Hydrogeology of Utah Lake with Emphasis on Goshen Bay

by

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HYDROGEOLOGY OF UTAH LAKE WITH EMPHASIS ON GOSHEN BAY

by Jacob D. Dustin, Ph. D.[1]
LaVere B. Merritt, Ph. D., P. E.[2]

ABSTRACT

This investigation of the hydrogeology of Utah Lake indicates that available aquifer recharge has been traditionally underestimated; the depth of valley fill is probably twice that previously supposed; artesian pressures force a considerable amount of ground-water upward through confining sedimentary layers; and water may pass from Cedar Valley into Goshen Valley.

The authors conclude 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 groundwater 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.

INTRODUCTION

Since arid regions receive very limited precipitation which often arrives mainly in the winter months or during infrequent, intense summer storms of short duration, water is a precious resource. Often great efforts are made to trap, store, conserve and preserve the available waters.

In arid-region lakes and reservoirs, water balances are often difficult to determine since precipitation may vary markedly over relatively short distances; evaporation rates, which are affected mainly by radiation, wind, atmospheric and vapor pressure, and water temperature, are difficult to calculate directly; and subsurface (groundwater) inflow/outflow may be unknown.

With respect to qualification of subsurface inflows and outflows to a lake, the traditional approach has been to measure all the water budget components as accurately as possible and assign a value to subsurface flow as necessary to balance the water budget. However, large errors may exist in the estimated values of other components in the water balance and result in large errors in subsurface flow estimates. The magnitude of such errors is not known until additional information is collected which supports or contradicts tentative hydrologic water budgets for a lake.

Utah Lake in central Utah is a complex hydrologic system for which determination of accurate water budgets is difficult. This study is aimed at a thorough evaluation of the subsurface hydrogeology of Utah Lake as a support to subsurface inflow estimates and evaluations. The study was made in 1977 and 1978 in conjunction with the early phases of a 3-year environmental assessment study for Utah Lake that was supported by the Water and Power Resources Service (formerly the U. S. Bureau of Reclamation).

BACKGROUND

Central Utah Project

To redistribute the available water in Utah, the Water and Power Resources Service (WPRS) of the U. S. Department of the Interior, in cooperation with the Central Utah Water Conservancy District, has undertaken the Central Water Project (CUP). This billion dollar project calls for a major water conservation and management effort to transport Utah's portion of Colorado River water from high-mountain headwater areas to lower-lying arable lands of central Utah (figure 1). 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 will be routed through Spanish Fork and Provo Canyons, respectively. Environmental impacts of these hydrologic changes on Utah Lake as well as proposed diking of portions of the lake are of concern.

Utah Lake

Utah Lake (figure 2) is a shallow, hyper-eutropic fresh-water lake occupying some 95,000 acres (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)

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This Bulletin is based on Dustin's Ph. D. dissertation of the same title, 1978, Brigham Young University, Provo Utah long and 10 miles (16 kilometers) wide at its maximum points while averaging only 9.5 feet (2.9 meters) in depth.

"Compromise level" is currently established at elevation 4,489.34 feet (1,368.35 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 natural 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 farmers with land bordering the lake shore, who view the lake as somewhat of a nuisance. Hostilities between the two groups have waned somewhat 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 poor due to its eutropic state, turbidity and fairly high dissolved solids content. Anthropogenic influences appear to have less impact on the water quality of the lake than do physical characteristics of the lake itself. Evaporation (approximately 340,000 acre feet annually) seems to have the greatest single impact; according to Fuhriman and others (1975, p. 4), approximately one third of the lake volume and one half of the average annual inflow is lost to evaporation. Thus evaporation about doubles the concentration of salts in the remaining water.

Diking Proposal

Proposals for ways to reduce effects of evaporation date back at least as early as 1902 (Swendsen, 1903, pp. 280-281). The most cost-efficient and viable plan seems to be to reduce the overall surface area of the lake by about 35 percent by diking off the Provo Bay and Goshen Bay regions of the lake. 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, total dissolved solids (TDS) concentrations would be reduced from 960 to 800 mg/l; sodium from 122 to 95 mg/l; and chloride from 189 to 138 mg/l during the same three year period (Fuhriman and others, 1975, p. 39).

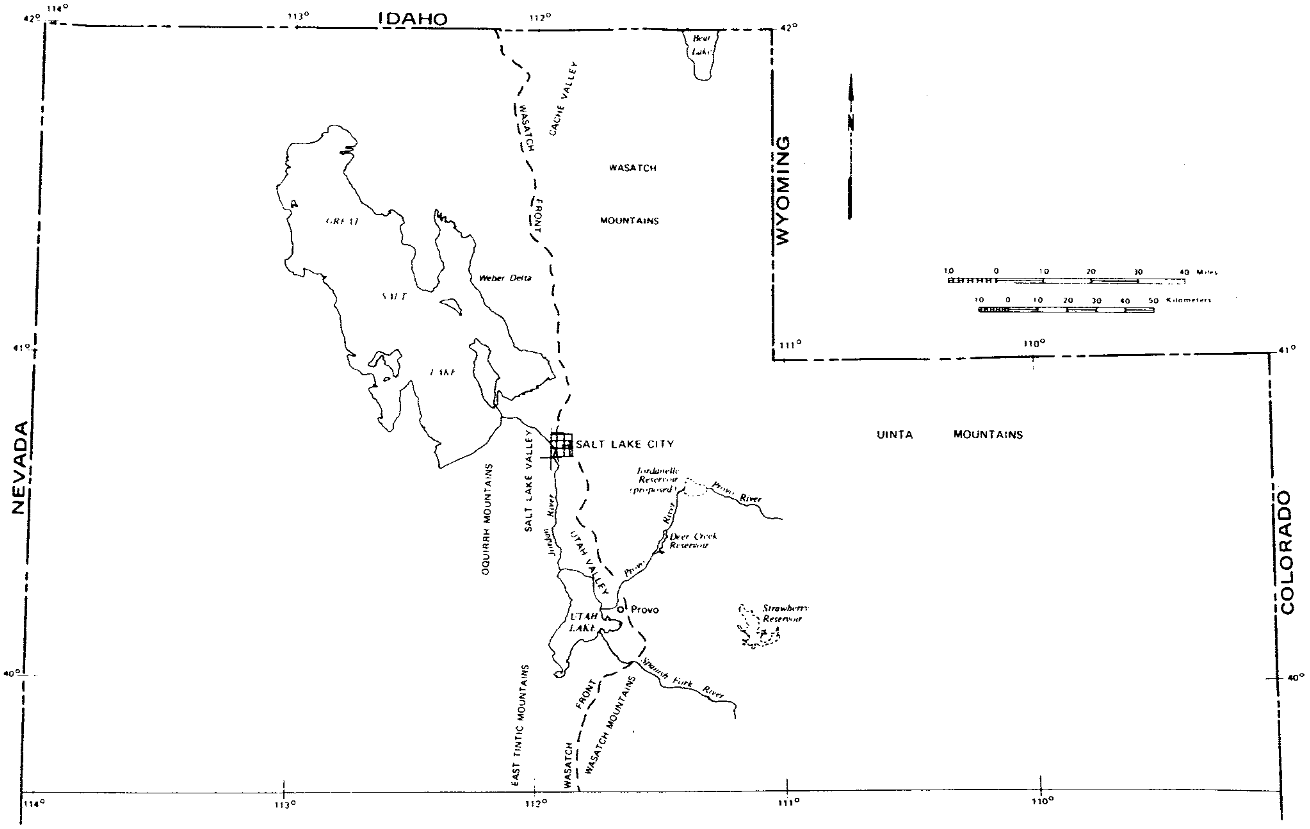


Figure 1. Northern Utah, showing location of Utah Lake and geographic features described in text.

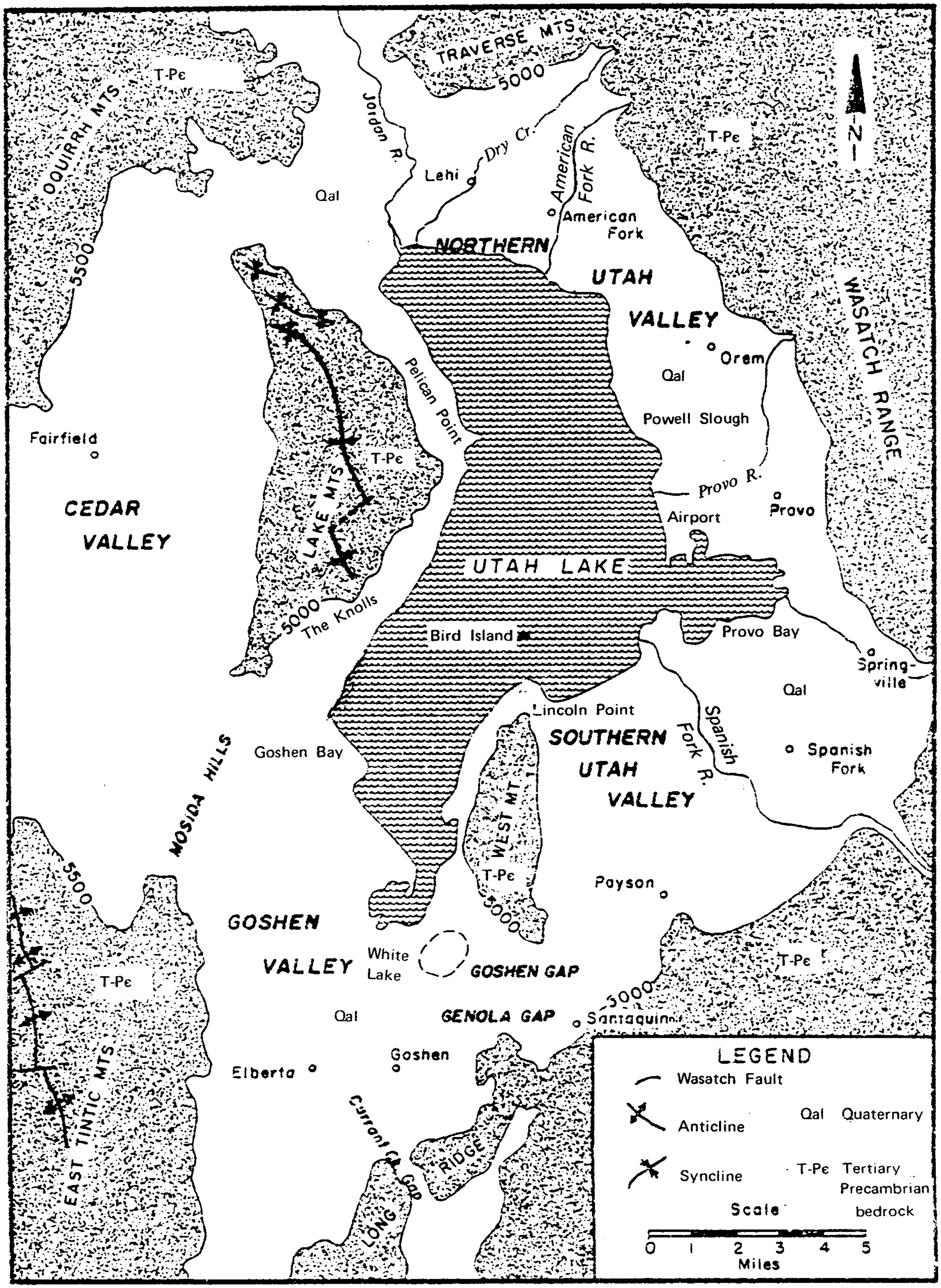


Figure 2. "Utah Lake Basin" study area.

PROBLEM STATEMENT

The primary focus of this study is the subsurface ground-water inflow into Utah Lake. Subsurface flow, for purposes of this investigation, includes shoreline seeps and springs. The single exception is Powell Slough which has been historically measured as a surface tributary. Specifically the following questions are addressed:

1. What is a realistic estimate of the subsurface inflow to Utah Lake?
2. Where does inflow enter the lake? Have all inflow areas been identified?
3. What are the major sources and recharge areas of the incoming ground-water?
4. What is the quality of the inflowing ground-water?
5. Can the subsurface inflows be located and measured?
6. How do locations of subsurface inflows affect the usefulness of proposed dikes in Utah Lake?

PREVIOUS INVESTIGATIONS

Richardson (1906) completed the first "comprehensive" groundwater survey in this area. He observed that:

1. Artesian conditions are the rule rather than the exception throughout northern and southern Utah Valley.
2. Flowing wells in and near the town of Lehi, at the north end of Utah Lake, 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 (pp. 48-49).
3. Artesian flow in Goshen Valley is limited primarily to the Currant Creek basin and in the near-vicinity of the lakeshore (p. 55).
4. Slight artesian pressures are evidenced near Pelican Point by two "feebly" flowing wells (p. 56).
5. The bulk of underground water in Utah Valley is provided by channel losses (p. 28) from streams and irrigation ditches.

Harding (April 1941, p. 2) 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 upward seepage) through confining clays and via "artesian leakage" (springs) through the breaks which occur in the clay strata.

Hunt, Varnes and Thomas (1953, p. 77) note that ground-water levels show seasonal and long-term fluctuations in response to runoff, aquifer withdrawls, drought cycles, etc. By 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) (p. 82-83). These gradients, combined with the observation that both artesian pressures and general water quality increase with depth, led the authors to the conclusion that the confining layers are not absolutely impervious and that large quantities of water probably move upward from the underlying aquifers to discharge into Utah Lake by seepage (p. 84-85).

Bissell (1963) and Cordova (1970) noted similar hydraulic gradients 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 researchers seem to be quite conservative. The opinion of these earlier researchers seems to be that inflow along the west side of the lake and in the Goshen Bay area is negligible to non-existent.

Previous Investigations of 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, Bassett and Merritt (1976a). These seeps and springs will be divided into general groupings according to location (figure 3).

