Goshen Valley. Water losses due to surface/subsurface return flow are very minimal. The second reason is that the land is not cultivated any further north than the "Mosida Point" area, and so return flow, even if it were a large amount, would probably have little impact on the areas of major inflow activity.

Next the water levels were checked in several wells in the northwestern part of Goshen Valley. The numbers in parenthesis following the well description in Figure 62 represent these water levels in feet above mean sea level. The possibility of a hydraulic gradient away from the "Fitzgerald 1" well both to the south and to the north is indicated suggesting a source may lie to the west. (Note: the water level in the Chipman well was determined in 1949 while the other levels were measured over 15 years later after the ground-water reservoir had been extensively developed; thus it is likely that the level in this abandoned well has dropped below 4502 since 1949). There is also a significant difference in yields for these wells varying all the way from 15 gpm from the Allen well to nearly 3000 gpm from "Fitzgerald 4" ("Fitzgerald 3" produces 1902 gpm with only an eight foot drawdown after six hours of pumping). The drillers of "Fitzgerald 4" reported that fractured bedrock being very large cracks filled with water was encountered from 205 feet (62 meters) to 300 feet (91 meters) where drilling ceased. This formation is not encountered in any of the deeper wells to the east or the south.

Chemical quality data was compared for water from a southern Cedar Valley well, the combined flow of "Fitzgerald 3" and "4", and other Goshen Valley wells south of the Fizgerald wells. The general indications for several of the constituents are listed below:

1. Calcium: The concentration tends to decrease from south to north and toward the lake in Goshen Valley and from north to southeast in Cedar Valley. The Fitzgerald sample concentration was somewhat higher than the closest Goshen wells and more than two times higher than the Cedar Valley well.

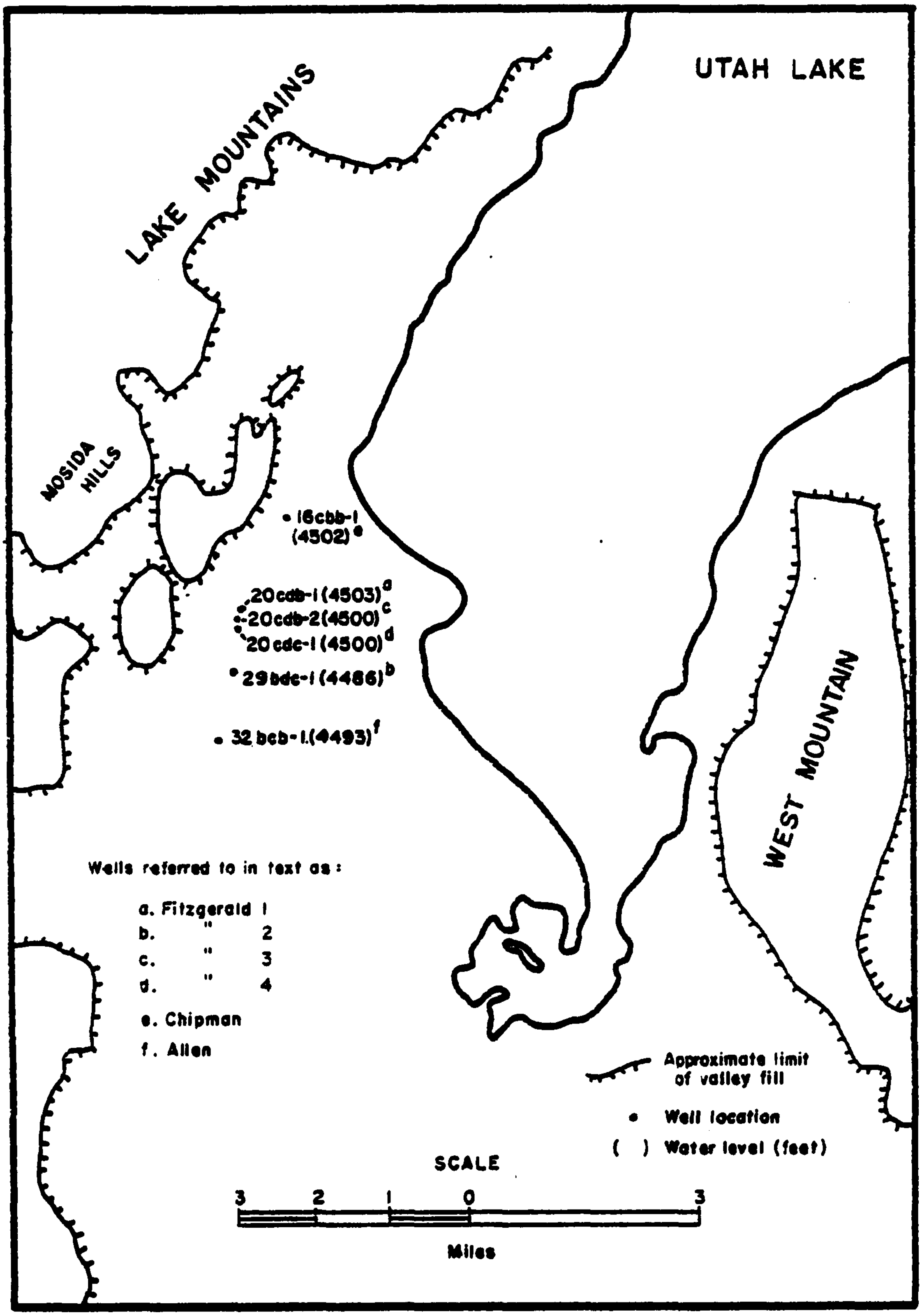

Figure 62. Wells in Northwestern Goshen Valley.

2. Magnesium: The trend is the same as with calcium.

3. Sodium: Fitzgerald wells are slightly higher.

4. Potassium: There is relatively little difference.

5. Bicarbonate: Fitzgerald wells have the highest concentration and the Cedar Valley well the next highest. Both sets are much higher than the other Goshen wells.

6. Sulfate: Concentrations decrease from south to north in Goshen Valley and increase from north to southeast in Cedar Valley. The Fitzgerald concentration is closer to the Cedar Valley sample than the other Goshen Valley samples.

7. Chloride: The trend is similar to the one for sulfate except that Fitzgerald sample favors the closer Goshen concentrations by a considerable margin.

8. Dissolved Solids: The trend is similar to chloride except the Fitzgerald sample only slightly favors the closer Goshen values.

There is insufficient data available at present to establish the source of the water in the Fitzgerald wells. However, after carefully evaluating Hoffman's (1951) geologic study of the Mosida Hills, the author feels that if Cedar Valley ground-water were the source, the most likely path water would follow would be as shown in Figure 63.

The fact that the hydraulic gradient is flatter to the north and east of the Fitzgeral wells indicates that water in that area would have a tendency to flow toward "North Mosida Cove". A line was established from the Chipman well to the beach directly below the old Mosida townsite and from there to the plumes off "Mosida Point". One half inch (1.27 cm) piezometers were then jetted in at the beach and plume locations.

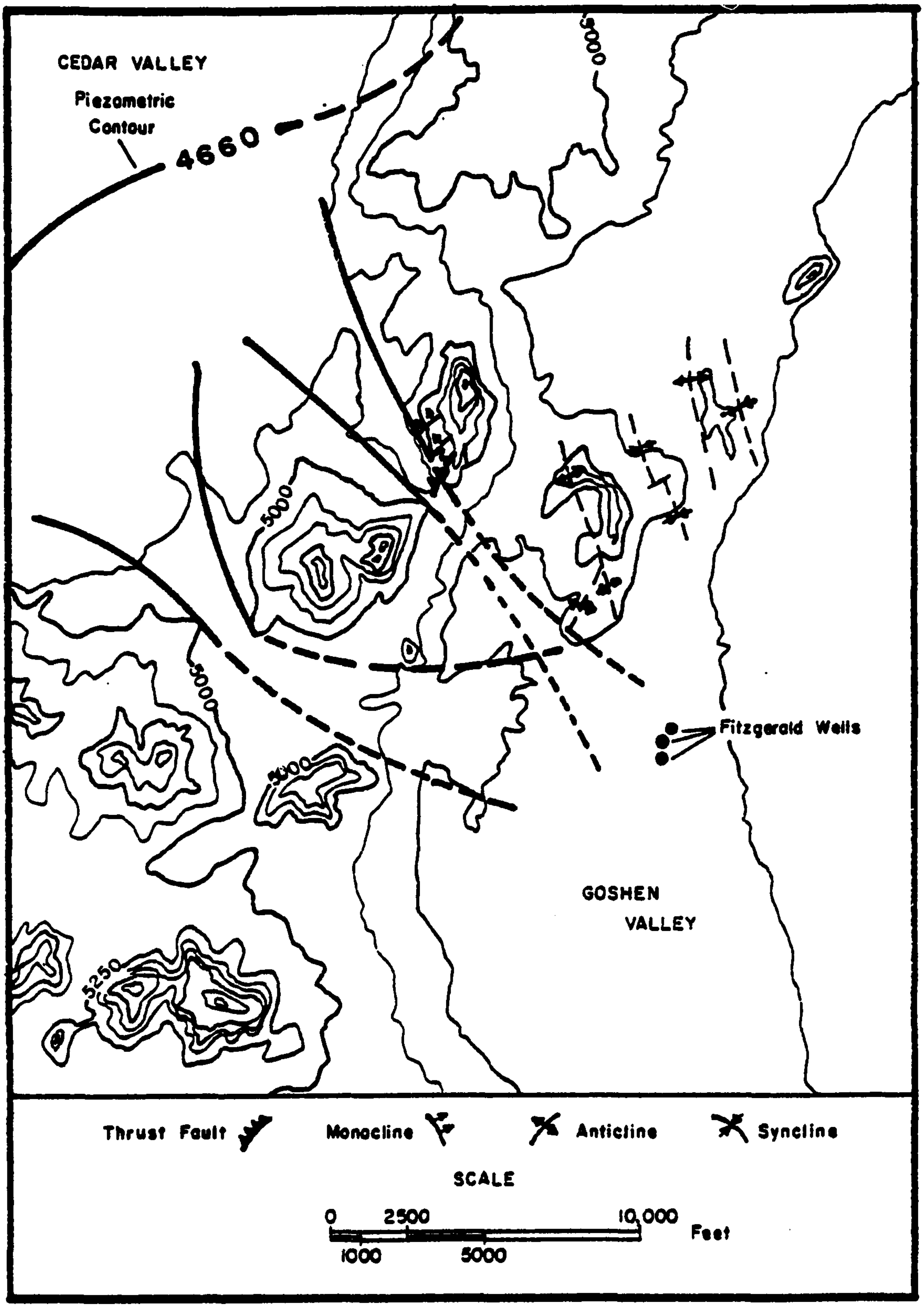

Figure 63. Most Likely Path for Water Flowing From Southeastern Cedar Valley.

Mosida beach piezometer. The piezometer at the lake edge was jetted to a depth of 61 feet (19 meters). The upper 10 feet (3 meters) was primarily an organic-rich silt mixed with fine clay and sand and the next 51 feet (16 meters) consisted of 3 to 5 foot (1 to 1.5 meters) thick layers of coarse sand (Figure 64) separated by thinner (usually less than a foot) layers of hard, cemented sand. The extremely fine sand encountered at all levels is shown in Figure 65. Water in the pipe stood at the same level as the lake, indicating that water was not confined below the upper layer of silt and clay. Thus the head responsible for the sand boils in the lake appears to come from a deeper level.

Sand boil piezometer. When the piezometer was installed near the plume off "Mosida Point", a totally different situation was encountered. The pipe sank rapidly with only a slight amount of pressure to a depth of 30.5 feet (9.3 meters) below the water surface (the water was 6.5 feet or approximately 2 meters deep). When the pressure hose was removed to add another section of pipe, trapped pressure forced a jet of clear water approximately 6 to 8 inches (15 to 20 cm) above the top of the pipe, which was 17 inches (43 cm) above the water surface. This flow continued for approximately 15 seconds before the water began to bring up a very fine black sediment and the pressure started to drop off. The more concentrated the sediment load became, the more the pressure decreased. The flow never did completely cease during the 30 minutes the crew remained on station, but by the end of that period, the water had become black with silt and the flow had reduced to a trickle.

The pressure which forced the water up the pipe could have been attributed to any one or a combination of three things:

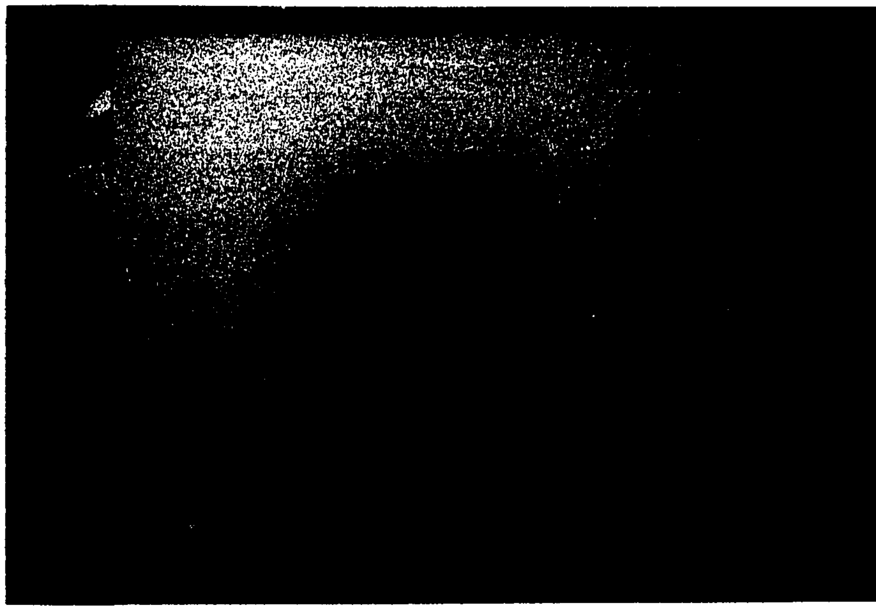

Figure 64. Coarse Sand from Mosida Piezometer Site.

Figure 65. Fine Sand from Mosida Piezometer Site.

1. The jetting rig could have "pressurized" the sediments.

2. Water contained in the sediments may have been compressed by the overburden of lake water and sediments and when the piezometer was placed, a relief vent was provided.

3. Actual artesian conditions were encountered.

The first reason is not considered likely because the pump was in operation less than 15 seconds, in which time less than three gallons of water could have been pumped into the sediments through a depth of 24 feet (7 meters). Similarly, the second reason is not considered plausible because the sediments were too easily penetrated, indicating too "loose" a structure to provide the type of overburden pressure required. The third cause is considered the most probable. The head loss observed was likely the result of "sanding" (the washing in of fine sediments) of the pipe.

A sample was collected from this piezometer, but there is a good possibility that it is not representative due to the fact that it may have contained some lake water. The sample was collected soon after sediment started appearing. This may not have allowed sufficient time to flush all the lake water from the pipe. The analysis showed 226 mg/l total alkalinity (as $CaCO_3$), 276 mg/l bicarbonate as HCO_3, 52 mg/l Ca, less than 1 mg/l CO_3, 236 mg/l Cl, a conductivity of 1685 umhos/cm at 25°C, a hardness (as $CaCO_3$) of 351 mg/l, 53 mg/l Mg, 209 mg/l SO_4, and a TDS of 905 mg/l. When compared to values for GB-3 in Table 4, it is noted that Ca is about the same while CO_3, Cl, conductivity, Mg, SO_4, and TDS are all higher for GB-3. When compared to the other Utah Lake locations though, all the values are comparable. The chemical data is inconclusive, but it does appear that the water from the plume area is of at least as good a quality as the main lake and perhaps somewhat better than that found in the lake waters of Goshen Bay.

Northwest Goshen Bay.

It was learned in an interview with Mr. Delbert Chipman (1978) (who has run sheep in the northwestern part of Goshen Valley for many years) that there used to be an old well somewhere just south of The Knolls which early settlers used as a watering hole on trips between Lehi and Elberta. He also recalled dipping water from a cold clear spring "...out about 50 yards from the present shoreline..." near the heavy growth of tamarac "...about a mile or so south of The Knolls..." as a boy.

The author then contacted Mr. Adelbert (Doyle) Smith who owns the property described above. Just a few months prior to our contacting him, he had discovered the location of the old well and had excavated to a depth of 12 feet (4 meters) with a small backhoe--uncovering a couple of old rusty buckets in the process. In describing the excavation project, he told of encountering a layer of gravel down "...about eight feet or so...". When the backhoe operator took the first large scoop of gravel out "...water came pouring in...and the wall caved in a little...". Once the excavation was complete, perforated 55 gallon oil drums were placed in the hole, a six inch (15 cm) diameter PVC pipe placed in the center of the drums, and the hole was then backfilled with gravel. Mr. Smith claims he can pump from 80 to 100 gallons (0.4 to 0.5 m^3) from the pipe in "...five or six minutes..." with his portable pump. He then has to wait for the pipe to refill.

Mr. Smith also pointed out the location of three separate submerged springs paralleling the beach and lying within 100 feet (30 meters) of the shoreline. These extend roughly from the southern to the northern boundaries of Section 26, Township 7 South, Range 1 West. This is the same area in which the large open lead was located on the 31 January flight, and the same area that Jensen's (1972) trend maps indicated as being high in Na, K, and Mg. Mr. Smith described these springs as "...cold and clear...". Several years earlier, he had forced a 55 gallon drum down about three feet (1 meters) over the two northern most springs, and then encased the apparent throat of each spring with a short section of six inch (15 cm) diameter PVC pipe. At the time, the lake had receded far enough that the springs were exposed, and he said the water "...bubbled freely..." over the lip of the pipe, which was six inches higher than the lake bed, and kept the sand in the bottom "bouncing". The author waded out to these two northern springs and was able to observe that both the barrels and the PVC pipe were still in place, though wave action had caused them both to tilt shoreward. The sand on the lakebed surrounding the springs was very clean and compact and bore the author's weight very well, whereas the sand at the bottom of the PVC pipe was very loose and obviously suspended by water issuing from below. The approximate locations of these springs are shown in the sketch in Figure 66.

It was further noted that there is a continuous seep the full length of this beach, which is characterized by numerous very small (one eighth inch or less) "upwellings" of water. The water from this beach area does not appear to be thermal, nor does it appear possible to channelize it for flow measurement. Mr. Smith said that his beach

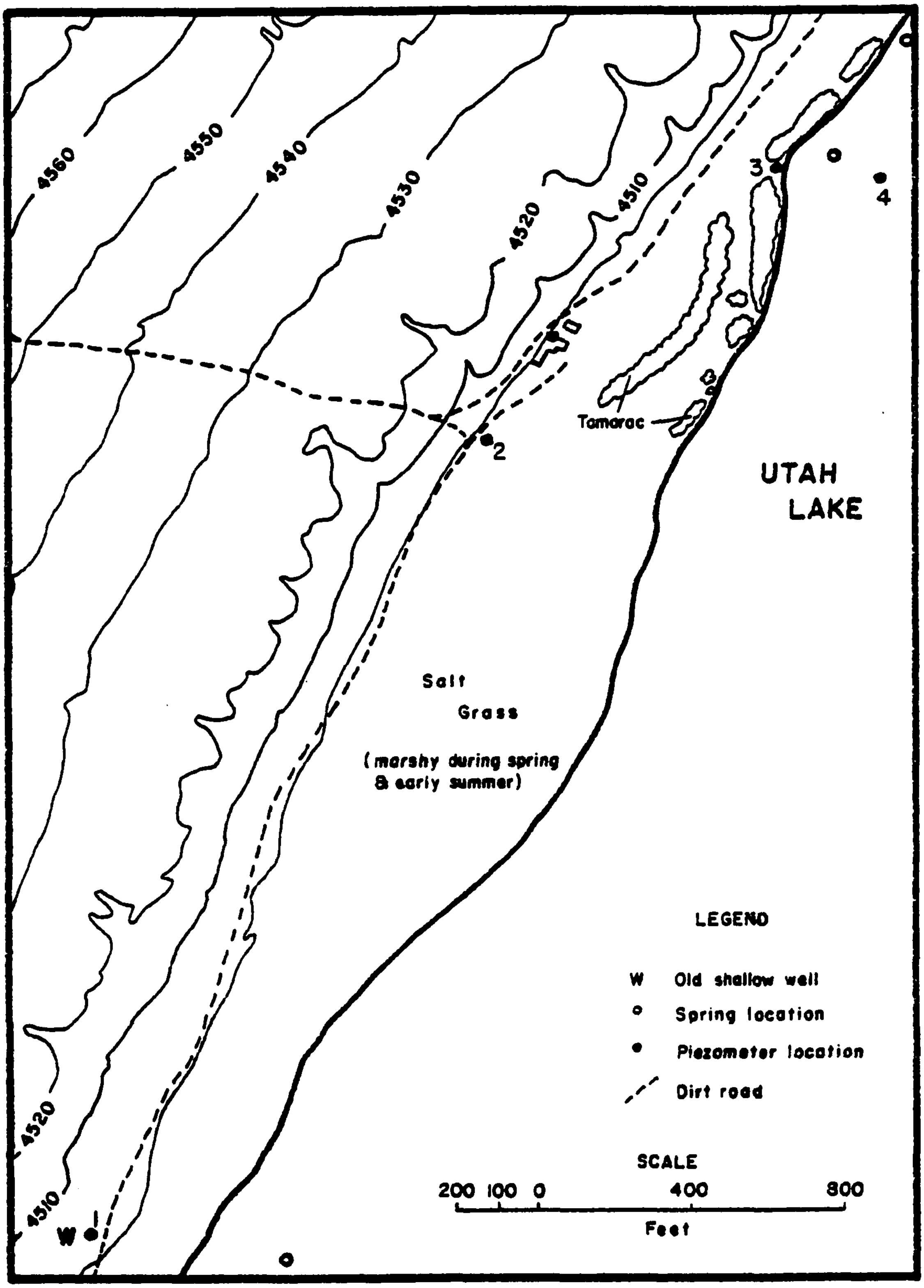

Figure 66. Well, Spring and Piezometer Locations on the Doyle Smith Property--Northwestern Goshen Bay.

area stays free of ice through all but the most severe winters and he is able to water his stock from any point along his waterfront by simply digging a small trench--which immediately fills with water even when the lake is lower than the bottom of the trench.