Northwest Springs

Springs within this grouping are the largest, deepest, warmest, and best documented within 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 springs the water was hot and in others, cold. In two springs the artesian pressure was ". . . sufficient to force the water 12 to 15 feet above the surface. . ." (p. 497). The most complete and comprehensive data on these springs are provided by Harding (April 1941) and Viers

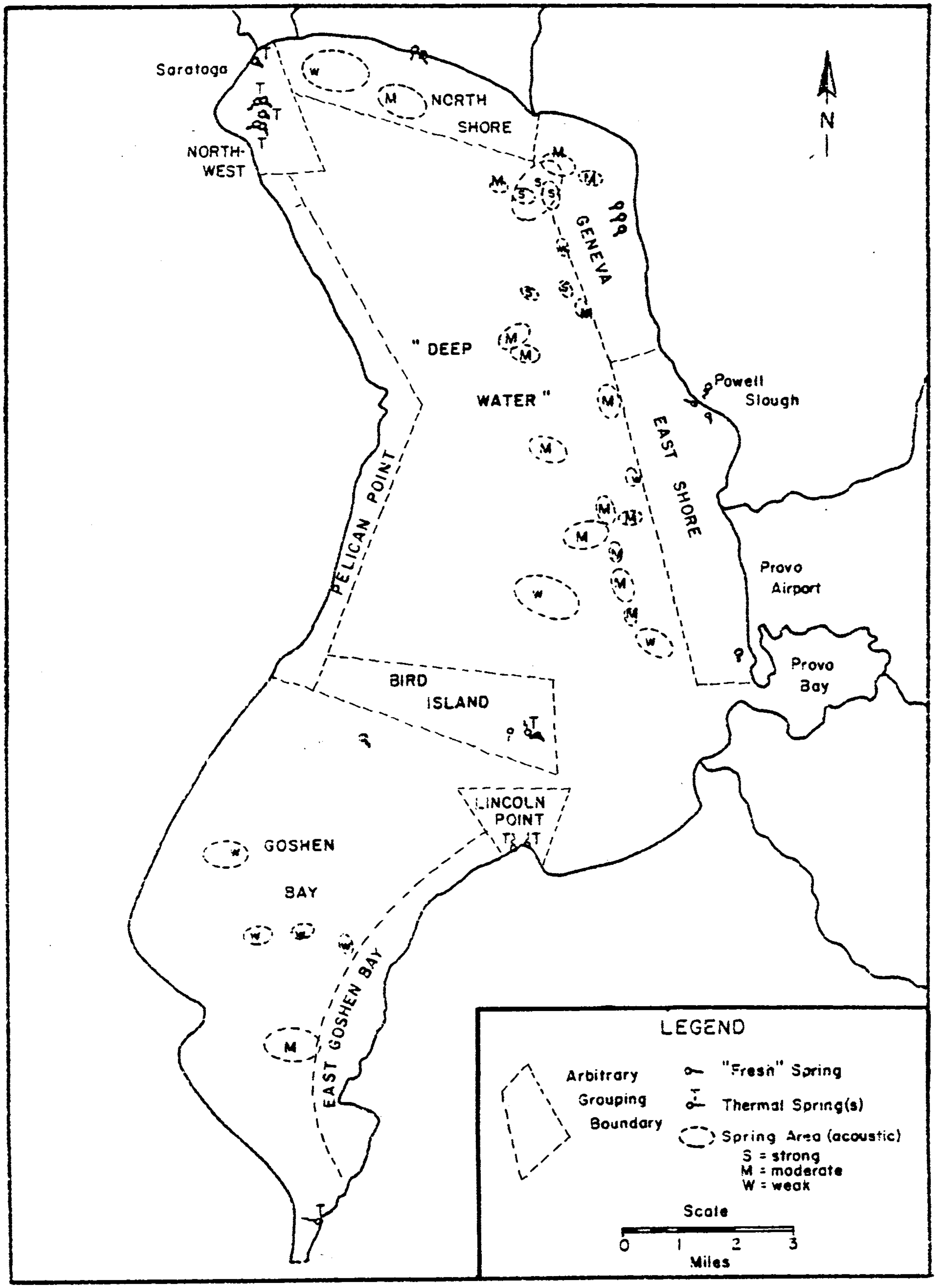


Figure 3. Generalized spring/seep groupings showing locations of known Utah Lake spring areas.

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

Within this grouping there are at least six distinct springs and several small groups (figure 3). Descriptive information on the major springs is listed in table 1.

At both Kidney and Snyder (Crater) Springs there are nearly continuous shoreline seeps indicating the sort of diffuse upward flow or "artesian sweating" phenomenon mentioned earlier. Most attempts to channelize these seeps for flow measurement have been futile.

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 springs and numerous small springs and seeps–all of which were warm (Viers, 1964, p. 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.

The best figures available for the flows from 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. The cumulative 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, p. 4-14). This last area appears to be the same surveyed and described by Viers, who estimated the flows at 5.95 to 7.95 cubic feet per second (cfs) (0.17 to 0.22 cubic meters per second) (1964, p. 52). This represents quite a discrepancy between the two sets of figures, but it should be pointed out that the 1935 figures are a result of measured flows whereas Viers' figures represent estimates. An important point to recognize in both cases is that these flows were determined when the lake level was extremely low as a result of drought conditions. Although 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. These estimates should be considered as minimums.

The waters flowing from these springs and seeps appear to come from a common source as there is little variation in quality from one sample point to another. The mean concentration of total dissolved solids (TDS) is 1,483 mg/l with a standard deviation of only 54 mg/l, (Milligan et al., (1966: table 6). Temperatures vary from 101°F (38.39°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 for a distance of approximately one mile (1.6 kilometers) from the shoreline (figure 3). All the springs in this area appear to produce high quality fresh water flows. Harding (April 1941) 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. . ." (p. 12).

Viers (1964, p. 42) described three springs, the smallest about 10 yards (9 meters) in diameter and the second 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. The electroconductivity (EC) at 25°C was 517 micromhos/cm in the two shore springs and 482 micromhos/cm in the offshore pool. Temperatures were 63°F (17.2°C) and 68°F (20°C) respectively.

Geneva Springs

The springs in this area (figure 3) produce cool water of fairly high quality (Fuhriman and others, 1975, p. 24). The main grouping of springs lies on a roughly north-south line from one fourth to one half mile offshore in S. 7, T. 6 S., R. 2 E. Another spring is located further north near the shore.

Generally, these springs are fairly deep (up to 40 feet or 13 meters); their depths can only be found by sounding with a lead line or by the use of sonar gear, although the turbidity may trigger "false bottom" reflections (Viers, 1964, p. 18). The sizes of the springs vary from 20 to 50 yards (18 to 46 meters) in diameter and from 9 to 15 feet (2.7 to 4.6 meters) deep (Viers,

Table 1. Major northwest springs (Adapted from Viers, 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

1964, p. 39). Harding (April 1941, p. 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, p. 39). 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, p. 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, p. 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 south to the Provo Bay area. The major area of offshore spring activity is concentrated in the vicinity of Powell Slough (figure 3). Another inflow area occurs approximately 600 yards (550 meters) offshore just south of the Provo airport. Numerous shoreline seeps are located from Powell Slough north to the Lake Bottom Canal drain. Viers, (1974, p. 36, 38) photographed one spring approximately 40 feet (12 meters) across located north of the Powell Slough inflow (p. 36). Two smaller springs under the lake and one onshore were less than 10 yards (9 meters) in diameter and from 10 to 15 feet (3 to 4.6 meters) deep with an EC of 635 micromhos/cm at 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 (Viers, 1964, p. 39).

The spring area southwest of the Provo airport was noted during a winter flight over the area by a thinning of the ice (Viers, 1964, p. 36). Apparently this spring has never been located or sampled.

Bird Island Springs

Bird Island (or Rock Island in the older literature) is composed of tufa deposits, thus indicating considerable spring activity at one time. Today, springs are present but none is of any great size (figure 3). Harding (April 1941, p. 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, p. 56, 61) noted that there is at least one large thermal spring located on the east bank of the north bay of the island which has sufficient flow to keep the bay fairly clear of suspended sediments although not sufficient to keep ice from forming. 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 (23.9°C) were measured here, both values much higher than lake readings. The other springs showed little or no evidence of inflow. 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, p. 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, p. 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

Numerous springs and seeps grouped into six spring areas exist on and around Lincoln Point. By convention, they have been numbered in order from east to west.

Harding (April 1941, p. 25) noted that the much higher concentrations of calcium and magnesium indicate that these spring waters move through different formations than the warm springs in the northwestern part of the lake. However, he assumed that a sample from one spring was representative **of the** whole group. Viers points out (1964, p. 86) that 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, p. 36) flow and temperature measurements and selected quality data from Milligan and others (1966, table 6) for these springs.

The data in table 6 of Milligan and others shows the mean TDS concentration in mg/l for spring 4 is 6,393 with a standard deviation of 138, and for the south Bird Island spring it is 6,598 with a standard deviation of 65. The north Bird Island spring has calcium, magnesium, potassium, and boron contents similar to spring 4, indicating a common source.

East Goshen Bay, Goshen Bay and Pelican Point Springs

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, Bassett and Merritt (1976a, p. 10) believe that these warm springs are associated with faulting along the west side of West Mountain.

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, p. 4). The WPRS completed an extensive shoreline mapping project during the low water period of the early 1960's, but their detailed maps show no evidence of seeps or springs near shore. However, acoustical profiling work by Brimhall et al. (1976 a) did indicate some inflow activity in the deeper water of the bay. Mundorff (1978) feels any subsurface inflows to the Goshen Bay area would be the result of irrigation return flow from cultivated areas on the west side 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 states that "seep-springs" are abundant from Lehi to Pelican Point on the shoreline near water level and that there are also a few springs ". . .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 (p. 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. 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 3. It is estimated that approximately 20 percent of the lake floor more than 1 kilometer offshore is spiked with springs or seeps (Brimhall and others, 1976a, p. 17).

Subsurface Inflow Estimates

Past inflow estimates for Utah Lake have tended to be conservative. With the exceptions of Fuhriman and others (1975) and Brimhall and others (1976a), these estimates have been based on the "missing part" of the water budget, tempered by observations and measurements of known spring inflows which indicate that individual flow rates are very small.

By using a mass balance model for both water and salt balances in the lake, Fuhriman's group arrived at a ground water inflow estimate from two to five times

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.

that of previous 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. In an attempt to establish a common base of reference for the earlier estimates, the total average annual inflow was fixed at 660,000 acre feet (811,800 m^3) (Viers, 1974, p. 17).

In the traditional water budget approach, evaporation and subsurface inflow are considered to be fixed quantities; water quality is not considered. Errors associated with such an approach are discussed in Dustin (1978). But in the salt balance approach, both evaporation and subsurface inflow are treated as variables while surface inflow, surface outflow, precipitation, and change in storage are considered to be fairly well fixed and quality becomes a major factor. In this approach the evaporation rates and subsurface inflow-outflow volumes are adjusted until agreement is reached between predicted and measured salt concentrations. This results in an upward revision of both evaporation and subsurface inflow. In discussing this revision with Fuhriman (1978), the authors 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 an increase in the subsurface inflow estimates. Subsurface inflow, based on recent modeling predictions, could be as high as 123,000 acre feet (151,290,000 cubic meters) per year or more realistically, 114,000 acre feet (Fuhriman and others 1980).

Chemical Quality Summary

The high total dissolved solids (TDS) content of Utah Lake water has been the source of great curiosity, particularly in light of the relatively low TDS concentrations in the measureable inflows. The high concentrations have been variously 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). Fuhriman and others (1975) show 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 4 shows the locations of the sample sites, and table 4 lists the mean values for several samples from each location, taken at different times over an eight year period (1970-1978) by the Brigham Young University researchers. The data on spring inflows come from Viers (1964) and Milligan and others (1966).

On the whole, the water in the main body of the lake is of fairly uniform quality. In Goshen Bay, however, the TDS, Mg, Na, K, Cl, and SO_4 concentrations show a definite increase. The slight variation in quality in the vicinity of PB-11 (figure 4) may well be due to the influence of both the spring which Viers noted in that area and the outflow from Provo Bay, likely the latter.

Statistical Distributions

Computer-assisted statistical trend mapping (using the "SYMAP" program) of various quality constituents by Jensen (1972) shows some interesting patterns in the southern portion of Utah Lake. His maps were based on data collected during June and October of 1970. Through the courtesy of the BYU Department of Geography, the authors secured the "SYMAP" program used by Jensen and reproduced the maps for sodium, magnesium, potassium, and chloride, which are included in this text as figure 5a through d respectively. The first three maps show a similar pattern along the southwestern shoreline of the lake, but the chloride map shows a striking "island" of lower chloride concentration in the middle of Goshen Bay. Jensen makes no attempt to explain these patterns but the authors feel that these are definite indications of ground-water inflow in mid-Goshen Bay and along the western shoreline just north of the mid-bay.

Table 3. Comparison of 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 and others, 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 and others (1975)	96,880	
Brimhall and others (1976a)	16% (105,000)	Based on Fuhriman and others.

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

Table 4. Summary data on the chemical quality of Utah Lake waters (see figure 4 for locations).

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

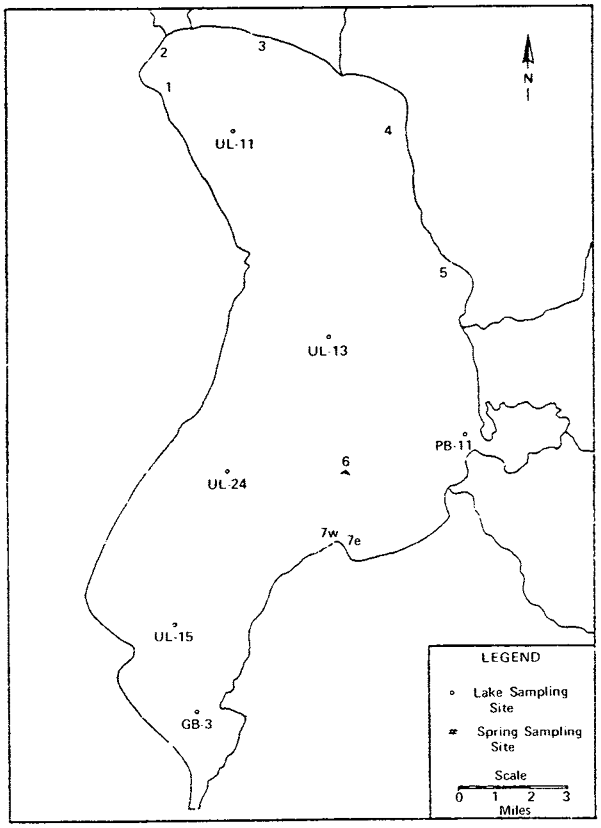


Figure 4. Chemical quality sampling sites.

DESIGN OF THIS INVESTIGATION

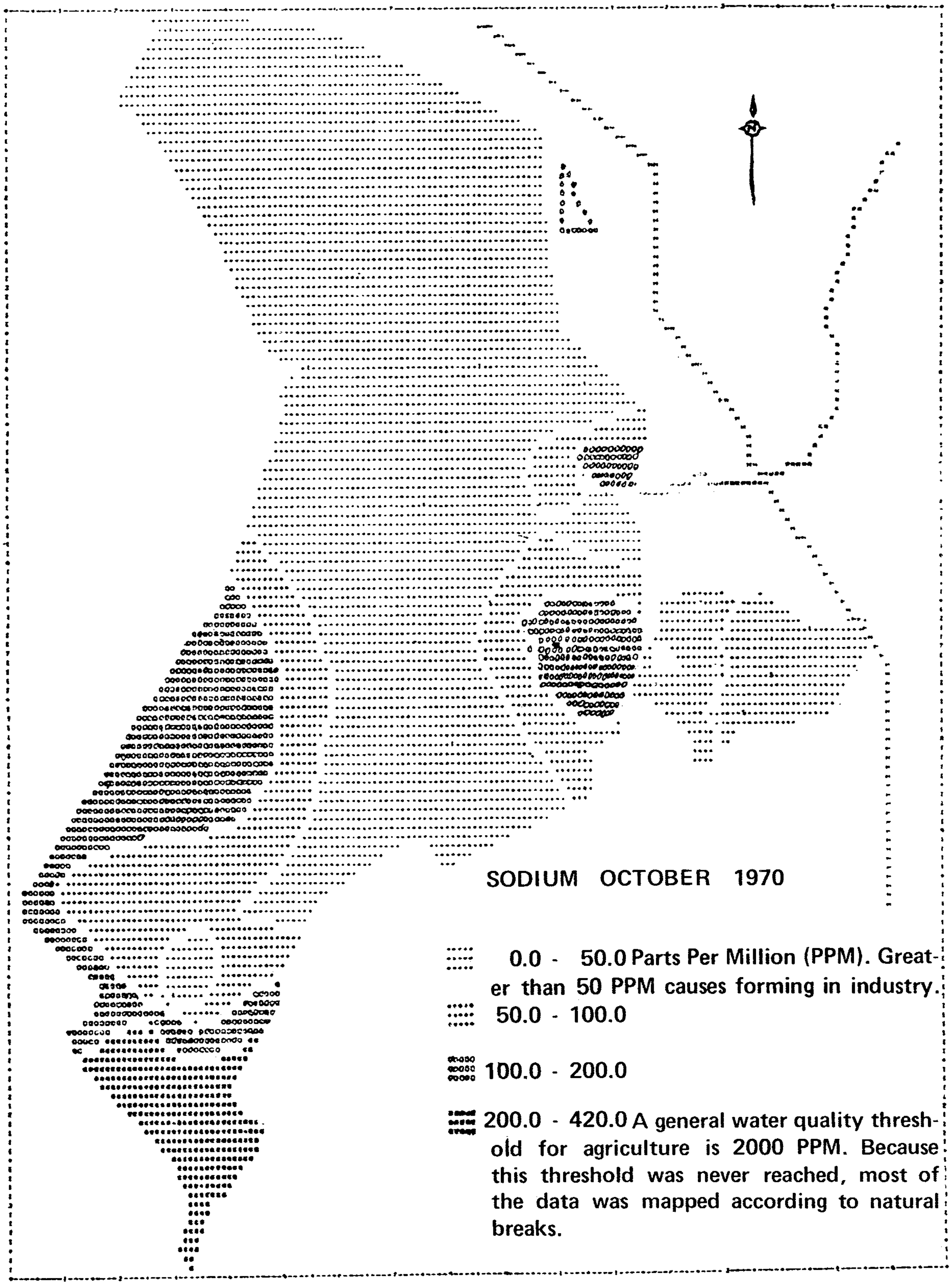
Following a thorough review of the previous investigators' findings as well as the tools and technology available, the following research format was selected:

1. Make a detailed review and evaluation of literature addressing the *geology and hydrogeology* of the Utah Lake Basin.
2. Review literature dealing with groundwater patterns in some "sister basins".
3. Use thermal imagery (infrared), to identify thermal gradients over the lake surface.
4. Make an aerial reconnaissance of the lake to pinpoint suspected inflow locations, using the thermal imagery as a guide.
5. Obtain representative quality samples of water from such inflow areas and establish piezometric profiles.