Mr. Smith also pointed out that the low-lying pasture area which borders the waterfront is very marshy during the spring and first half of the summer. Salt grass growing in these pastures was still very green and appeared to be doing quite well as late as November of 1978. An additional evidence of abundant ground-water is that this stretch of beach sports one of the heaviest, most luxurient growths of tamarac around the lake.

Piezometers. Piezometers were installed in the four locations shown in Figure 66. A very coarse gravel layer was encountered in the first three locations and piezometers could only be jetted to 25 feet (8 meters) at number 1, 41 feet (12 meters) at number 2, and 10.5 feet (3.2 meters) at number 3. This layer was not encountered at site 4 (100 yards or 91 meters offshore at a depth of 42 feet or 13 meters) but water did jet from the pipe in a manner similar to that encountered at the Mosida offshore site. The flow and pressure here did not appear as great as that at the Mosida site however.

After allowing water levels to stabilize for three weeks, readings were taken and elevations established relative to the lake level. At the time the elevations were taken, the stage recorder at the Jordan pumping plant showed the lake was at -2.73 feet (-0.83 meters) or 4486.61 MSL. The level in the old shallow well was measured at 4487.7 (1.1 foot difference); 4487.5 in piezometer 1 (located 13 feet east-northeast of the well); 4488.0 in piezometer 2; 4487.7 in 3; and 4487.9 in number

4. These readings show that there is a gradient toward the lake in the water table aquifer, and that artesian pressures may exist within the lakebed off the Smith beach. Further testing and evaluation would be required to confirm the existance of such pressures and to obtain sufficient data to estimate the amount of water which is entering the lake in this particular area of Goshen Bay.

Chemical quality. Samples were collected and analyzed from the old shallow well and from the offshore piezometer. These results were then compared to the chemical analysis of well number (C-6-1) 31dab-1 located at the extreme eastern edge of Cedar Valley north and west of the Smith property and on the opposite side of Lake Mountain. This comparison is shown in Table 5. The indications are that the offshore sample was contaminated with lake water and the values shown are probably not representative.

The sample from the shallow Smith well was not diluted, however and is a representative of unconfined water in this area. The high concentrations of Mg, K and Na correlate with Jensen's findings. Note in Table 6 how the value for each parameter (except chloride and conductivity) increases slightly going from the west side to the east side of Lake Mountain. These increases are consistent with the theory of water escaping from Cedar Valley through Lake Mountain in that such increased concentrations would be expected of water passing through limestone and dolomitic formations. Figure 67 is a photograph of the southeast end of the major Lake Mountain syncline (note the westerly dip of the east limb and the easterly dip of the west limb). The Smith property (trees along shoreline) is in direct line with this synclinal axis. Whether the ground-water on the Smith property originates in

TABLE 5

Comparison of the Chemical Quality of Ground-Water on the Southeastern and Western Sides of Lake Mountain

Parameter	Sample Source		
	Offshore Piezometer	Smith Shallow Well	Cedar Valley Well
Total Alkalinity ($CaCO_3$)(mg/ℓ)	174	362	395
Bicarbonate (HCO_3)(mg/ℓ)	212	442	324
Calcium (Ca) (mg/ℓ)	56	117	82
Carbonate (CO_3) (mg/ℓ)	31	21	---
Chloride (Cl) (mg/ℓ)	248	209	355
Conductivity (25 C)(umhos/cm)	1631	1739	2060
Hardness as $CaCo_3$ (mg/ℓ)	391	815	680
Magnesium (mg) (mg/ℓ)	61	127	116
Potassium (K) (mg/ℓ)	---	21.7	179
Sodium (Na) (mg/ℓ)	---	205	
Sulfate (SO_4) (mg/ℓ)	253	331	291
TDS (mg/ℓ)	977	1302	1230

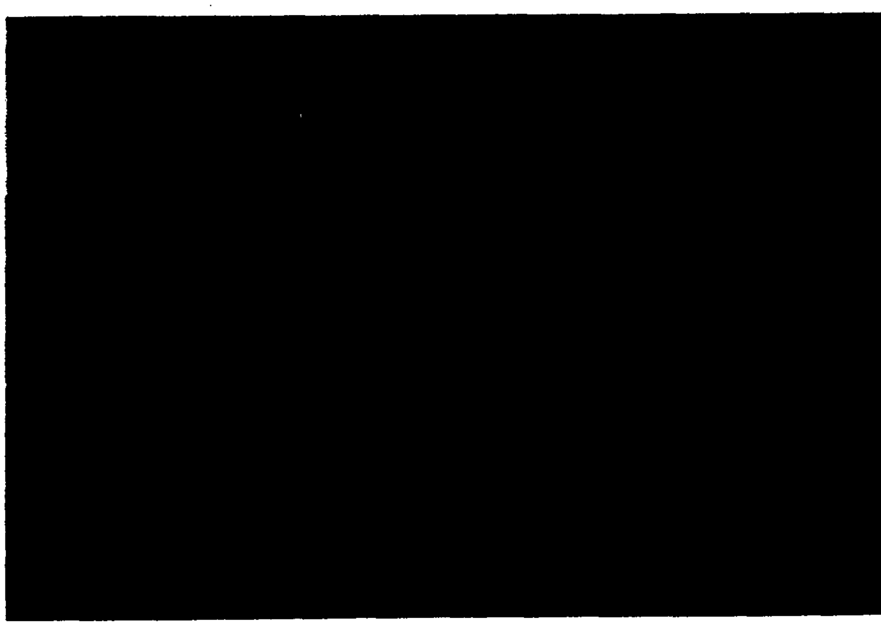

Figure 67. Southeast End of Major Lake Mountain Syncline (Smith Property in Foreground).

Cedar Valley or as preciptation over Lake Mountain, it does seem most likely that the synclinal axes direct the flow and the flow appears to be in a southeasterly direction.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The findings presented in the preceding chapters and the subsequent discussion of their implications provide the basis for several conclusions with respect to subsurface inflow to Utah Lake. These conclusions are presented as answers to the six questions posed in the problem statement section in the introductory chapter.

1. Based on the hydrogeology of the Utah Lake Basin, it is possible that the annual volume of subsurface inflow is in excess of 100,000 acre feet (123 x 10^6 m^3). The author feels that Fuhriman's latest estimate (1978) of 170 cfs (123,000 acre feet/year or 151.4 m^3/year) is not unreasonable.

2. Considering the nature of the valley fill, the availability of recharge water, and the piezometric contours; it appears that most of the subsurface inflow occurs in the eastern half of the main lake, from Lincoln Point to the Saratoga area. However, findings herein also establish the presence of sizeable previously unidentified ground-water inflows in the Goshen Bay area.

3. The major source of subsurface inflow to Utah Lake appears to be the Valley's fresh-water aquifers, which receive most of their recharge directly and indirectly from the Wasatch Mountains. Most of this inflow occurs as diffuse seepage over much of the lake bed, induced by artesian pressures. Additional ground-water inflow occurs

as mineralized thermal water derived from very deep sources. The groundwater source(s) for the inflows discovered in Goshen Bay have not been determined conclusively, but there is strong evidence to support the hypothesis that much of this flow may originate as precipitation over the Oquirrh Mountains and Lake Mountain.

4. The quality of the fresh water entering the main lake most nearly resembles water found in the Shallow Pleistocene aquifer. Thermal flows in the southern end of the lake are much more mineralized than those in the northern end. Analyses of samples from various mineral springs (see Appendix B) sampled by the author agree closely with the results reported by other investigators, indicating a fairly stable quality from these sources. The quality of the water entering the lake in Goshen Bay appears to be generally of equal to lower quality than the main lake--lower quality (higher levels) in bicarbonate, calcium, conductivity, magnesium, potassium, sodium, sulfate, and dissolved solids.

5. Precise quantification of these individual inflows would be economically infeasible when viewed from a cost-benefit perspective as the inflow is too diffuse. It appears that a steady influx over a very broad area contributes most of the volume--not individual flows. The author estimates that roughly 85 percent of the total subsurface inflow, approximately 102,000 acre feet (125×10^6 m^3) per year, occurs in the main lake; and that a maximum of 15 percent, or 18,000 acre feet (22.1×10^6 m^3) per year occurs south of the proposed Goshen Bay Dike. These figures are based on the assumption that Fuhriman's subsurface inflow estimate of 123,000 acre feet per year is reasonable. The assignment of 15 percent to the Goshen Bay area is based on the author's assessment

of Brimhall's accoustical profiling indications as well as the 10,000 to 19,000 acre foot "unaccounted for" water which may be leaving Cedar Valley (Feltis, 1967:18-19).

6. Effects of the results of this investigation on the proposed Utah Lake dikes are limited mainly to Goshen Bay. With the discovery of "new" ground-water inflows in the area behind the proposed Goshen Bay dike alignment, other management alternatives need to be given consideration. The quality of this ground-water would seem to be the major factor in determining whether provisions should be made to segregate or integrate these waters with the main lake water.

Recommendations

More ground-water piezometric pressure and quality data are needed from Utah Lake and in the surrounding areas where inter-basin ground-water movement is suspected. Since the Goshen Bay area is of interest due to possible diking from the main Lake, efforts there are needed. Additional data from southeastern Cedar Valley would also be of value. Based on the author's findings, further investigations in the following areas are of particular interest.