Mathematical modeling of the Utah Lake Basin water budget was not done for this report because of the lack of accurate and sufficient data, 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, but 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 OF UTAH LAKE BASIN

Hunt and others, (1953) point out that Utah Valley, Goshen Valley, and Cedar Valley were formed as a result of Basin and Range block faulting, or the raising of adjacent mountain blocks relative to valley blocks; these valleys are basically structural grabens. It is generally accepted that these basins began to develop as a



SODIUM OCTOBER 1970

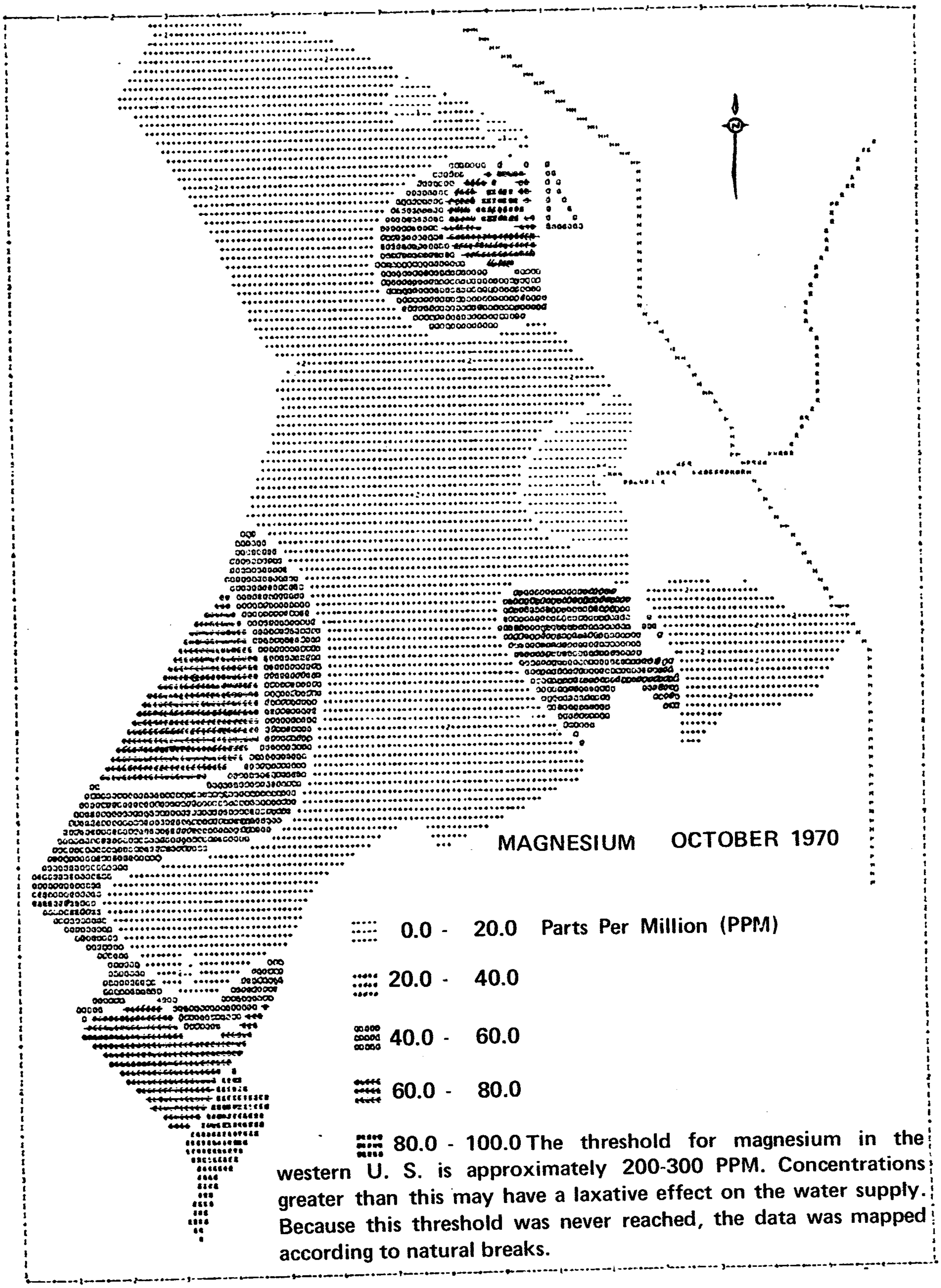
⠿ 0.0 - 50.0 Parts Per Million (PPM). Greater than 50 PPM causes forming in industry.

⠿ 50.0 - 100.0

▨ 100.0 - 200.0

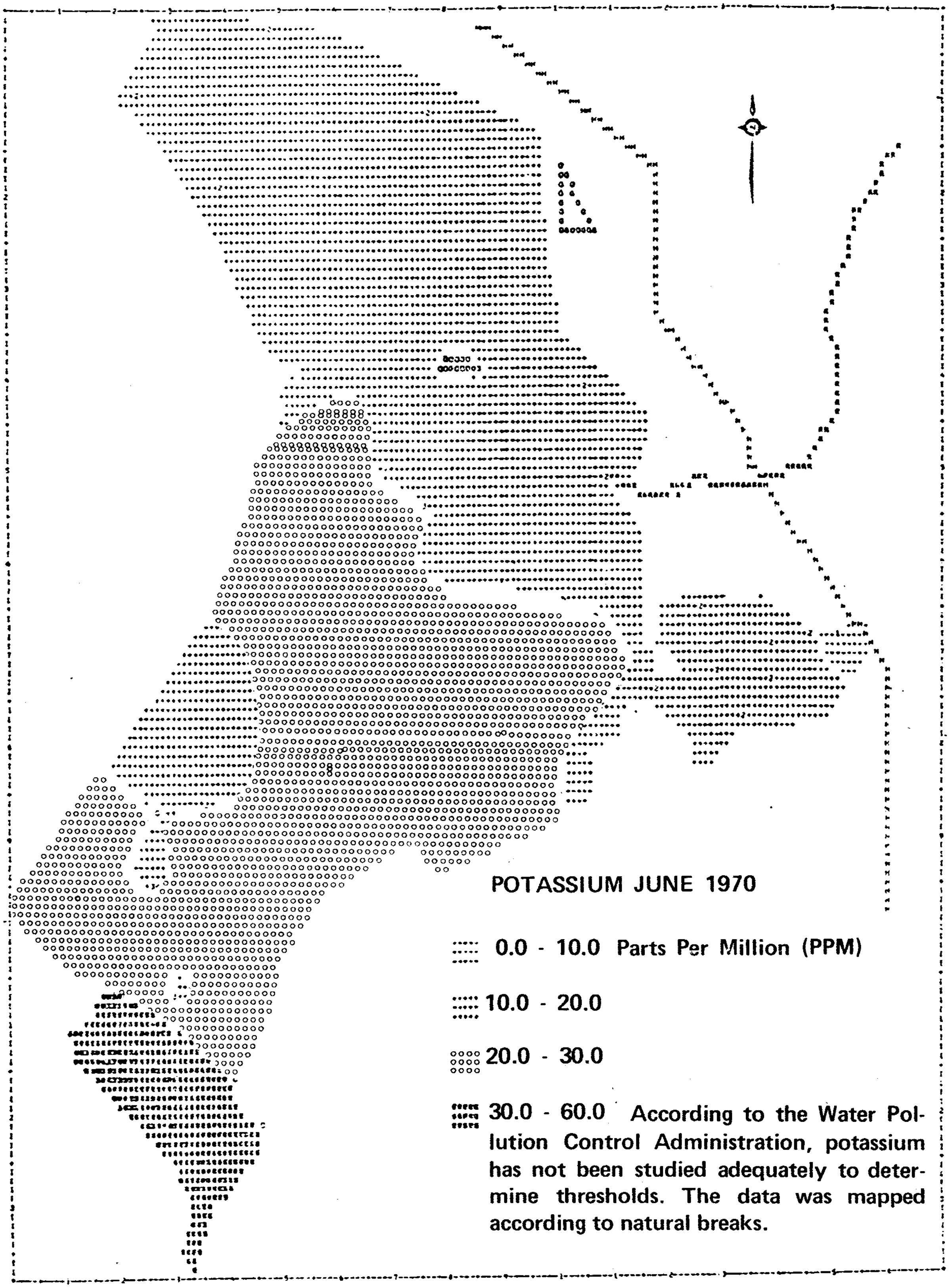
■ 200.0 - 420.0 A general water quality threshold for agriculture is 2000 PPM. Because this threshold was never reached, most of the data was mapped according to natural breaks.

Figure 5a. Sodium distribution, October 1970 (Jensen, 1972).



The threshold for magnesium in the western U. S. is approximately 200-300 PPM. Concentrations greater than this may have a laxative effect on the water supply. Because this threshold was never reached, the data was mapped according to natural breaks.

Figure 5b. Magnesium distribution, October 1970 (Jensen, 1972).



According to the Water Pollution Control Administration, potassium has not been studied adequately to determine thresholds. The data was mapped according to natural breaks.

Figure 5c. Potassium distribution, June 1970 (Jensen, 1972).

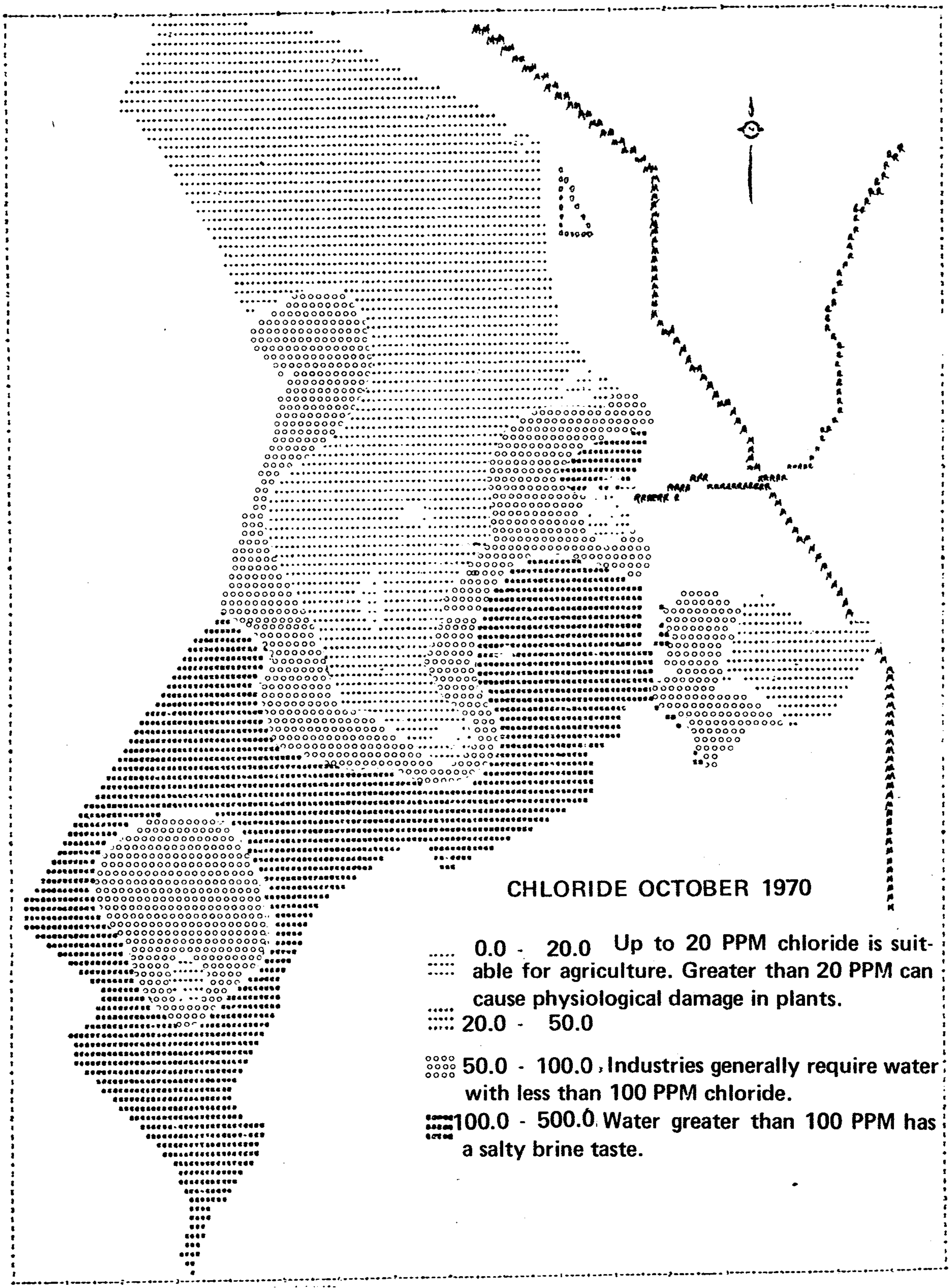


Figure 5d. Chloride distribution, June 1970 (Jensen, 1972).

structural entity about mid-Tertiary time. By early Pleistocene, Utah Valley had the proportions we recognize today. A simplified geologic map of the area is shown in figure 2.

Basin Fill

Sediments comprising the valley fill in the basin are of Tertiary and younger age and form fairly distinct layers. These layers are thinnest in the northern end of the basin and gradually thicken in a southeasterly direction. Most of the valley sediments appear to have been derived from the rocks of the surrounding mountains, but some are volcanic ash deposits.