1. Comprehensive piezometric investigations of the aquifers in the Lake Mountain and Mosida Hills areas are needed to establish conclusively whether or not Cedar Valley ground-water enters Goshen Valley. This study should include the drilling of at least three test wells at the southeastern end of Lake Mountain. One well should be located between Lake Mountain and the highway at the end of the major synclinal axis in the SE1/4 Section 23, T7S, R1W. It is further recommended that the second well be placed approximately one half mile east of

the first well and the third one half mile south of the first well. Data obtained from well drilling logs, water samples, and pumping tests could be used to determine water-bearing and transfer properties and hydraulic gradients of the aquifers. Similar wells should be drilled in the Mosida Hills area west of the Fitzgerald wells. Specifically, the two most promising locations are the SW1/4 SW1/4 of Section 18, T8S, R1W and the SW1/4 NW 1/4 of Section 24, T8S, R2W. If water is encountered in Section 18, then another well should be drilled in the W1/2 NE1/4 of Section 13, T8S, R1W. If water is found in Section 24, then attention should be given to the area northwest of Greeley Pass along the boundary of Sections 14 and 23, T8S, R2W. Tracer methods might possibly be successful in these areas.

2. Several piezometers should also be placed in a line from the highway to the lake (1) on the Smith property, (2) near the old Mosida townsite, and (3) in Sections 27 and 28, T8S, R1W, to establish the hydraulic gradients for these areas. The author found it impossible to penetrate beyond a coarse gravel layer (generally located at approximately 30 feet) with his light jetting equipment. Alternative installation techniques other than 1/2 inch pipe jetting should be investigated.

3. Additional attempts should be made to install piezometers in Goshen Bay in the "plume" area off "Mosdia Point" in such a way as to prevent contamination and sanding. Further study of various techniques would be required, but the driving of small diameter, fine-mesh well points may be a solution provided a stable driving platform were available. Personal attempts to drive 1 1/4 inch well points with a boat-mounted "over-the-bow" driver assembly were frustrating

as boat position could not be maintained and off-center blows caused failure of pipe joints. At least two and preferably three such piezometers should be installed at each location at varying depths in order to determine whether an upward gradient exists and to obtain data from which inflow volume calculations might be made. Similar work should be done in the area offshore from the Smith property at the south end of Lake Mountain. Piezometers should also be placed in a representative number of the areas indicated in Brimhall's lake bed sonar work as possible spring activity areas (Brimhall, et al., 1976a) to test his spring inflow theory and provide additional refinements to it.

4. The possibility of a "mounding effect" of percolating waters over Lake Mountain and West Mountain ought to be investigated so a more accurate determination of hydraulic gradients might be made for these areas. Piezometers (wells) used in such a study would need to be capable of penetrating coarse materials and/or bedrock and extending to considerble depths.

5. At least one test well ought to be drilled in southeastern Cedar Valley to a depth sufficient to test for aquifers which may lie below the 200 foot (61 meter) level. Particular attention should be given to water quality and piezometric data.

6. Attention might also be given to further thermal imagery using other wavelength bands, but careful evaluation of cost-benefit ratios is needed in such cases since coordination of equipment availability and favorable conditions is very "tricky" and expensive. Before undertaking an additional thermal scanning study, attention should be given to a densitometric study of the imagery films obtained in 1977.

7. Studies of various diking management alternatives should consider the discovery of these "new" ground-water inflows in Goshen Bay. These alternatives should address alternates such as the effect of isolating these flows from the main lake, legal implications, pumping provisions, and ponding/channeling arrangements behind the dike. Hopefully, information from further studies as suggested above would firm up water quantity, quality and inflow areas prior to final decisions on these alternates being made.

CHAPTER 7

SUMMARY

This investigation was undertaken in response to a need for a more complete understanding of the geohydrology of Utah Lake. A comprehensive review of the findings of other researchers formed a base for this study (Chapter 2). The geology and hydrogeology of the Utah Lake Basin was given detailed attention and thermal imagery, aerial reconnaissance, and piezometric investigations were employed to identify subsurface inflow areas and possible sources of these inflows.

Results indicate that: available aquifer recharge has been traditionally, and perhaps significantly, underestimated; the depth of valley fill in the basin may be at least twice that previously supposed; the hydrogeology of similar basins suggests that a considerable volume of water may be forced upward through restricting layers by artesian pressures; and geologically speaking, there is ample opportunity for water to pass from Cedar Valley into Goshen Valley. It was concluded that subsurface inflow to Utah Lake occurs primarily in the form of diffuse seepage over broad areas in the lake bed, total annual subsurface inflow may exceed 100,000 acre feet (123 x 10^6 m^3), and that precipitation over the Oquirrh Mountains may provide an additional source of groundwater to Utah Lake.

Previously unknown ground-water inflows were suspected in the Goshen Bay area as a result of evidence from thermal imagery and chemical quality trends. Presence of inflows was verified and some locations fixed by visual observations from aircraft. Source areas were tentatively identified based on hydraulic gradients and comparisons of chemical quality data. The author concluded that these inflows contribute a maximum of 18,000 acre feet (22.1 x 10^6 m^3) of relatively low quality ground-water to the Goshen Bay area and that at least some of this water may move through Mosida Hills and Lake Mountain from Cedar Valley. These findings justify the consideration of additional ground-water investigations and management alternatives with respect to the location and operation of the proposed Goshen Bay dike of the Bonneville Unit of the Cenral Utah Project.

APPENDICES

APPENDIX A

WELL-NUMBERING SYSTEM USED IN UTAH

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number identifies the well and locates its position to the nearest 10-acre tract in the land net. By this system, the State is divided into four quadrants by the Salt Lake Base Line and Meridian, and these quadrants are designated by the uppercase letters A, B, C and D, thus, A, for the northeast quadrant; B, for the northwest; C, for the southwest; and D, for the southeast quadrant. Numbers designated the township and range, respectively, follow the quadrant letter, and the three are enclosed in parenthesis. The number after the parentheses designates the section, and the lowercase letters give the location within the section. The first letter indicates the quarter section, which is generally a tract of 160 acres; the second letter indicates the 40-acre tract, and the third indicates the 10-acre tract. The numbers that follow the letters indicate the number of the well within the 10-acre tract. Thus, well (D-8-2) 24 bdd-1, in southern Utah County, is in the SE 1/4 SE 1/4 N 1/4 section 24, Township 8 South, Range 2 East, and is the first well constructed in that tract (see Figure 68). (Cordova, 1969:2).

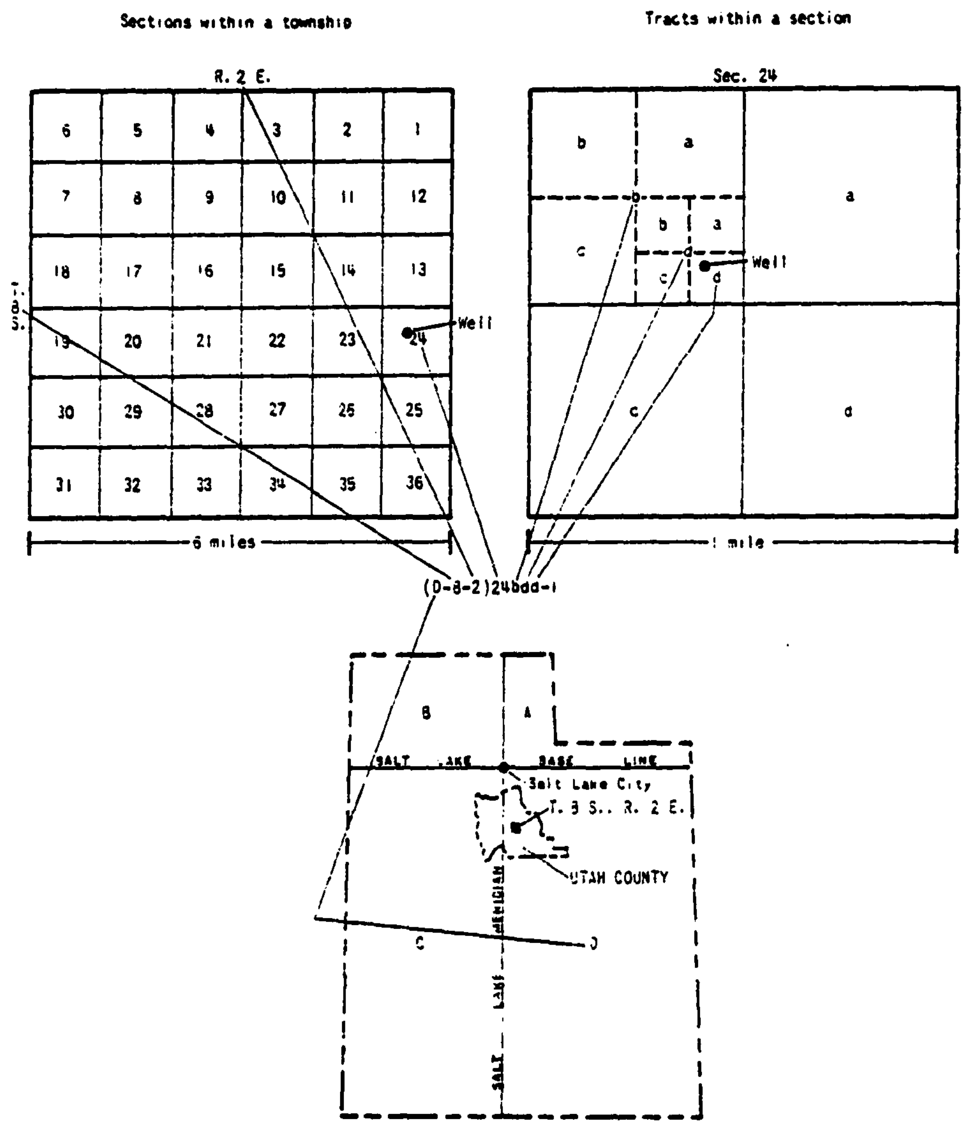

Figure 68. Well-numbering System Used in Utah.

APPENDIX B

SELECTED CHEMCIAL ANALYSES

BYU Environmental Analysis Laboratories
368 CB
Brigham Young University
Provo, Utah 84602
CERTIFICATE OF ANALYSIS
#781298

NJ-1

Date 26 September 1978

Requested By USBR/Ut. Lake

Lab. Sample No. NJ-1 Date Sample Rec'd. 22 July 1978

Sample Source/Desc. Fairfield Spring

Parameter	Result	Units
ROUTINE ANALYSIS		
Alk. (tot) as $CaCO_3$	193	mg/l
Bicarbonate as HCO_3	235	mg/l
Calcium as Ca	55	mg/l
Carbonate as CO_3	<1	mg/l
Chloride as Cl	15.1	mg/l
Conductivity (25°C)	479	umhos/cm
Fluoride as F	0.16	mg/l
Hardness as $CaCO_3$	252	mg/l
Hydroxide as OH	<0.1	mg/l
Magnesium as Mg	27	mg/l
pH	8.18	
Potassium as K	0.8	mg/l
Sodium as Na	8.95	mg/l
Sulfate as SO_4	70	mg/l
Total Diss. Solids	239	mg/l@180° C
Turbidity	4	NTU

Parameter	Result Unfiltered	Result Filtered	Units
TRACE ELEMENTS			
Aluminum as Al	<100		ug/l
Arsenic as As	2.03		ug/l
Barium as Ba	<100		ug/l
Cadmium as Cd	<.30		ug/l
Chromium as Cr	<5		ug/l
Copper as Cu	<5		ug/l
Iron as Fe	21		ug/l
Lead as Pb	3.0		ug/l
Manganese as Mn	<10		ug/l
Mercury as Hg	<.015		ug/l
Molybdenum as Mo	<50		ug/l
Nickel as Ni	<5		ug/l
Selenium as Se	<.30		ug/l
Silver as Ag	<2		ug/l
Zinc as Zn	<5		ug/l

Parameter	Result	Units
NUTRIENTS		
Nitrogen (total Kjeldahl as N)		mg/l
Nitrogen org. as N		mg/l
Ammonia as N	<0.010	mg/l
Nitrate as N	1.09	mg/l
Nitrite as N		mg/l
Phosph. total as P		mg/l
Phosph. ortho as P	0.005	mg/l

Parameter	Result	Units
SPECIAL PARAMETERS		
BOD (5 day)		mg/l
COD		mg/l
TOC		mg/l
Boron as B		ug/l
Cyanide as CN		mg/l
Silica as SiO_2	8	mg/l
Oil and Grease		mg/l
Phenols as Phenol		ug/l
Surfactant as MBAS		mg/l
MPN Coliform total		/100ml
MPN Fecal Coliform		/100ml
MPN Fecal Strep.		/100ml
Suspended Solids		mg/l
Volatile S. Solids		mg/l

Certified

BYU Environmental Analysis Laboratories
368 CB
Brigham Young University
Provo, Utah 84602
CERTIFICATE OF ANALYSIS
#781299

NJ-2

Date 26 September 1978

Requested By USBR/Ut. Lake

Lab. Sample No. NJ-2 Date Sample Rec'd. 28 July 1978

Sample Source/Desc. Erickson Flowing Well. (One block east of the Stagecoach Inn, city of Fairfield)

Parameter	Result	Units
ROUTINE ANALYSIS		
Alk. (tot) as $CaCO_3$	209	mg/l
Bicarbonate as HCO_3	255	mg/l
Calcium as Ca	62	mg/l
Carbonate as CO_3	<1	mg/l
Chloride as Cl	19	mg/l
Conductivity (25°C)	459	umhos/cm
Fluoride as F	0.29	mg/l
Hardness as $CaCO_3$	260	mg/l
Hydroxide as OH	<.1	mg/l
Magnesium as Mg	26	mg/l
pH	8.1	
Potassium as K	1.1	mg/l
Sodium as Na	12.2	mg/l
Sulfate as SO_4	30	mg/l
Total Diss. Solids	250	mg/l@180° C
Turbidity	0.3	NTU

Parameter	Result Unfiltered	Result Filtered	Units
TRACE ELEMENTS			
Aluminum as Al	<100		ug/l
Arsenic as As	2.81		ug/l
Barium as Ba	122		ug/l
Cadmium as Cd	0.32		ug/l
Chromium as Cr	5		ug/l
Copper as Cu	5		ug/l
Iron as Fe	20		ug/l
Lead as Pb	3.9		ug/l
Manganese as Mn	10		ug/l
Mercury as Hg	.015		ug/l
Molybdenum as Mo	50		ug/l
Nickel as Ni	5		ug/l
Selenium as Se	30		ug/l
Silver as Ag	2		ug/l
Zinc as Zn	5		ug/l

Parameter	Result	Units
NUTRIENTS		
Nitrogen (total Kjeldahl as N)		mg/l
Nitrogen org. as N		mg/l
Ammonia as N	<0.010	mg/l
Nitrate as N	0.35	mg/l
Nitrite as N		mg/l
Phosph. total as P		mg/l
Phosph. ortho as P	0.004	mg/l

Parameter	Result	Units
SPECIAL PARAMETERS		
BOD (5 day)		mg/l
COD		mg/l
TOC		mg/l
Boron as B		ug/l
Cyanide as CN		mg/l
Silica as SiO_2	14	mg/l
Oil and Grease		mg/l
Phenols as Phenol		ug/l
Surfactant as MBAS		mg/l
MPN Coliform total		/100ml
MPN Fecal Coliform		/100ml
MPN Fecal Strep.		/100ml
Suspended Solids		mg/l
Volatile S. Solids		mg/l

Certified

BYU Environmental Analysis Laboratories
368 CB
Brigham Young University
Provo, Utah 84602
CERTIFICATE OF ANALYSIS
#781302

MJ-5

Date 26 September 1978

Requested By USBR/Ut. Lake

Lab. Sample No. MJ-5 Date Sample Rec'd. 28 July 1978

Sample Source/Desc. Goshen Artesian (2 miles north of Goshen)

Parameter	Result	Units	Parameter	Result Unfiltered	Result Filtered	Units
ROUTINE ANALYSIS			TRACE ELEMENTS			
Alk. (tot) as $CaCO_3$	343	mg/l	Aluminum as Al	160		ug/l
Bicarbonate as HCO_3	418	mg/l	Arsenic as As	20.3		ug/l
Calcium as Ca	69	mg/l	Barium as Ba	310		ug/l
Carbonate as CO_3	<1	mg/l	Cadmium as Cd	0.30		ug/l
Chloride as Cl	455	mg/l	Chromium as Cr	5		ug/l
Conductivity (25°C)	2062	umhos/cm	Copper as Cu	5		ug/l
Fluoride as F	0.59	mg/l	Iron as Fe	344		ug/l
Hardness as $CaCO_3$	411	mg/l	Lead as Pb	3.2		ug/l
Hydroxide as OH	<.1	mg/l	Manganese as Mn	152		ug/l
Magnesium as Mg	58	mg/l	Mercury as Hg	.08		ug/l
pH	8.3		Molybdenum as Mo	50		ug/l
Potassium as K	35.0	mg/l	Nickel as Ni	7		ug/l
Sodium as Na	255	mg/l	Selenium as Se	.30		ug/l
Sulfate as SO_4	139	mg/l	Silver as Ag	2		ug/l
Total Diss. Solids	1131	mg/l@180°C	Zinc as Zn	10		ug/l
Turbidity	33	NTU				

Parameter	Result	Units	Parameter	Result	Units
NUTRIENTS			SPECIAL PARAMETERS		
Nitrogen (total Kjeldahl as N)		mg/l	BOD (5 day)		mg/l
Nitrogen org. as N		mg/l	COD		mg/l
Ammonia as N	0.011	mg/l	TOC		mg/l
Nitrate as N	0.19	mg/l	Boron as B		ug/l
Nitrite as N		mg/l	Cyanide as CN		mg/l
Phosph. total as P		mg/l	Silica as SiO_2	55	mg/l
Phosph. ortho as P	0.009	mg/l	Oil and Grease		mg/l
			Phenols as Phenol		ug/l
			Surfactant as MBAS		mg/l
			MPN Coliform total		/100ml
			MPN Fecal Coliform		/100ml
			MPN Fecal Strep.		/100ml
			Suspended Solids		mg/l
			Volatile S. Solids		mg/l

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368 CB
Brigham Young University
Provo, Utah 84602
CERTIFICATE OF ANALYSIS
#781300

MJ-3

Date 26 September 1978

Requested By USBR/Ut. Lake

Lab. Sample No. MJ-3 Date Sample Rec'd. 28 July 1978

Sample Source/Desc. Fitzgerald Well. (Combined Flow)

Parameter	Result	Units	Parameter	Result Unfiltered	Result Filtered	Units
ROUTINE ANALYSIS			TRACE ELEMENTS			
Alk. (tot) as $CaCO_3$	237	mg/l	Aluminum as Al	<100		ug/l
Bicarbonate as HCO_3	289	mg/l	Arsenic as As	21.3		ug/l
Calcium as Ca	78	mg/l	Barium as Ba	<100		ug/l
Carbonate as CO_3	<1	mg/l	Cadmium as Cd	0.30		ug/l
Chloride as Cl	186	mg/l	Chromium as Cr	5		ug/l
Conductivity (25°C)	1129	umhos/cm	Copper as Cu	5		ug/l
Fluoride as F	0.62	mg/l	Iron as Fe	22		ug/l
Hardness as $CaCO_3$	362	mg/l	Lead as Pb	4.0		ug/l
Hydroxide as OH	<.1	mg/l	Manganese as Mn	10		ug/l
Magnesium as Mg	41	mg/l	Mercury as Hg	.015		ug/l
pH	8.1		Molybdenum as Mo	50		ug/l
Potassium as K	12.1	mg/l	Nickel as Ni	5		ug/l
Sodium as Na	113	mg/l	Selenium as Se	.30		ug/l
Sulfate as SO_4	66	mg/l	Silver as Ag	2		ug/l
Total Diss. Solids	653	mg/l@180°C	Zinc as Zn	15		ug/l
Turbidity	0.3	NTU				

Parameter	Result	Units	Parameter	Result	Units
NUTRIENTS			SPECIAL PARAMETERS		
Nitrogen (total Kjeldahl as N)		mg/l	BOD (5 day)		mg/l
Nitrogen org. as N		mg/l	COD		mg/l
Ammonia as N	<0.010	mg/l	TOC		mg/l
Nitrate as N	2.25	mg/l	Boron as B		ug/l
Nitrite as N		mg/l	Cyanide as CN		mg/l
Phosph. total as P		mg/l	Silica as SiO_2	19	mg/l
Phosph. ortho as P	0.004	mg/l	Oil and Grease		mg/l
			Phenols as Phenol		ug/l
			Surfactant as MBAS		mg/l
			MPN Coliform total		/100ml
			MPN Fecal Coliform		/100ml
			MPN Fecal Strep.		/100ml
			Suspended Solids		mg/l
			Volatile S. Solids		mg/l

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IM-4

BYU Environmental Analysis Laboratories
360 CB
Brigham Young University
Provo, Utah 84602
CERTIFICATE OF ANALYSIS
#78134

Date 25 January 1978

Requested By Ut Lake/USBR/Min. Springs

Lab. Sample No. IM-4 Date Sample Rec'd. 27 September 1977

Sample Source/Desc. Ut Lake: Lincoln Pt. east side, north of spit - confluence of numerous springs:

Parameter	Result	Units
ROUTINE ANALYSIS		
Alk. (tot) as $CaCO_3$	482	mg/l
Bicarbonate as HCO_3	544	mg/l
Calcium as Ca	223	mg/l
Carbonate as CO_3	<1	mg/l
Chloride as Cl	1260	mg/l
Conductivity (25°C)	5230	umhos/cm
Fluoride as F	2.2	mg/l
Hardness as $CaCO_3$	857	mg/l
Hydroxide as OH	<.1	mg/l
Magnesium as Mg	70	mg/l
pH	7.5	
Potassium as K	87	mg/l
Sodium as Na	725	mg/l
Sulfate as SO_4	462	mg/l
Total Diss. Solids	3115	mg/l @180°C
Turbidity	0.5	NTU
NUTRIENTS		
Nitrogen (total Kjeldahl as N)		mg/l
Nitrogen org. as N		mg/l
Ammonia as N	<.01	mg/l
Nitrate as N	.64	mg/l
Nitrite as N		mg/l
Phosph. total as P	.010	mg/l
Phosph. ortho as P	.005	mg/l