An airborne magnetometer survey by the U. S. Geological Survey in 1947 indicated that the fill in Utah Valley was very uniform with no anomalies to indicate buried hills containing dense rocks, to a depth ". . . of at least a few thousand feet. . ." (Hunt et al., 1953, p. 37-38). Later, Cook and Berg (1961) reported that gravity surveys over the basin implied a depth of some 8,000 to 10,000 feet (2,400 to 3,000 meters). However, information from a wildcat well, drilled 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. A company spokesman reported that drilling was abandoned in Tertiary sediments, without reaching bedrock at a depth of 13,000 feet (3,962 meters) and that geologists now estimate that Paleozoic formations may not be reached for another 5,000 to 7,000 feet (1,500 to 2,100 meters) (Mann, personal interview, 1978).

Pre-Lake Bonneville Basin-fill Sediments

The oldest identifiable valley fill formation, found only in drill holes in Utah Valley, is the Salt Lake Formation. This formation contains an unknown thickness of well stratified volcanic and clastic sediments which appears to have been deposited in lakes or playas in late Tertiary time. Reworked ash, probably washed in from pyroclastic volcanic deposits from surrounding highlands, are interstratified with conglomerates.

Based on well logs, the depth to the top of these late Tertiary deposits varies from approximately 175 to 200 feet (50 to 60 meters) in the north end of Utah Valley and to 450 to 500 feet (135 to 150 meters) in the south end.

At the end of the Tertiary period, the last of the Tertiary lakes receded and perhaps even disappeared. In Pleistocene pre-lake Bonneville time, the sedimentation was characterized by deposition of huge alluvial fans which extended far into the valleys. These deposits were separated by at least three periods when lakes, presumably glacial, filled the basin. 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 Sediments

Lake Bonneville was formed at the conclusion of the Pleistocene time. At its maximum size, the lake covered an area of some 20,000 square miles (50,800 square kilometers) and obtained a maximum depth of about 1,000 feet (305 meters) (Bissell, 1968) (figure 6).

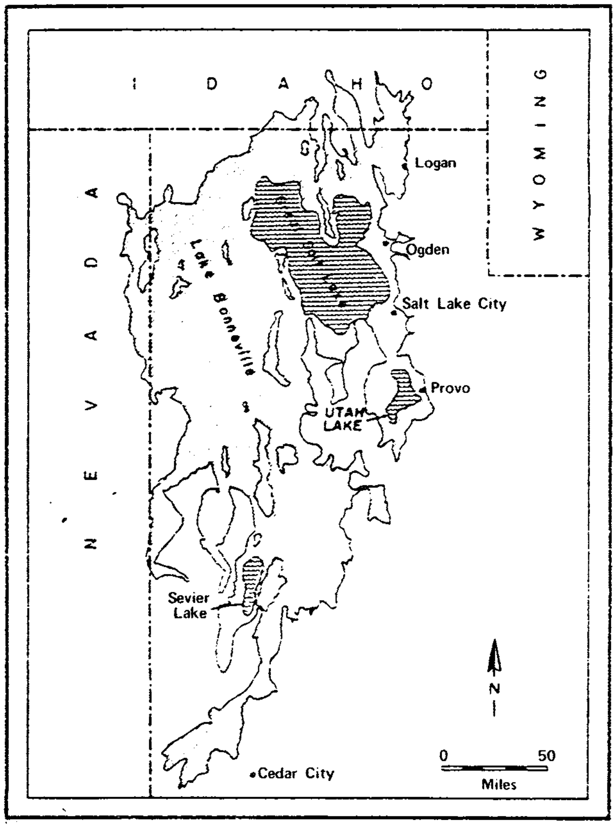


Figure 6. Lake Bonneville at its maximum size (Adapted from Bissell, 1968).

Lake Bonneville experienced at least three major substages: the Alpine, Bonneville, and Provo. The oldest, the Alpine substage, contributed most of the Lake Bonneville sediments. The Alpine sediments are characterized by vast quantities of fine-grained materials, with over half silt size or finer. During the Bonneville substage the lake rose to its maximum elevation, eventually breaching Red Rock Pass near Preston, Idaho, and flowing into the Snake River drainage. The volume of Bonneville sediments is relatively insignificant, indicating the Bonneville substage was relatively short lived (Hunt and others, 1953,p. 40).

A rapid and permanent drop in the water level (nearly 300 feet or 90 meters in Utah Valley) preceded the Provo substage (Gilbert, 1890, p. 269). 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 from the older Alpine and Bonneville deposits (Hunt et al., 1953, p. 41).

Lake Bonneville gradually receded, leaving Utah Lake, Salt Lake and Sevier Lake as surviving remnants. Sediments have continued to accumulate in Utah Lake but at a very slow rate of approximately one meter per millenium (Brimhall et al., 1976, p. 24).

Cedar Valley Fill

Utah Valley, Cedar Valley, and Goshen Valley have a common geologic history and structure, but Cedar Valley differs slightly from the valleys to the east in that the elevation of its floor averages some 300 feet (90 meters) higher than that of Utah Valley, although both slope from northwest to southeast. Its higher elevation suggests that Cedar Valley has not accumulated as much depth-of-fill as the other two valleys. Cedar Valley fill is composed primarily of alluvial fans; lacustrine clay, silt, sand, and gravel; and eolian sand and silt. Because it is rather sheltered and lacks large perennial streams, its 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, p. 10).

Structure and Geology of Lake Mountain and The Mosida Hills

Lake Mountain and the Mosida Hills separate Cedar Valley on their west from Goshen and Utah Valleys on their east (figure 7). Feltis (1967, p. 12-13) has suggested that some groundwater may be leaving Cedar Valley ". . . along the bedding planes and through fractures and solution channels in the rocks. . ." Feltis' theory is given further discussion in the hydrogeologic section of the Lake Mountains and the Mosida Hills. Attention needs to be given to the structure of this area to determine the practicality of his suggestion.

Lake Mountain

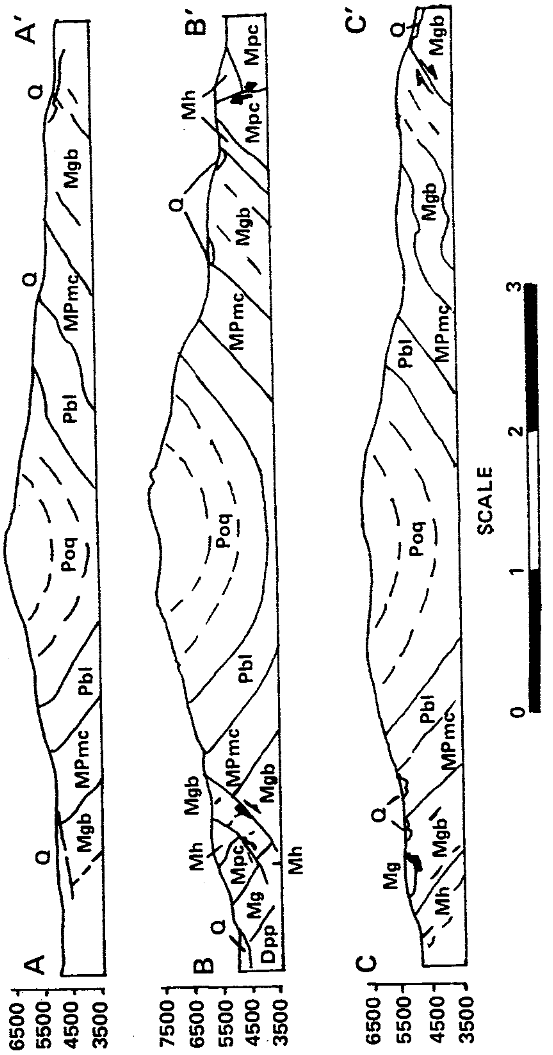
Lake Mountain is basically a syncline comprised of faulted and jointed Paleozoic sedimentary formations (figure 7). The major syncline has been offset approximately one third of a mile (0.54 kilometers) to the west at its southern end by tear faulting (Bullock, 1951, p. 25). The geologic sections A-A′, B-B′ and C-C′, depict the Lake Mountain structure.

The youngest exposed formation, the Pennsylvanian-Permian Oquirrh, consists of alternating beds of sandstone, limestone and orthoquartzites. Underlying this formation is the Manning Canyon Shale, predominantly a black or variegated shale with orthoquartzite beds common in the lower part and limestone beds in the upper. Below this is the 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 underlying Humbug Formation is composed of interbedded sandstone, orthoquartzite, dolomites, and limestone. Beneath the Humbug is the Pine Canyon Limestone, 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 the Gardner Dolomite; the basal member of this formation consists of sugary dolomites while the upper layers are primarily fossiliferous limestone. At the base of the section is the Devonian Pinyon Peak Limestone, which grades from limestone into dolomite to the north. The basal layer consists of medium to coarse-grained dolomites and limestone which tend to weather to a sandy texture; the mid-layer is comprised of irregularly mottled dolomites, and the upper layer is of calcareous and sugary dolomite.

Bullock (1951) observed that the entire Lake Mountain block is tilted southward and that 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. He also observed that the synclinal axes, faults, joints, and stratigraphic horizons ". . . are important controls of drainage lines. . ." (p. 39).

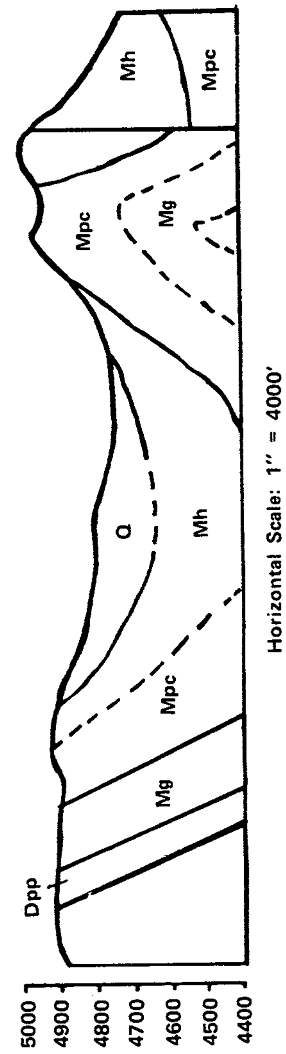
The Mosida Hills

The Mosida Hills lie immediately south of and adjacent to the Lake Mountains (figure 7). A series of



Geologic Sections of Lake Mountain.

(Bullock, 1951)



Geologic Section of the Mosida Hills.

(Adapted from Hoffman, 1951)

SYMBOLS ON SECTIONS

Q	Quaternary	Mgb	Great Blue Limestone
Poq	Oquirrh Formation	Mh	Humbug Formation
Pbl	Basal Oquirrh Limestone	Mpc	Pine Canyon Limestone
MPmc	Manning Canyon Shale	Mg	Gardner Dolomite
		Dpp	Pinyon Peak Limestone

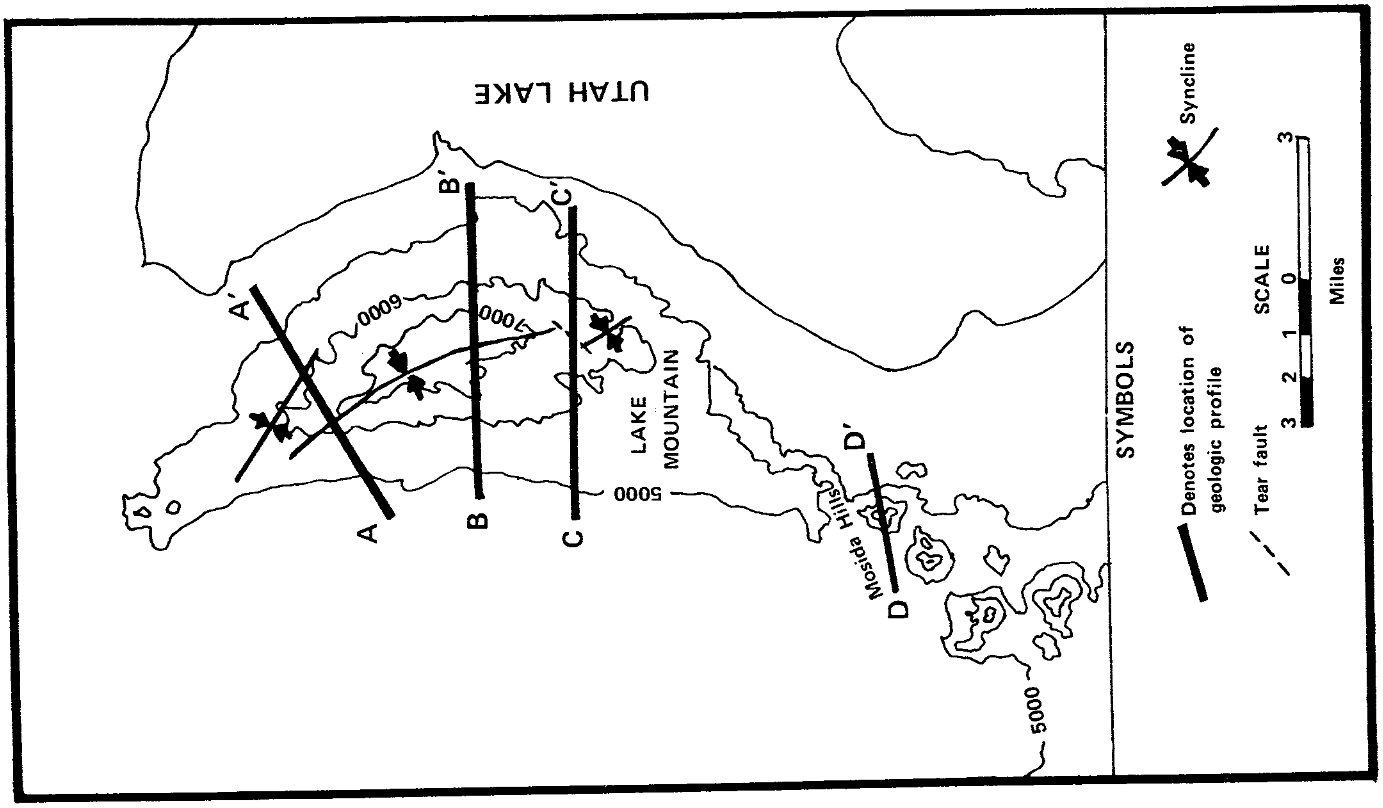


Figure 7. Lake Mountain and the Mosida Hills.

low passes through this area connects Cedar and Goshen Valleys. According to Hoffman (1951), the sedimentary formations have a general north to northwest strike and dip northeast 45 to 50 degrees, disappearing into Cedar Valley alluvium. Structurally, these hills tend to be characterized by thrust faults and by generally north-south striking anticlines with high angle faults striking normal to the structural trend.

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 places quicksands were found. Along the western shore a strata of hard material (presumed to be hardpan or cemented sand, gravel and boulders) was overlain by "2 or 3 feet" (approximately 0.75 meters) of sandy clay. Their equipment limited penetrations to a depth of 108 feet (32.9 meters) (Horton, 1905, p. 490-494).

In 1962, the U. S. Bureau of Reclamation conducted a reconnaissance study of the location of the proposed Goshen Bay dike. Figure 8 shows the location of the dike and of the 28 bore holes, approximately 90 feet (27 meters) deep, associated with the study. Figure 9 depicts the profile along the proposed dike axis. The report describes the sediments 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, p. 5). These silts and clays thin progressively to approximately 19 feet (5.8 meters) near the shoreline. The silt is described as being very homogeneous suggesting an eolian rather than a fluvial origin (p. 6).