Parameter	Result UnFiltered	Result Filtered	Units
TRACE ELEMENTS			
Aluminum as Al	<100		ug/l
Arsenic as As	1.8		ug/l
Barium as Ba	900		ug/l
Cadmium as Cd	<0.30		ug/l
Chromium as Cr	11		ug/l
Copper as Cu	<5		ug/l
Iron as Fe	24		ug/l
Lead as Pb	161		ug/l
Manganese as Mn	<10		ug/l
Mercury as Hg	3.8		ug/l
Molybdenum as Mo	<0.05		ug/l
Nickel as Ni	74		ug/l
Selenium as Se	2.0		ug/l
Silver as Ag	4.3		ug/l
Zinc as Zn	<5		ug/l
SPECIAL PARAMETERS			
BOD (5 day)			mg/l
COD			mg/l
TOC			mg/l
Boron as B	1130		ug/l
Cyanide as CN			mg/l
Silica as SiO_2			mg/l
Oil and Grease			mg/l
Phenols as Phenol			ug/l
Surfactant as MBAS			mg/l
MPN Coliform total			/100ml
MPN Fecal Coliform			/100ml
MPN Fecal Strep.			/100ml
Suspended Solids			mg/l
Volatile S. Solids			mg/l

Certified [signature]

IU-2

BYU Environmental Analysis Laboratories
360 CB
Brigham Young University
Provo, Utah 84602
CERTIFICATE OF ANALYSIS
#78306

Date 15 March 1978

Requested By Ut. Lake/USBR/Mineral Springs

Lab. Sample No. IU-2 Date Sample Rec'd. 14 October 1977

Sample Source/Desc. Utah Lake - Lincoln Pt. #2.

Parameter	Result	Units
ROUTINE ANALYSIS		
Alk. (tot) as $CaCO_3$	480	mg/l
Bicarbonate as HCO_3	[illegible]	mg/l
Calcium as Ca	151	mg/l
Carbonate as CO_3	<1	mg/l
Chloride as Cl	1370	mg/l
Conductivity (25°C)		umhos/cm
Fluoride as F	2.2	mg/l
Hardness as $CaCO_3$	[illegible]	mg/l
Hydroxide as OH	<.1	mg/l
Magnesium as Mg	90	mg/l
pH	7.95	
Potassium as K	63	mg/l
Sodium as Na	769	mg/l
Sulfate as SO_4	[illegible]	mg/l
Total Diss. Solids	4270	mg/l @180°C
Turbidity	1.0	NTU
NUTRIENTS		
Nitrogen (total Kjeldahl as N)		mg/l
Nitrogen org. as N		mg/l
Ammonia as N	<0.01	mg/l
Nitrate as N	.22	mg/l
Nitrite as N		mg/l
Phosph. total as P	.[illegible]	mg/l
Phosph. ortho as P	.027	mg/l

Parameter	Result UnFiltered	Result Filtered	Units
TRACE ELEMENTS			
Aluminum as Al	<100		ug/l
Arsenic as As	6.7		ug/l
Barium as Ba	[illegible]		ug/l
Cadmium as Cd			ug/l
Chromium as Cr	[illegible]		ug/l
Copper as Cu	<5		ug/l
Iron as Fe	40		ug/l
Lead as Pb			ug/l
Manganese as Mn	<10		ug/l
Mercury as Hg	[illegible]		ug/l
Molybdenum as Mo	[illegible]		ug/l
Nickel as Ni	<20		ug/l
Selenium as Se	1.2		ug/l
Silver as Ag			ug/l
Zinc as Zn	<5		ug/l
SPECIAL PARAMETERS			
BOD (5 day)			mg/l
COD			mg/l
TOC			mg/l
Boron as B	1250		ug/l
Cyanide as CN			mg/l
Silica as SiO_2			mg/l
Oil and Grease			mg/l
Phenols as Phenol			ug/l
Surfactant as MBAS			mg/l
MPN Coliform total			/100ml
MPN Fecal Coliform			/100ml
MPN Fecal Strep.			/100ml
Suspended Solids			mg/l
Volatile S. Solids			mg/l

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6/77

IM-6

BYU Environmental Analysis Laboratories
368 CB
Brigham Young University
Provo, Utah 84602
CERTIFICATE OF ANALYSIS
#78136

Date 25 January 1978

Requested By: Ut Lake/USBR/Min. Springs

Lab. Sample No.: IM-6 Date Sample Rec'd. 27 September 1977

Sample Source/Desc. Ut Lake: Lincoln Pt. - spring pool ~10 yds. north of NE corner of storage pond

Parameter	Result	Units
ROUTINE ANALYSIS		
Alk. (tot) as $CaCO_3$	554	mg/l
Bicarbonate as HCO_3	676	mg/l
Calcium as Ca	530	mg/l
Carbonate as CO_3	<1	mg/l
Chloride as Cl	2559	mg/l
Conductivity (25°C)	9370	umhos/cm
Fluoride as F	2.3	mg/l
Hardness as $CaCO_3$	1610	mg/l
Hydroxide as OH	<.1	mg/l
Magnesium as Mg	129	mg/l
pH	7.9	
Potassium as K	160	mg/l
Sodium as Na	1150	mg/l
Sulfate as SO_4	605	mg/l
Total Diss. Solids	6210	mg/l @180°C
Turbidity	0.9	NTU
NUTRIENTS		
Nitrogen (total Kjeldahl as N)		mg/l
Nitrogen org. as N		mg/l
Ammonia as N	<.01	mg/l
Nitrate as N	.11	mg/l
Nitrite as N		mg/l
Phosph. total as P	.015	mg/l
Phosph. ortho as P	.010	mg/l

Parameter	Result UnFiltered	Result Filtered	Units
TRACE ELEMENTS			
Aluminum as Al	<100		ug/l
Arsenic as As	2.8		ug/l
Barium as Ba	1550		ug/l
Cadmium as Cd	<0.30		ug/l
Chromium as Cr	23		ug/l
Copper as Cu	9		ug/l
Iron as Fe	90		ug/l
Lead as Pb	3.8		ug/l
Manganese as Mn	25		ug/l
Mercury as Hg	0.23		ug/l
Molybdenum as Mo	<0.05		ug/l
Nickel as Ni	100		ug/l
Selenium as Se	1.3		ug/l
Silver as Ag	18.5		ug/l
Zinc as Zn	7		ug/l
SPECIAL PARAMETERS			
BOD (5 day)			mg/l
COD			mg/l
TOC			mg/l
Boron as B	2240		ug/l
Cyanide as CN			mg/l
Silica as SiO_2			mg/l
Oil and Grease			mg/l
Phenols as Phenol			ug/l
Surfactant as MBAS			mg/l
MPN Coliform total			/100ml
MPN Fecal Coliform			/100ml
MPN Fecal Strep.			/100ml
Suspended Solids			mg/l
Volatile S. Solids			mg/l

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IM-5

BYU Environmental Analysis Laboratories
368 CB
Brigham Young University
Provo, Utah 84602
CERTIFICATE OF ANALYSIS
#78135

Date 25 January 1978

Requested By: Ut Lake/USBR/Min. Springs

Lab. Sample No.: IM-5 Date Sample Rec'd. 27 September 1977

Sample Source/Desc. Ut Lake: Lincoln Pt. - NW end of (old) swimming pool

Parameter	Result	Units
ROUTINE ANALYSIS		
Alk. (tot) as $CaCO_3$	625	mg/l
Bicarbonate as HCO_3	762	mg/l
Calcium as Ca	455	mg/l
Carbonate as CO_3	<1	mg/l
Chloride as Cl	2533	mg/l
Conductivity (25°C)	9960	umhos/cm
Fluoride as F	2.4	mg/l
Hardness as $CaCO_3$	1630	mg/l
Hydroxide as OH	<.1	mg/l
Magnesium as Mg	122	mg/l
pH	7.4	
Potassium as K	180	mg/l
Sodium as Na	1185	mg/l
Sulfate as SO_4	570	mg/l
Total Diss. Solids	6120	mg/l @180°C
Turbidity	0.7	NTU
NUTRIENTS		
Nitrogen (total Kjeldahl as N)		mg/l
Nitrogen org. as N		mg/l
Ammonia as N	.90	mg/l
Nitrate as N	<.05	mg/l
Nitrite as N		mg/l
Phosph. total as P	.011	mg/l
Phosph. ortho as P	.009	mg/l

Parameter	Result UnFiltered	Result Filtered	Units
TRACE ELEMENTS			
Aluminum as Al	<100		ug/l
Arsenic as As	5.5		ug/l
Barium as Ba	1557		ug/l
Cadmium as Cd	<0.3[illegible]		ug/l
Chromium as Cr	20		ug/l
Copper as Cu	14		ug/l
Iron as Fe	220		ug/l
Lead as Pb	367		ug/l
Manganese as Mn	55		ug/l
Mercury as Hg	<.25		ug/l
Molybdenum as Mo	<0.05		ug/l
Nickel as Ni	155		ug/l
Selenium as Se	1.1		ug/l
Silver as Ag	15.6		ug/l
Zinc as Zn	7		ug/l
SPECIAL PARAMETERS			
BOD (5 day)			mg/l
COD			mg/l
TOC			mg/l
Boron as B	2130		ug/l
Cyanide as CN			mg/l
Silica as SiO_2			mg/l
Oil and Grease			mg/l
Phenols as Phenol			ug/l
Surfactant as MBAS			mg/l
MPN Coliform total			/100ml
MPN Fecal Coliform			/100ml
MPN Fecal Strep.			/100ml
Suspended Solids			mg/l
Volatile S. Solids			mg/l

Certified [illegible]

IM 3

BYU Environmental Analysis Laboratories
348 CB
Brigham Young University
Provo, Utah 84602
CERTIFICATE OF ANALYSIS
#78133

Date 25 January 1978

Requested By Ut Lake/USBR/Min. Springs

Lab. Sample No. IM-3 Date Sample Rec'd. 27 September 1977

Sample Source/Desc. Ut Lake: Bird Island North end of west area of North Bay (~120 yds NW of light).