Under this silt and clay layer is a thin layer of highly compacted red clay of moderate to high plasticity, and under the clay are interbedded and lensed sands and silts ranging from coarse silts to fine to medium clean sands. The cleaner sands were ". . . full of water showing some artesian pressure. . .". Large quantities of marsh gas (principally 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 (p. 6).

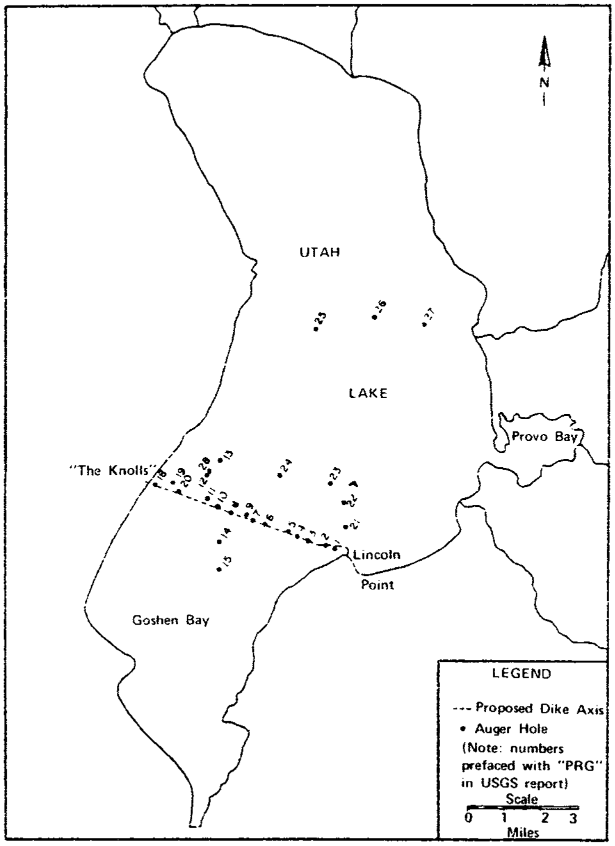
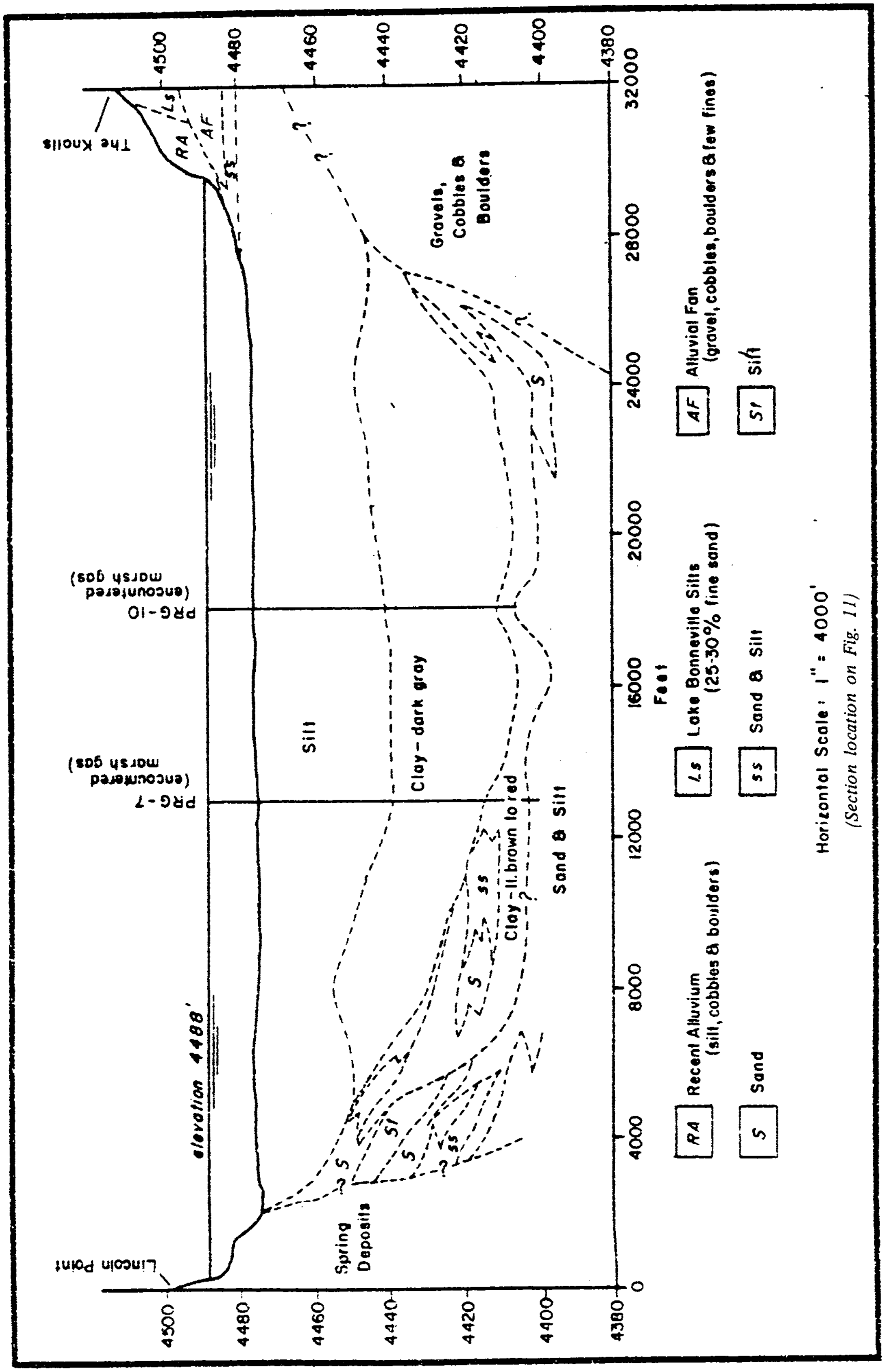


Figure 8. Reconnaissance Borings–Goshen Bay dike (USBR, 1963).

The logs of holes 25, 26 and 27 (figure 8) indicate that the same character and layering of sediments is present at mid-lake. The dark gray clay layer of figure 9 was very obvious in the acoustical profiles done by Brimhall and others, (1976a) and persisted over the entire lake bed. It is reasonable to assume that the lake bed has a fairly homogenous character in its upper layers.

Distribution Patterns and Nature of the Upper Sediments

Sonerholm (1974) and Bingham (1975) have made computer-assisted statistical trend mappings of the mineral and the particle size distributions in Utah Lake sediments. As would be expected, the coarser grained materials are found along the eastern edge of the lake and the very fine grained materials in the deeper water. Brimhall and Merritt (1976b, p. 15) noted that the pre-



(Section location on Fig. 11)

Figure 9. Geologic profile of proposed Goshen Bay dike axis (USBR, 1963).

dominant mineral in the upper sediments is calcite. The next most abundant minerals are quartz, the clay minerals illite, montmorillonite and mixed layer types, and other silicates.

Lake Bed Faulting

Acoustical profiling work done by Brimhall and others (1976a) has provided a rather detailed picture of recent faulting within the bed of Utah Lake to a depth of about 25 meters (figure 10). The presence of a major fault extending in a rough north-south arc from Lincoln Point, through Bird Island, and on north to Saratoga Springs is suggested by the presence of thermal springs at each of these locations and is supported by the gravimetric work of Cook and Berg (1961).

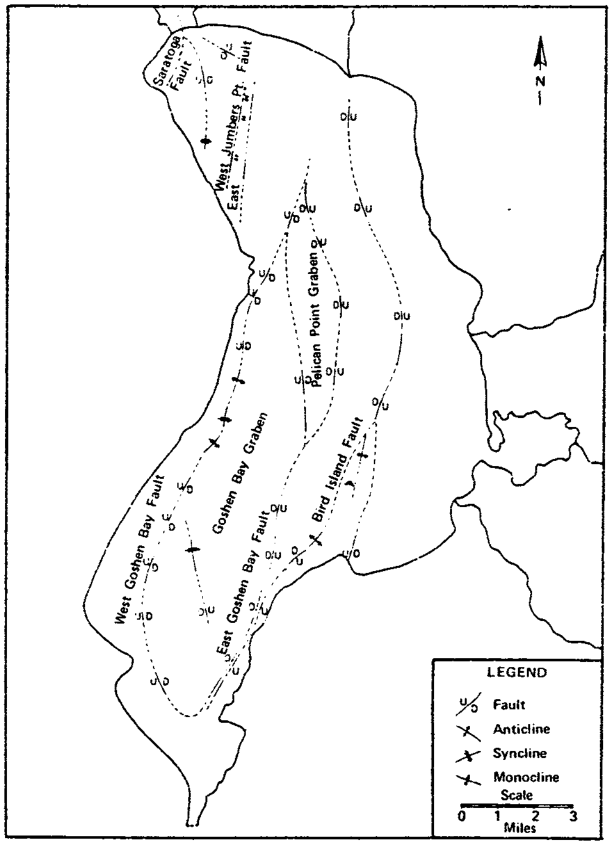


Figure 10. Lake bed faulting (Adapted from Brimhall et al., 1976a).

The Bird Island Fault (figure 10) is displaced from 6.5 feet (2 meters) to less than 1.5 feet (0.5 meters); displacements along the East Goshen Bay Fault range from 3.3 feet (1 meter) to less than 1.5 feet (0.5 meters). The greatest displacements are on the East and West Jumbers Point Faults, 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 and Merritt, 1976b, p. 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 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 channelways 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, p. 4).

HYDROGEOLOGY OF UTAH LAKE BASIN

Basin Aquifers

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 makes positive identification of these aquifers difficult, but some correlation does exist through at least the Pleistocene. Figures 11a through i show these aquifers in a series of geologic cross sections, based on selected well logs, across Utah and Goshen valleys. (See Cordova, 1969, p. 2, for well numbering system).

Ground-water moving away from the mountains and toward the valley is confined in layers of sand and gravel between clay and silt layers and produces artesian pressures in areas of all three valleys. These artesian pressures are prevalent throughout all of Utah Valley north of Payson.

In Goshen Valley, artesian conditions are confined mainly to the eastern part of the valley between Goshen and Utah Lake and flow generally occurs only below an elevation of 4,520 feet (1,378 meters) (Cordova, 1970, p. 13-14).

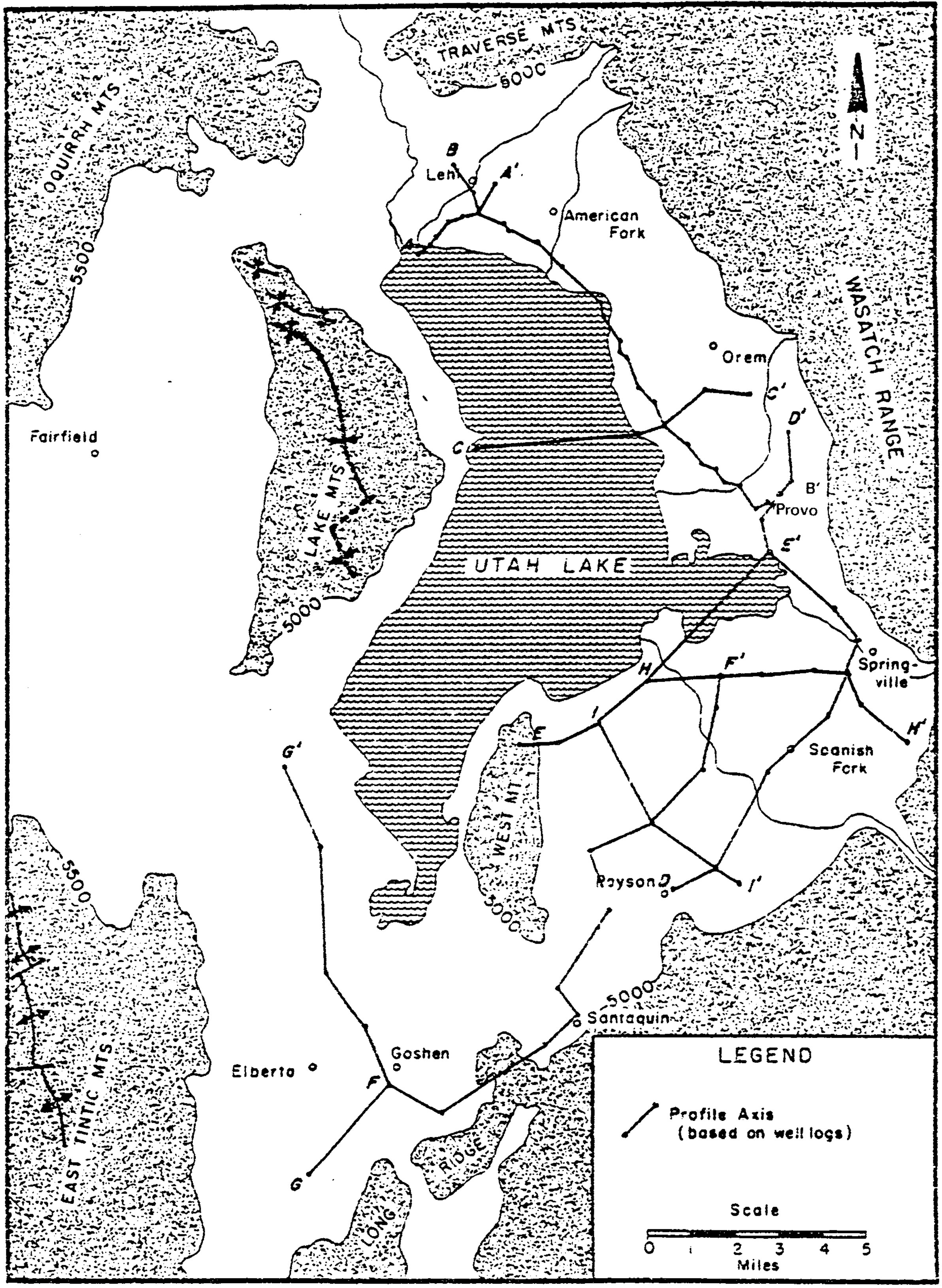


Figure 11. Locations of geologic sections for figures 11a - 11i.
(Letters on sections above correspond with letters on geologic sections).

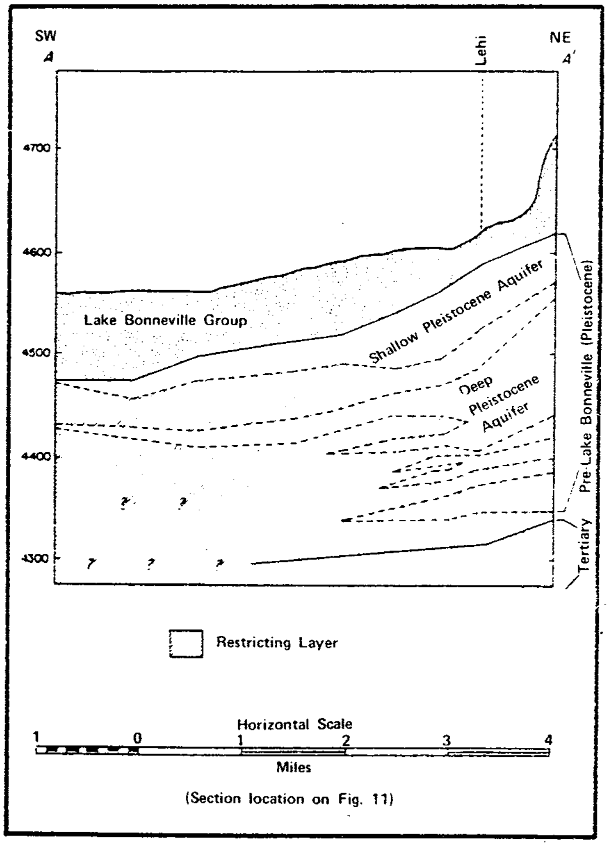


Figure 11a. Section A-A': Utah Lake to Highland Bench (Adapted from Hunt et al., 1953).

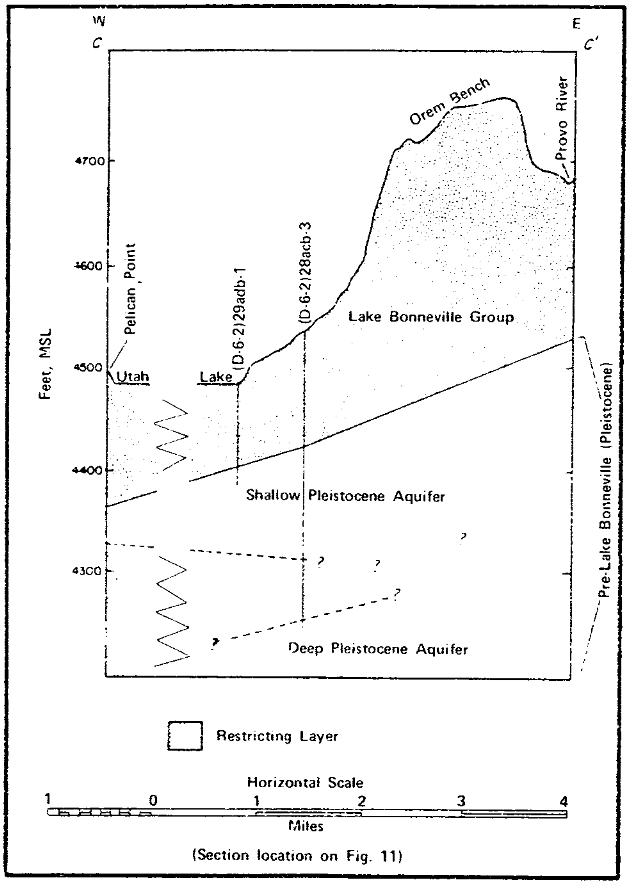


Figure 11c. Section C-C': Pelican Point to Orem (Adapted from Hunt et al., 1953).

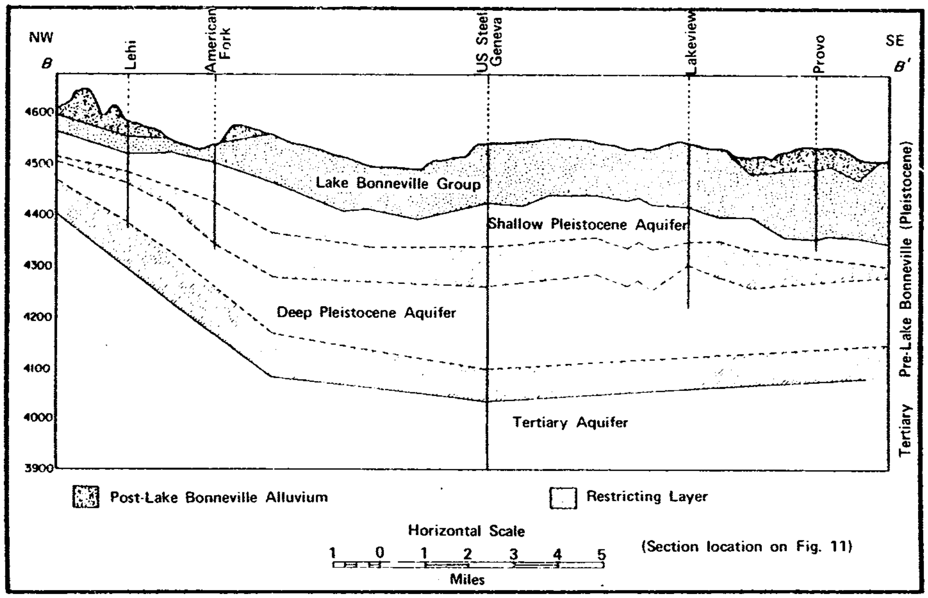
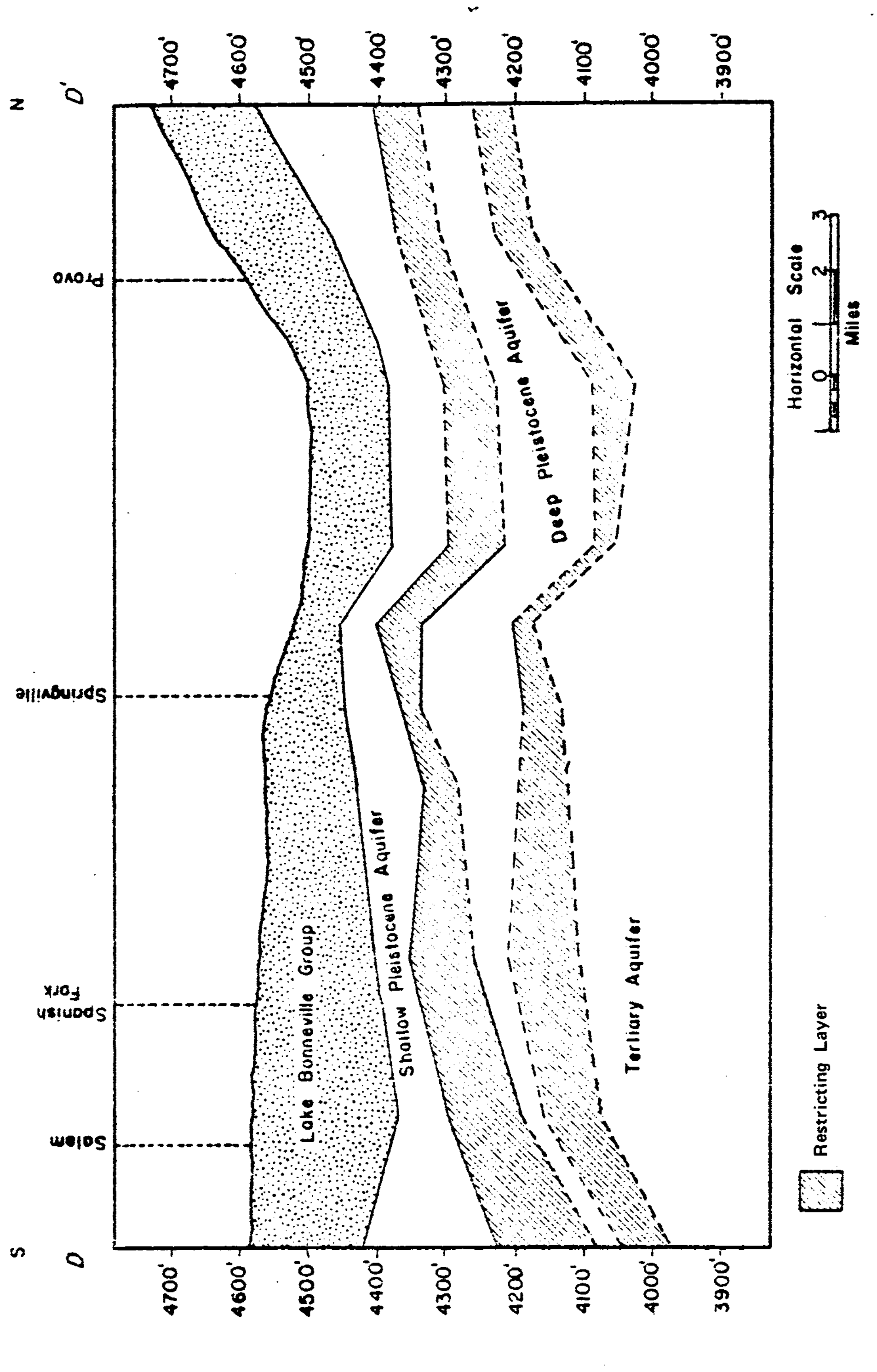
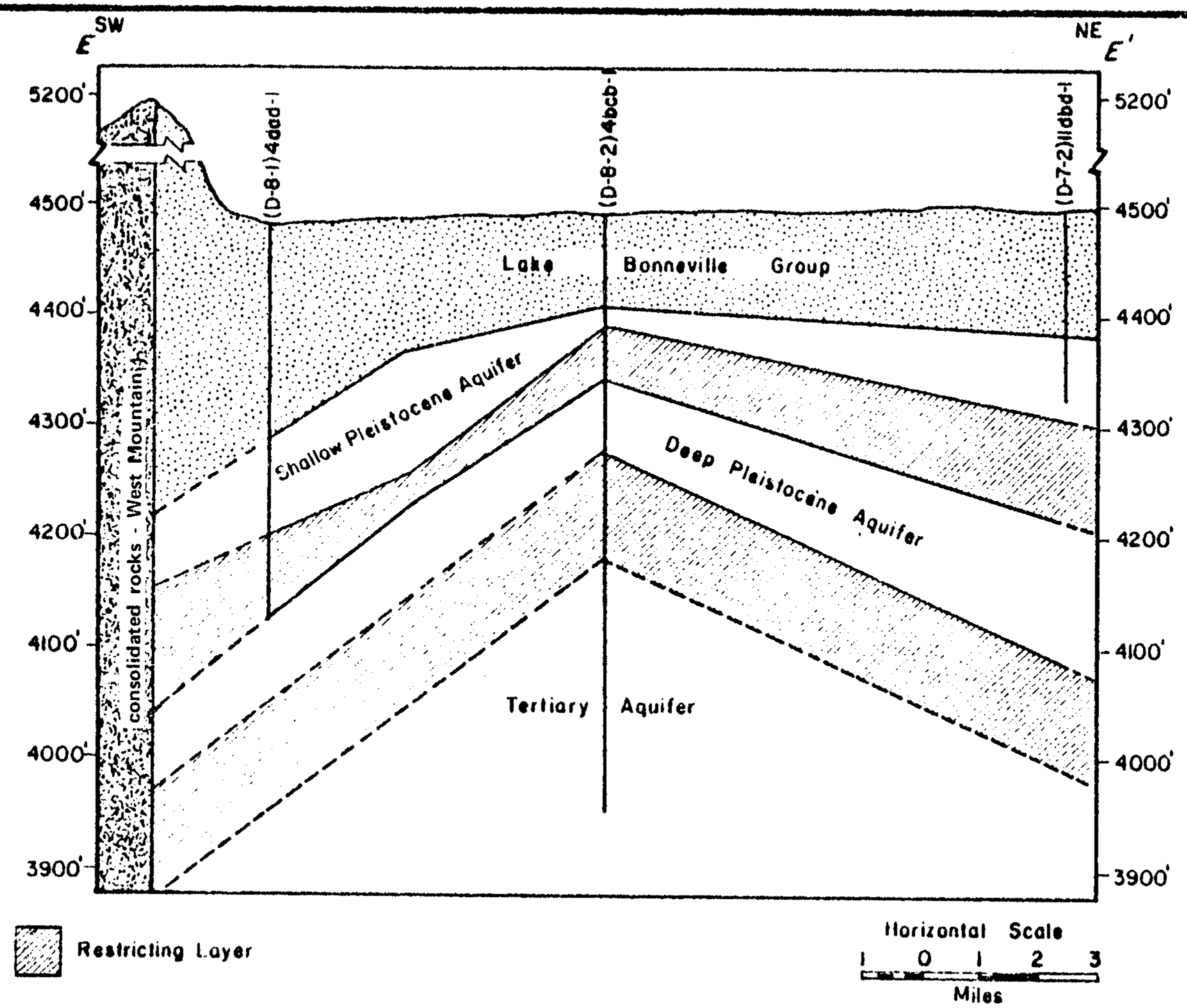


Figure 11b. Section B-B': North of Lehi to Provo (Adapted from Hunt et al., 1953).



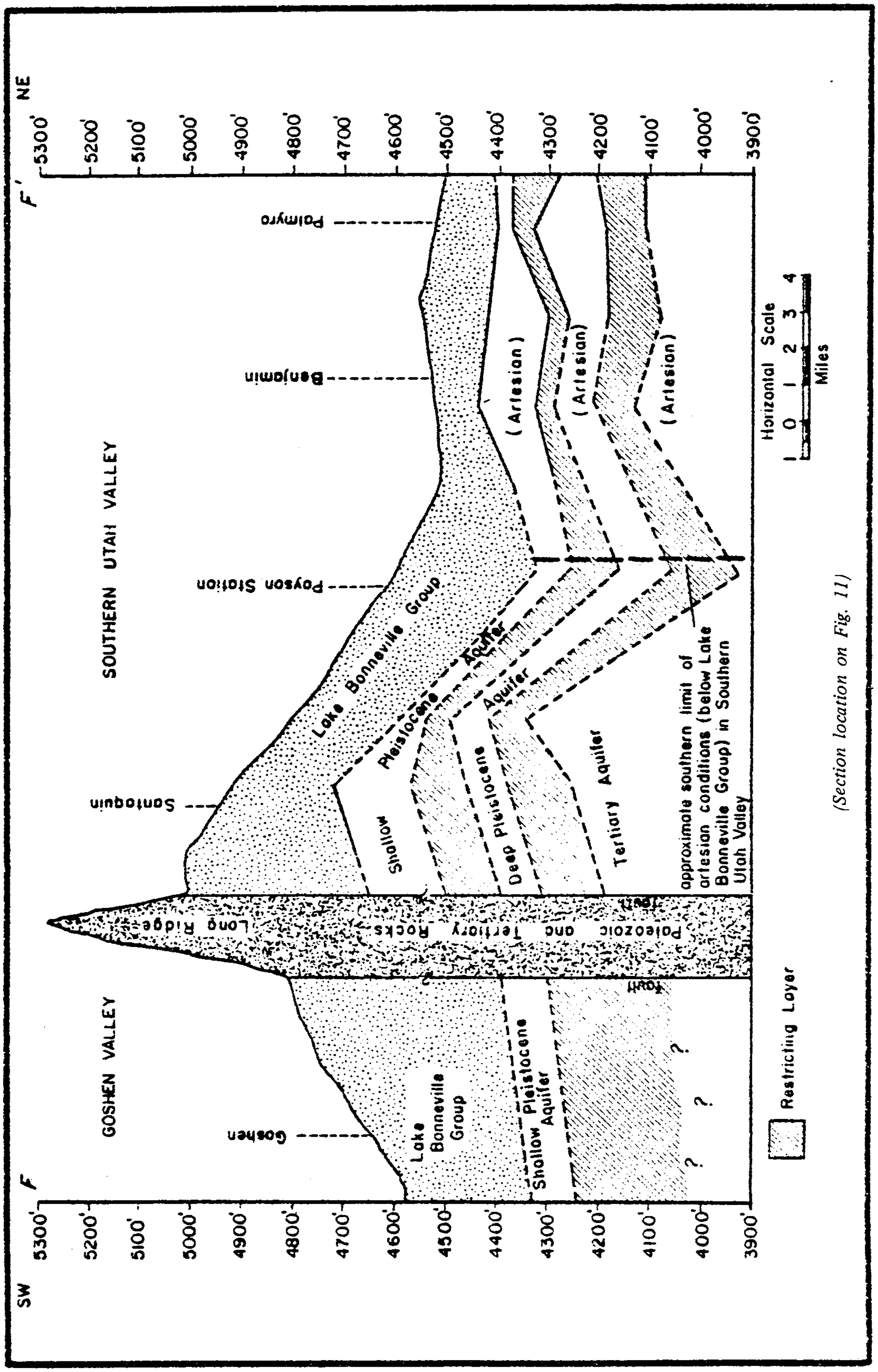
(Section location on Fig. 11)

Figure 11d. Section D-D': Payson to North Provo (Adapted from Cordova, 1970).