Parameter	Result	Units
ROUTINE ANALYSIS		
Alk. (tot) as $CaCO_3$	206	mg/l
Bicarbonate as HCO_3	251	mg/l
Calcium as Ca	53	mg/l
Carbonate as CO_3	<1	mg/l
Chloride as Cl	[illegible]	mg/l
Conductivity (25°C)	[illegible]	umhos/cm
Fluoride as F	1.0	mg/l
Hardness as $CaCO_3$	436	mg/l
Hydroxide as OH	<.1	mg/l
Magnesium as Mg	70	mg/l
pH	8.06	
Potassium as K	23	mg/l
Sodium as Na	365	mg/l
Sulfate as SO_4	275	mg/l
Total Diss. Solids	[illegible]	mg/l 180° C
Turbidity	11	NTU
NUTRIENTS		
Nitrogen (total Kjeldahl as N)		mg/l
Nitrogen org. as N		mg/l
Ammonia as N	170	ug/l
Nitrate as N	.15	mg/l
Nitrite as N		mg/l
Phosph. total as P	.121	mg/l
Phosph. ortho as P	.012	mg/l

Parameter	Result UnFiltered	Result Filtered	Units
TRACE ELEMENTS			
Aluminum as Al	350		ug/l
Arsenic as As	5.7		ug/l
Barium as Ba	750		ug/l
Cadmium as Cd	<0.3		ug/l
Chromium as Cr	<5		ug/l
Copper as Cu	<5		ug/l
Iron as Fe	312		ug/l
Lead as Pb	18		ug/l
Manganese as Mn	30		ug/l
Mercury as Hg	0.20		ug/l
Molybdenum as Mo	<0.05		ug/l
Nickel as Ni	46		ug/l
Selenium as Se	1.3		ug/l
Silver as Ag	3.8		ug/l
Zinc as Zn	13		ug/l

Parameter	Result	Units
SPECIAL PARAMETERS		
BOD (5 day)		mg/l
COD		mg/l
TOC		mg/l
Boron as B	450	ug/l
Cyanide as CN		mg/l
Silica as SiO_2		mg/l
Oil and Grease		mg/l
Phenols as Phenol		ug/l
Surfactant as MBAS		mg/l
MPN Coliform total		/100ml
MPN Fecal Coliform		/100ml
MPN Fecal Strep.		/100ml
Suspended Solids		mg/l
Volatile S. Solids		mg/l

Certified F.B. Merritt

IM-1

BYU Environmental Analysis Laboratories
348 CB
Brigham Young University
Provo, Utah 84602
CERTIFICATE OF ANALYSIS
#78131

Date 25 January 1978

Requested By Ut Lake/USBR/Min. Springs

Lab. Sample No. IM-1 Date Sample Rec'd. 27 September 1977

Sample Source/Desc. Ut. Lake: Bird Island - North Bay.

Parameter	Result	Units
ROUTINE ANALYSIS		
Alk. (tot) as $CaCO_3$	183	mg/l
Bicarbonate as HCO_3	223	mg/l
Calcium as Ca	[illegible]	mg/l
Carbonate as CO_3	<1	mg/l
Chloride as Cl	[illegible]	mg/l
Conductivity (25°C)	[illegible]	umhos/cm
Fluoride as F	.90	mg/l
Hardness as $CaCO_3$	400	mg/l
Hydroxide as OH	<.1	mg/l
Magnesium as Mg	[illegible]	mg/l
pH	8.18	
Potassium as K	[illegible]	mg/l
Sodium as Na	[illegible]	mg/l
Sulfate as SO_4	[illegible]	mg/l
Total Diss. Solids	1710	mg/l 180° C
Turbidity	[illegible]	NTU
NUTRIENTS		
Nitrogen (total Kjeldahl as N)		mg/l
Nitrogen org. as N		mg/l
Ammonia as N	.075	mg/l
Nitrate as N	<.05	mg/l
Nitrite as N		mg/l
Phosph. total as P	.116	mg/l
Phosph. ortho as P	.012	mg/l

Parameter	Result UnFiltered	Result Filtered	Units
TRACE ELEMENTS			
Aluminum as Al	[illegible]		ug/l
Arsenic as As	5.8		ug/l
Barium as Ba	[illegible]		ug/l
Cadmium as Cd	<0.33		ug/l
Chromium as Cr	7		ug/l
Copper as Cu	[illegible]		ug/l
Iron as Fe	[illegible]		ug/l
Lead as Pb	15		ug/l
Manganese as Mn	25		ug/l
Mercury as Hg	0.21		ug/l
Molybdenum as Mo	<0.05		ug/l
Nickel as Ni	[illegible]		ug/l
Selenium as Se	2.0		ug/l
Silver as Ag	3.7		ug/l
Zinc as Zn	15		ug/l

Parameter	Result	Units
SPECIAL PARAMETERS		
BOD (5 day)		mg/l
COD		mg/l
TOC		mg/l
Boron as B	450	ug/l
Cyanide as CN		mg/l
Silica as SiO_2		mg/l
Oil and Grease		mg/l
Phenols as Phenol		ug/l
Surfactant as MBAS		mg/l
MPN Coliform total		/100ml
MPN Fecal Coliform		/100ml
MPN Fecal Strep.		/100ml
Suspended Solids		mg/l
Volatile S. Solids		mg/l

Certified F.B. Merritt

JB-2

BYU Environmental Analysis Laboratories
360 CB
Brigham Young University
Provo, Utah 84602
CERTIFICATE OF ANALYSIS
#78311

Date 14 March 1978

Requested By Ut. Lake/USBR/Mineral Springs

Lab. Sample No. JB-2 Date Sample Rec'd. 10 November 1977

Sample Source/Desc. Saratoga #2. Small spring flowing into harbor.

Parameter	Result	Units	Parameter	Result Unfiltered	Result Filtered	Units
ROUTINE ANALYSIS			TRACE ELEMENTS			
Alk. (tot) as $CaCO_3$	322	mg/l	Aluminum as Al	<100		ug/l
Bicarbonate as HCO_3	393	mg/l	Arsenic as As	33		ug/l
Calcium as Ca	207	mg/l	Barium as Ba	110		ug/l
Carbonate as CO_3	<1	mg/l	Cadmium as Cd	2.3		ug/l
Chloride as Cl	390	mg/l	Chromium as Cr	16		ug/l
Conductivity (25°C)	2[illegible]	umhos/cm	Copper as Cu	<5		ug/l
Fluoride as F	2.2	mg/l	Iron as Fe	114		ug/l
Hardness as $CaCO_3$	733	mg/l	Lead as Pb	8.8		ug/l
Hydroxide as OH	<.1	mg/l	Manganese as Mn	145		ug/l
Magnesium as Mg	5[illegible]	mg/l	Mercury as Hg	0.4		ug/l
pH	7.50		Molybdenum as Mo	<50		ug/l
Potassium as K	30	mg/l	Nickel as Ni	6.0		ug/l
Sodium as Na	274	mg/l	Selenium as Se	1.6		ug/l
Sulfate as SO_4	595	mg/l	Silver as Ag	<.5		ug/l
Total Diss. Solids	1610	mg/l@180° C	Zinc as Zn	10		ug/l
Turbidity	2	NTU				

Parameter	Result	Units	Parameter	Result	Units
NUTRIENTS			SPECIAL PARAMETERS		
Nitrogen (total Kjeldahl as N)		mg/l	BOD (5 day)		mg/l
Nitrogen org. as N		mg/l	COD		mg/l
Ammonia as N	.323	mg/l	TOC		mg/l
Nitrate as N	.32	mg/l	Boron as B	510	ug/l
Nitrite as N		mg/l	Cyanide as CN		mg/l
Phosph. total as P	.030	mg/l	Silica as SiO_2		mg/l
Phosph. ortho as P	.017	mg/l	Oil and Grease		mg/l
			Phenols as Phenol		ug/l
			Surfactant as MBAS		mg/l
			MPN Coliform total		/100ml
			MPN Fecal Coliform		/100ml
			MPN Fecal Strep.		/100ml
			Suspended Solids		mg/l
			Volatile S. Solids		mg/l

Certified [illegible]

NJ-10

BYU Environmental Analysis Laboratories
360 CB
Brigham Young University
Provo, Utah 84602
CERTIFICATE OF ANALYSIS
#781307

Date 26 September 1978

Requested By USBR/Ut. Lake

Lab. Sample No. NJ-10 Date Sample Rec'd. 28 July 1978

Sample Source/Desc. Saratoga Upper Pool Spring.

Parameter	Result	Units	Parameter	Result Unfiltered	Result Filtered	Units
ROUTINE ANALYSIS			TRACE ELEMENTS			
Alk. (tot) as $CaCO_3$	160	mg/l	Aluminum as Al	<100		ug/l
Bicarbonate as HCO_3	195	mg/l	Arsenic as As	32.8		ug/l
Calcium as Ca	205	mg/l	Barium as Ba	145		ug/l
Carbonate as CO_3	<1	mg/l	Cadmium as Cd	.35		ug/l
Chloride as Cl	405	mg/l	Chromium as Cr	50		ug/l
Conductivity (25°C)	2240	umhos/cm	Copper as Cu	9		ug/l
Fluoride as F	2.04	mg/l	Iron as Fe	20		ug/l
Hardness as $CaCO_3$	731	mg/l	Lead as Pb	2.3		ug/l
Hydroxide as OH	<.1	mg/l	Manganese as Mn	10		ug/l
Magnesium as Mg	53	mg/l	Mercury as Hg	0.22		ug/l
pH	7.9		Molybdenum as Mo	50		ug/l
Potassium as K	25	mg/l	Nickel as Ni	5		ug/l
Sodium as Na	211	mg/l	Selenium as Se	.30		ug/l
Sulfate as SO_4	405	mg/l	Silver as Ag	2		ug/l
Total Diss. Solids	1543	mg/l@180° C	Zinc as Zn	14		ug/l
Turbidity	1.5	NTU				

Parameter	Result	Units	Parameter	Result	Units
NUTRIENTS			SPECIAL PARAMETERS		
Nitrogen (total Kjeldahl as N)		mg/l	BOD (5 day)		mg/l
Nitrogen org. as N		mg/l	COD		mg/l
Ammonia as N	0.018	mg/l	TOC		mg/l
Nitrate as N	1.06	mg/l	Boron as B		ug/l
Nitrite as N		mg/l	Cyanide as CN		mg/l
Phosph. total as P		mg/l	Silica as SiO_2	26	mg/l
Phosph. ortho as P	0.051	mg/l	Oil and Grease		mg/l
			Phenols as Phenol		ug/l
			Surfactant as MBAS		mg/l
			MPN Coliform total		/100ml
			MPN Fecal Coliform		/100ml
			MPN Fecal Strep.		/100ml
			Suspended Solids		mg/l
			Volatile S. Solids		mg/l

Certified

REFERENCES

1. Bingham, Clair C., "Recent Sedimentation Trends in Utah Lake," Vol. XXII, pt. 1, Brigham Young University Geology Studies. Provo: Brigham Young University Press, 1975.