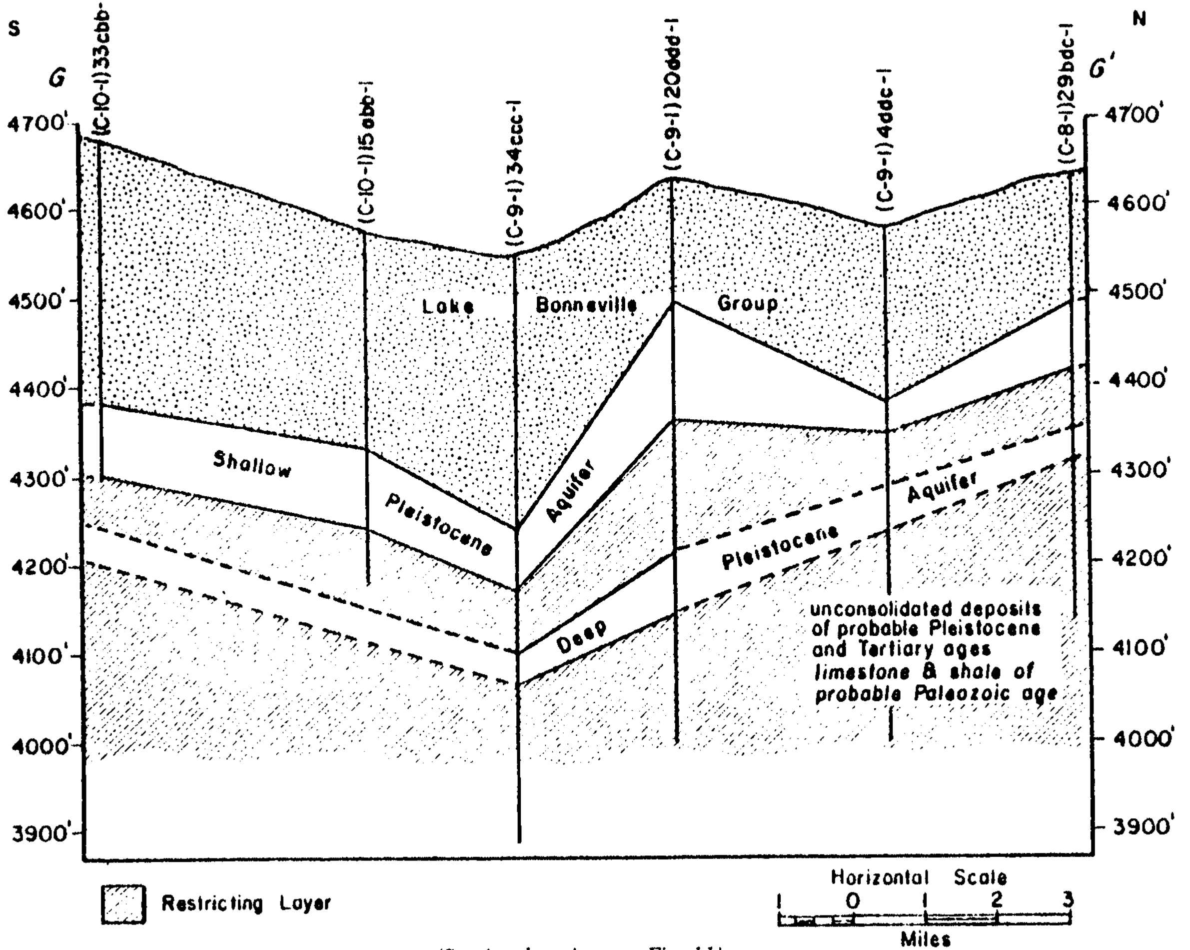
(Section location on Fig. 11)

Figure 11e. Section E-E': West Mountain to South Provo (Adapted from Cordova, 1970).



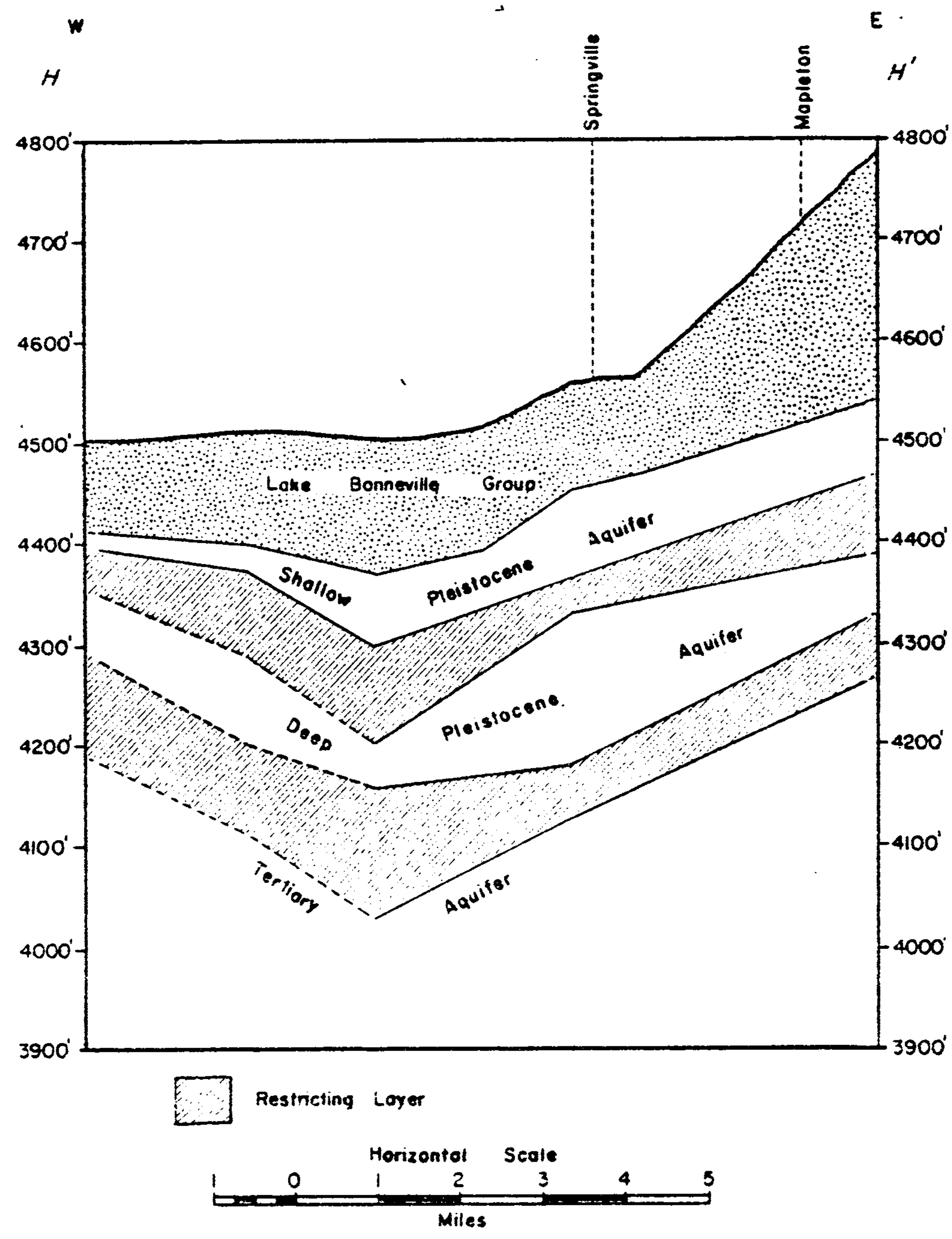
(Section location on Fig. 11)

Figure 11f. Section F-F': Goshen to Palmra (Adapted from Cordova, 1970).



(Section location on Fig. 11)

Figure 11g. Section G-G′: South of Elberta to Mosida (Adapted from Cordova, 1970).



(Section location on Fig. 11)

Figure 11h. Section H-H': Utah Lake to Mapleton (Adapted from Cordova, 1970).

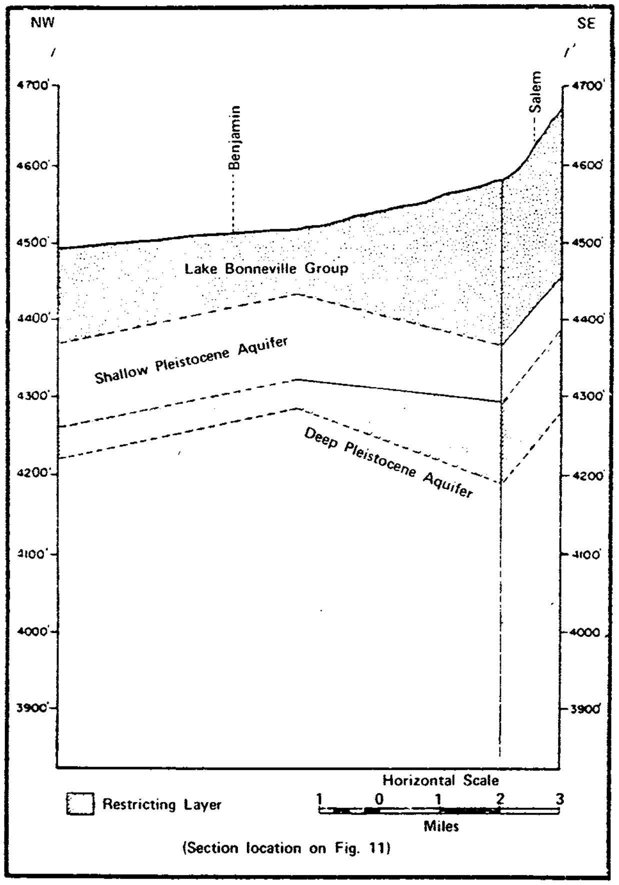


Figure 11i. Section I-I': Benjamin Slough to Salem (Adapted from Cordova, 1970).

In Cedar Valley, artesian conditions exist east of the Oquirrh Mountains (Feltis, 1967, p. 12). Fairfield has flowing wells which produce from aquifers at depths of 100 to 824 feet (30 to 251 meters). 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. This reduction in pressure may possibly be due to the discharge of water into the bedrock on the east edge of the valley.

Water Table Aquifer

The Water Table aquifer is the uppermost of the aquifers and is associated with the sediments of 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 poor quality. 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 southeastern part. In both valleys the hydraulic gradient is toward the east and southeast although the floor of Cedar Valley is some 300 feet (91 meters) higher than that in Utah and Goshen valleys.

Shallow Pleistocene

Depths to this aquifer range from about 38 feet (12 meters) near American Fork to some 300 feet (90 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 are associated primarily with the Pleistocene 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 (Hunt and others, 1953), Cordova (1970), Feltis (1967), Cordova (1969), and Subitsky (1962).

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 and others, 1953, p. 83) forms the confining layer between the Shallow Pleistocene and the Deep Pleistocene aquifers. The deep Pleistocene aquifer has the same areal extent as the Shallow, but the hydrostatic head is from 15 to 20 feet higher. 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) (figures 11a through 11i). The quality of the water is better than in the overlying Shallow Pleistocene aquifer.

Tertiary

The highest quality ground-water is found in the Tertiary aquifer, from 200 to over 500 feet (61 to 152 meters) below the ground surface throughout the basin. Its thickness has never been adequately established. The artesian pressures are also highest (Hunt and others, 1953, and Cordova, 1970).

Deep Tertiary aquifers

In 1977, electric logs from the Gulf Oil "Banks No. 1" well (figure 11) showed additional fresh water strata located between depths of 870 and 900 feet (265 to 274 meters), 1,125 and 1,140 feet (343 and 348 meters), 1,190 and 1,225 feet (363 and 373 meters), 1,415 and 1,455 feet (431 and 44 meters), 1,510 and 1,570 feet (460 and 478 meters), 1,630 and 1,645 feet (497 and 501 meters); and 1,720 and 1,750 feet (524 and 533 meters). At this last level the water is highly saline, and at 5,000 feet (1,524 meters) the fill material is characterized by shaly deposits mixed with sand (Mann, personal communication, 1978).

Storage and Transmissibility Coefficients

The storage and transmissibility coefficients for northern Utah Valley, southern Utah and Goshen valleys, and Cedar Valley were determined by Hunt, Varnes and Thomas (1953), Cordova and Mower (1967), and Feltis (1967). In general, the values decrease away from the mountains, 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 12, 13 and 14, respectively.

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 hydrostatic heads of 5 to 10 feet higher than the Deep Pleistocene. Examination of the piezometric contours shows that:

1. All aquifers have common sources of recharge.
2. The hydraulic gradients trend toward the lowest topography (Utah Lake) from all directions.
3. The gradient in Cedar Valley suggests that water may be flowing around and through the Lake Mountain and Mosida Hills area (Feltis, 1967).

Hunt, Varnes and Thomas (1953, p. 82-83) noted that the piezometric surfaces appear to be unaltered by large well withdrawals 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 the "central and lower" part of the valley.

Sources of Recharge

Figures 12 through 14 indicate that most recharge occurs near the major tributary canyons and along a narrow band around the base of the Wasatch Range for Utah Valley, and the Oquirrh Mountains for Cedar Valley. Contours in Goshen Valley suggest recharge is from both the southeast and the west to northwest.

Richardson (1906, p. 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,
4. Infiltration and deep percolation of precipitation and overland flow over the valley floor.

Hunt, Varnes and Thomas (1953) 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.