2. Bissell, Harold J, Lake Bonneville: Geology of Southern Utah Valley, Utah. U.S. Geological Survey Professional Paper No. 257-B. Washington: Government Printing Office, 1963.

3. Bissell, Harold J., "Bonneville--An Ice Age Lake," Vol. XV, pt. 4. Brigham Young University Geology Studies. Provo: Brigham Young University Press, 1968.

4. Bolke, E.L., and K.M. Waddell, Ground-Water Conditions in the East Shore Area, Box Elder, Davis, and Weber Counties, Utah 1960-69. Utah State Engineer Technical Publication No. 35. Salt Lake City, Utah: Utah State Engineer, 1972.

5. Briggs, G.F., and A.G. Fiedler, eds. Ground-Water and Wells, St. Paul: Johnson Division, UOP, Inc., 1975.

6. Brimhall, Willes H., Irvin G. Bassett, and LaVere B. Merritt, Reconnaissance Study of Deep-Water Springs and Strata of Utah Lake. Mountainland Association of Governments Technical Report No. 3. Provo: Mountainland Association of Governments, 1976.

7. Brimhall, Willis H., and La Vere B. Merritt, The Geology of Utah Lake: Implications for Resource Management. Mountainland Association of Governments Technical Working Paper No. 12. Provo: Mountainland Association of Governments, 1976.

8. Bullock, Kenneth C., Geology of Lake Mountain, Utah, Utah Geological and Mineralogical Survey Bulletin No. 41. Salt Lake City: University of Utah, 1951.

9. Chipman, Delbert, Personal interview. American Fork, Utah, September 28, 1978.

10. Cook, K.L., and J.W. Berg, Jr., Regional Gravity Survey Along the Central and Southern Wasatch Front, Utah. U.S. Geological Survey Professional Paper No. 316-E. Washington: Government Printing Office, 1961.

11. Cordova, Robert M., Personal interview, Salt Lake City, Utah, July 14, 1978.

12. Cordova, Robert M., Ground-Water Conditions in Southern Utah Valley and Goshen Valley, Utah. State of Utah Department of Natural Resources Technical Publication No. 28. Salt Lake City, Ut.: Utah State Engineer, 1970.

13. Cordova, R.M., Selected Hydrologic Data Southern Utah and Goshen Valleys, Utah. Utah Bsic Data Release No. 16. Salt Lake City: Utah Department of Natural Resources, 1969.

14. Cordova, R.M. and R.W. Mower, The Effect of Pumping Large-Discharge Wells on the Ground-Water Reservoir in Southern Utah Valley, Utah County, Utah. Utah State Engineer Information Bulletin No. 18. Salt Lake City: Utah State Engineer, 1967.

15. Cordova, R.M., and Seymour Subitzky, Ground-Water in Northern Utah Valley, Utah: A Progress Report for the Period 1948-63. Utah State Engineer Technical Publication No. 11, Salt Lake City: Utah State Engineer, 1965.

16. Davis, Stanely N., and Roger J.M. DeWiest, Hydrogeology, New York: John Wiley & Sons, 1966, 463 pp.

17. DeWiest, Roger J.M, Geohydrology, New York: John Wiley & Sons, 1965, 366 pp.

18. Feltis, R.D., Ground-Water Conditions in Cedar Valley, Utah County, Utah. Utah State Engineer Technical Publication No. 16. Salt Lake City, Ut.: Utah State Engineer, 1967.

19. Feth, J.H., D.A. Barker, L.G. Moore, R.J. Brown, and C.E. Viers, Lake Bonneville: Geology and Hydrology of the Webver Delta District, Including Ogden, Utah. U.S. Geological Survey Professional Paper No. 518. Washington: Government Printing Office, 1966.

20. Fischer, William, A., Dan A. Dvis, and Theresa M. Sousa, Fresh-Water Springs of Hawaii from Infrared Images. Hydrologic Investigations Atlas HA-218. U.S. Geological Survey. Washington: Government Printing Office, 1966.

21. Fuhriman, Dean K., Personal interview, Provo, Utah, May 8, 1978.

22. Fuhriman, Dean K., LaVere B. Merritt, Jerald S. Bradshaw, and James R. Barton, Water Quality Effect of Diking a Shallow Arid-Region Lake. U.S. Environmental Protection Agency Technical Series EPA-660/2-75-007. Corvallis: U.S. Environmental Protection Agency, 1975.

23. Gilbert, Grove C., Lake Bonneville. U.S. Geological Survey Monograph No. 1. Washington: Government Printing Office, 1890.

24. Hales, Wayne B., "Characteristics of Prevailing Winds at the Provo Municipal Airport," Vol. XXV, Proceedings of the Utah Academy of Sciences. Provo: Brigham Young University Press, 1948.

25. Harding, S.T., "Moisture Losses From Marginal Areas Around Utah Lake," Unpublished Report of Investigation for Board of Canal Presidents of the Associated Canals of Salt Lake Count from 1937 to 1940. March 1941.

26. Harding, S.T., "Springs Rising Withint the Bed of Utah Lake," Unpublished Report of Investigations for Board of Canal Presidents of the Associated Canals of Salt Lake County from 1937 to 1940. April 1941.

27. Himebaugh, Theodore A., "Infiltration in Goshen Valley," Unpublished Report prepared for Dr. Dean K. Fuhriman Department of Civil Engineering, Brigham Young University, Provo, 1977.

28. Horton, A.H., Utah Lake Investigations. Third Annual Report of the Reclamation Service, 1903-4. U.S. Geological Survey, Department of the Interior, Washington: Government Printing Office, 1905.

29. Hoffman, Floyd H., "Geology of the Mosida Hills Area, Utah," Unpublished M.S. Thesis, Brigham Young University, Provo, 1951.

30. Hunt, Charles B., Helen D. Varnes, and Harold E. Thomas, Lake Bonneville: Geology of Northern Utah Valley, Utah. U.S. Geological Survey Professional Paper NO. 257-A. Washington: Government Printing Office, 1953.

31. Israelsen, O.W., and W.W. McLaughlin, Drainage of Land Overlying an Artesian Ground-Water Reservoir. Utah Agriculture Experimental Station Bulletin No. 242. Logan: Utah State University, 1942.

32. Jensen, Johnny R., "A Thematic Atlas of Utah Lake," Unpublished M.S. Thesis, Brigham Young University, Provo, 1972.

33. Jeppson, Roland W. and others, "Normal Annual Precipitation," Hydrologic Atlas of Utah. Utah Water Resources Laboratory, PRWG35-1. Logan: Utah State University, 1969.

34. Jones, John Edwin, Calculation of Evapotranspiration Using Color-Infrared Photography. U.S. Geological Survey Professional Paper No. 655-O. Washington: Government Printing Office, 1977.

35. Lovelace, Erice G., "Utah Lake Water Budget Study: June 1970 Through December 1971," Unpublised Master of Civil Engineering Project Report, Brigham Young University, Provo, 1972.

36. Mann, Craig, Personal interview. Casper, Wyoming, July 17, 1978.

37. Milligan, James H., Ray E. Marsell, and Jay M. Bagley, Mineralized Springs in Utah and Their Effect on Manageable Water Supplies. Utah Water Research Laboratory REport WG23-6. Logan: Utah State University, 1966.

38. Mundorff, J.C., Personal interview, Salt Lake City, Utah, May 3, 1978.

39. Mundorff, J.C., Major Thermal Springs of Utah. Utah Geological and Mineralogical Survey Water-Resources Bulletin 13. Salt Lake City: University of Utah, 1970.

40. Nelson, Jame D., "Utah Lake Water Quality Study 1968-1972," Unpublished Master of Civil Engineering Project Report, Brigham Young University, Provo, 1972.

41. Peck, E.L., Hydrometeorology of Great Salt Lake. University of Utah Engineering Experimental Station Bulletin No. 63. Salt Lake City: University of Utah, 1954.

42. Richardson, G.B., Underground Water in the Valleys of Utah Lake and Jordan River, Utah. U.S. Geological Soceity of Water Supply and Irrigation paper No. 157. Washington: Government Printing Office, 1906.

43. Riley, James A., "Utah Lake Water Budget Study 1970-71," Unpublished Master of Civil Engineering Project Report. Brigham Young University, Provo, 1972.

44. Smith, Adelbert D., Personal interview. American Fork, Utah, September 29, 1978.

45. Sonerholm, Paul A., "Normative Mineral Distributions in Utah Lake Sediments: A Statistical Analysis," Vol. XXXI, pt. 3 Brigham Young University Geology Studies. Provo: Brigham Young University Press, 1974.

46. Subitzky, Seymour, Records of Selected Wells and Springs Selected Driller's Logs of Wells and Chemical Analyses of Ground and Surface Waters Northern Utah Valley, Utah County, Utah. Basic-Data Report No. 2. Salt Lake City: Utah State Engineer, 1962.

47. Swendsen, G.L., First Annual Report of the Reclamation Service From June 17 to December 1, 1902. U.S. Geological Survey, Department of the Interior, Washington: Government Printing Office, 1903.

48. _______, Investigations in Utah. Second Annual Report of the Reclamation Service, 1902-3. U.S. Geological Survey Department of Interior. Washington: Government Printing Office, 1904.

49. _______, Operations in Utah. Third Annual Report of the Reclamation Service, 1903-4. U.S. Geological Survey, Department of the Interior, Washington: Goverment Printing Office, 1905.

50. U.S. Bureau of Reclamation., Reconnaissance Geology Report of the Proposed Goshen Bay Dike. U.S. Bureau of Reclamation Central Utah Projects Report No. GM-68. Provo: Central Utah Projects Office, 1963.

51. Viers, C.E., The Chemical Quality of Utah Lake. Unpublished report for Department of the Interior, Bureau of Reclamation, Region 4. Salt Lake City, Utah, May 1964.

52. Williams, J. Steward, Lake Bonneville: Geology of Southern Cache Valley, Utah, U.S. Geological Survey Professional Paper No. 257-C, Washington: Government Printing Office, 1962.

HYDROGEOLOGY OF UTAH LAKE WITH EMPHASIS ON GOSHEN BAY

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ABSTRACT

This investigation provides a comprehensive picture of the hydrogeology of Utah Lake. The results indicate that available aquifer recharge has been traditionally underestimated; the depth of valley fill is probably twice that which had been previously supposed; artesian pressures force a considerable amount of ground-water upward through confining layers; and there is ample opportunity for water to pass from Cedar Valley into Goshen Valley.

The author concludes that diffuse seepage accounts for the majority of subsurface inflow to the lake; the total annual subsurface inflow is in excess of 100,000 acre feet (123 x 10^6 m^3); and ground-water does enter through the bottom of Goshen Bay. The ground-water flowing into Goshen Bay is of a relatively low quality and the maximum volume is estimated to be on the order of 18,000 acre feet (22.1 x $10^6 m^3$) per year. Much of this Goshen Bay water may come from Cedar Valley.

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