Recharge figures reported by Cordova and Subitsky (1965) for northern Utah Valley, Cordova (1970) for southern Utah and Goshen valleys, and Feltis (1967) for Cedar Valley all represent conservative minimum values. The volume of subterranian recharge issuing from fractured bedrock along the mountain base-aquifer interface cannot presently be and may never be accurately determined. Cordova (1978) feels that the amount could be comparatively large considering the bedrock lithology (highly fractured limestone). The sparse vegetation along the mountain front, even though the area receives considerable precipitation, (figure 15) 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

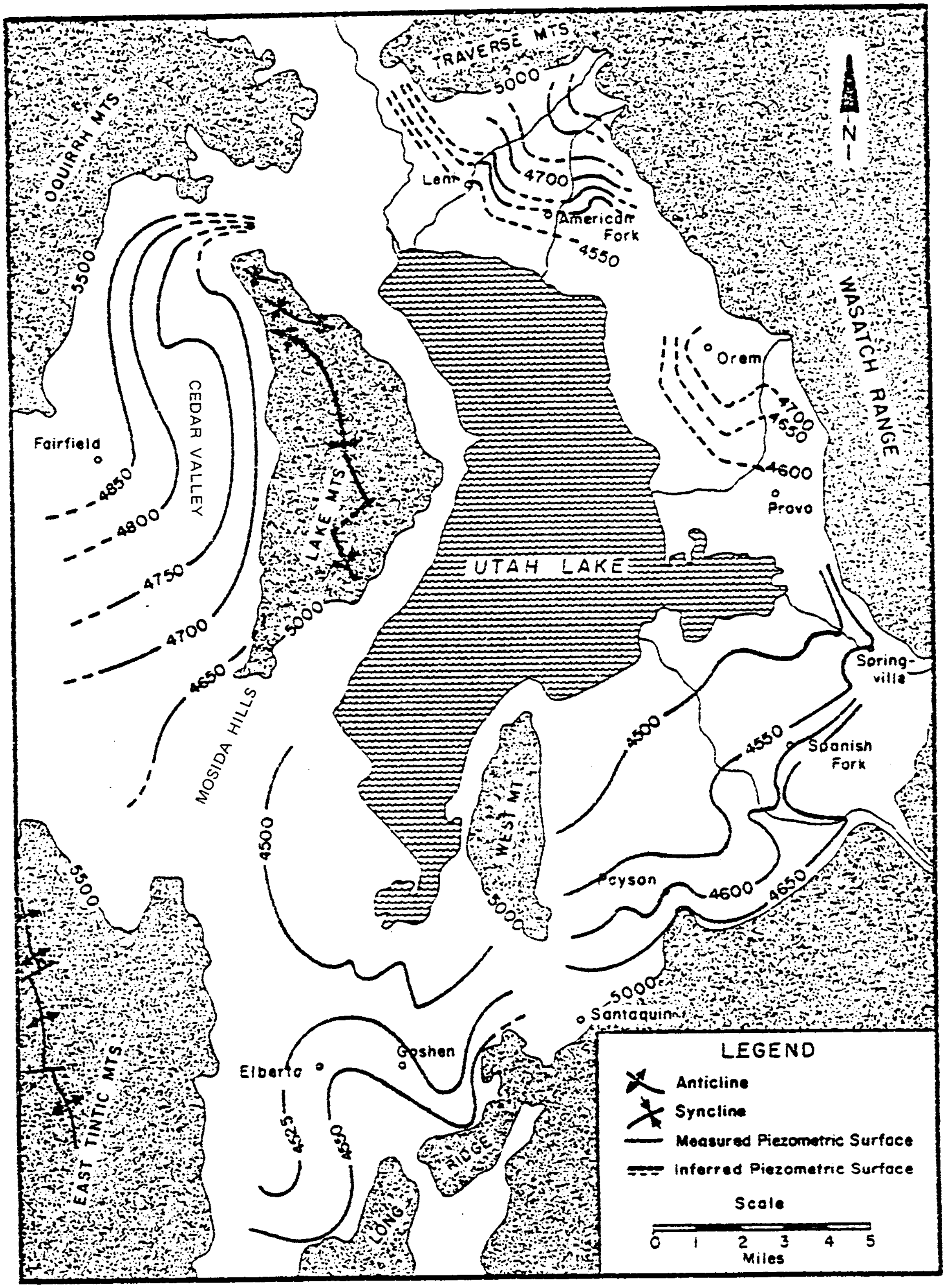


Figure 12. Piezometric contours for the water table aquifer (Adapted from Hunt et al., 1953, Feltis, 1967, and Cordova, 1970).

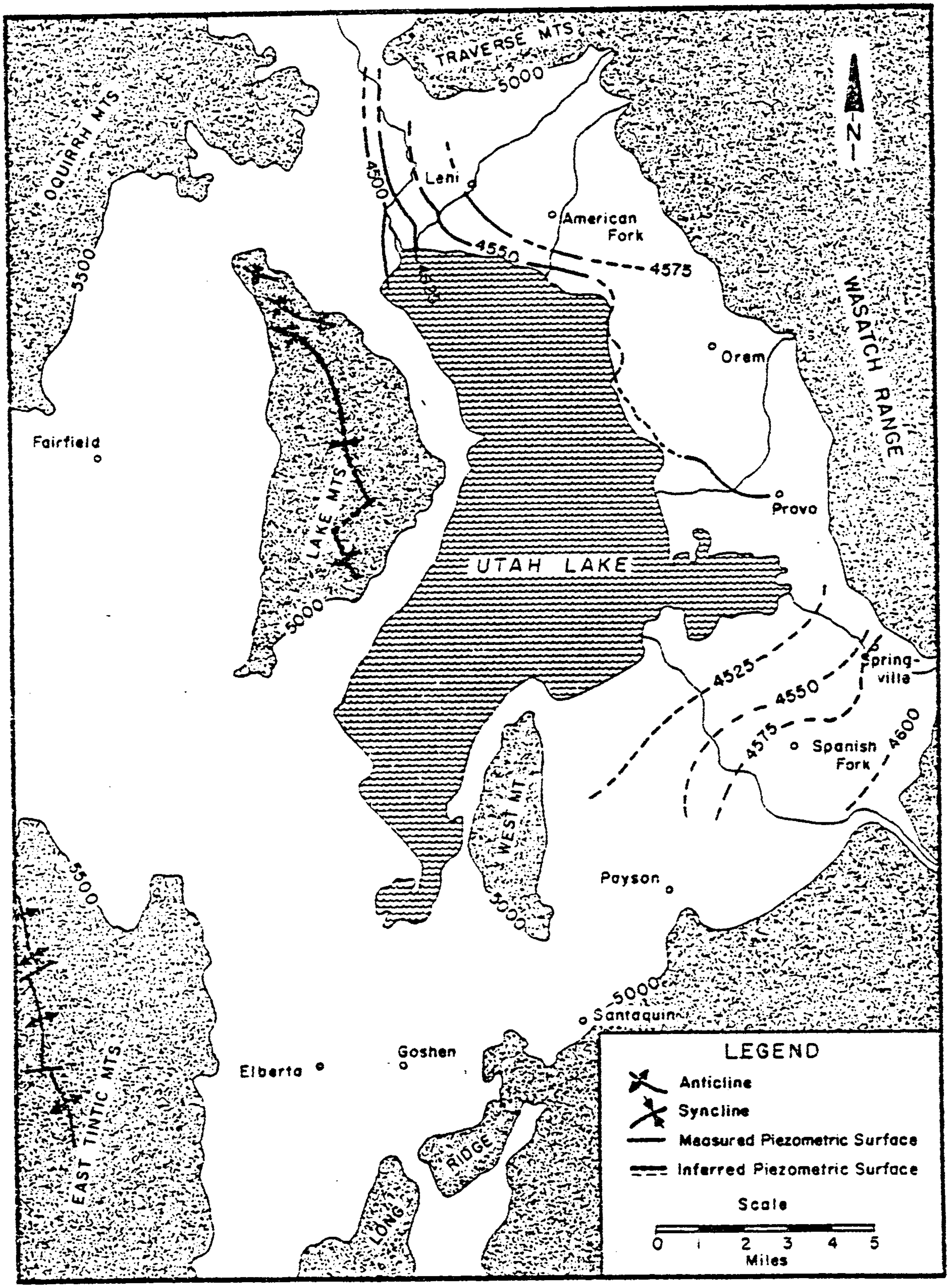


Figure 13. Piezometric contours for the Shallow Pleistocene aquifer (Adapted from Hunt et al., 1953, and Cordova, 1970).

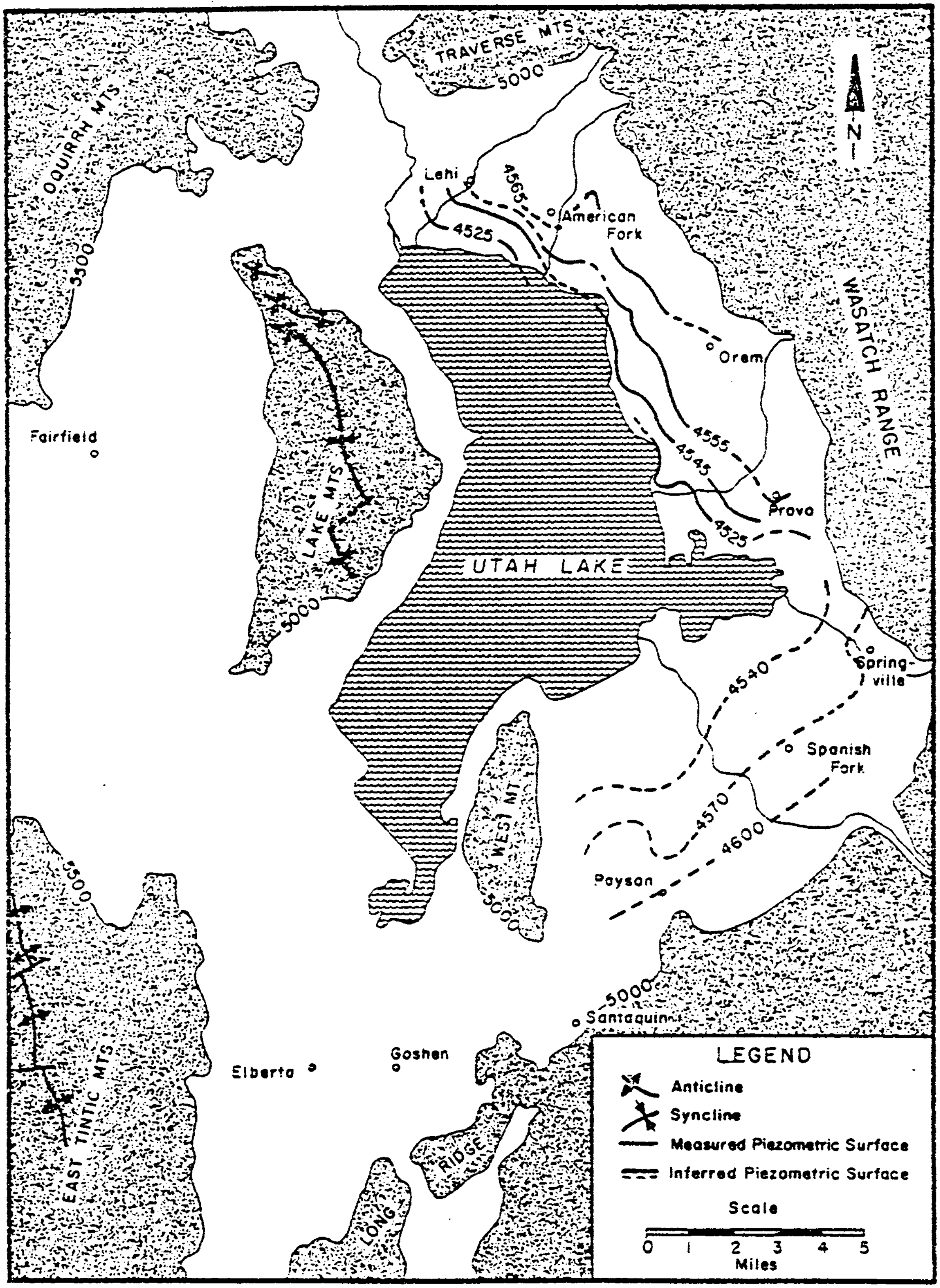


Figure 14. Piezometric contours for the Deep Pleistocene aquifer (Adapted from Hunt et al., 1953, and Cordova, 1970).

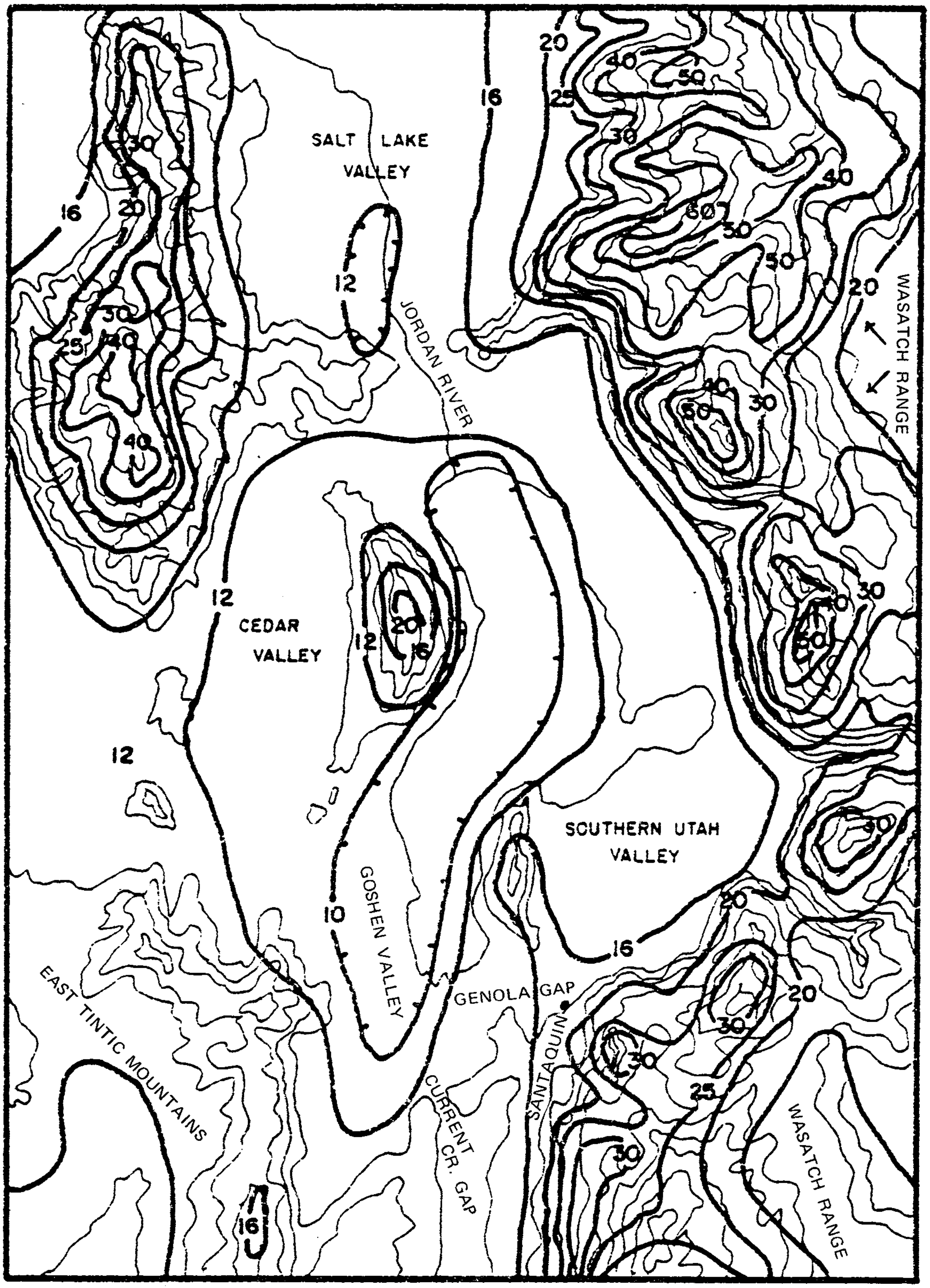


Figure 15. Isohyets depicting annual precipitation in inches. (Finer lines show topographic contours)

disregarding the subterranian bedrock recharge, 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 inflow estimates to Utah Lake would be a 70 to 80 percent increase over previous estimates (assuming it all entered the lake).

Cordova and Subitsky (1965, p. 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 mountain-front source of recharge.

In Goshen Valley some recharge comes from the East Tintic Mountains to the southwest but most comes from the Wasatch Range to the southeast; only limited precipitation falls on the East Tintic Mountains (figure 15), and piezometric contours indicate major recharge through Currant Creek Gap. The profile of the water table through Goshen and Genola gaps (figure 16) is consistent with such a theory.

Cordova (1970, p. 46) noted that West Mountain is possibly a recharge area and water may flow both east and west from there. The topography of the Santaquin/Goshen Gap area, which slopes westward as well as northward, and the lithology of the Goshen/Genola gap region (fractured limestone), suggests the possibility that the hydraulic gradient could carry some water through to Goshen Valley. But a flow would be relatively small compared to that coming through Currant Creek Gap.

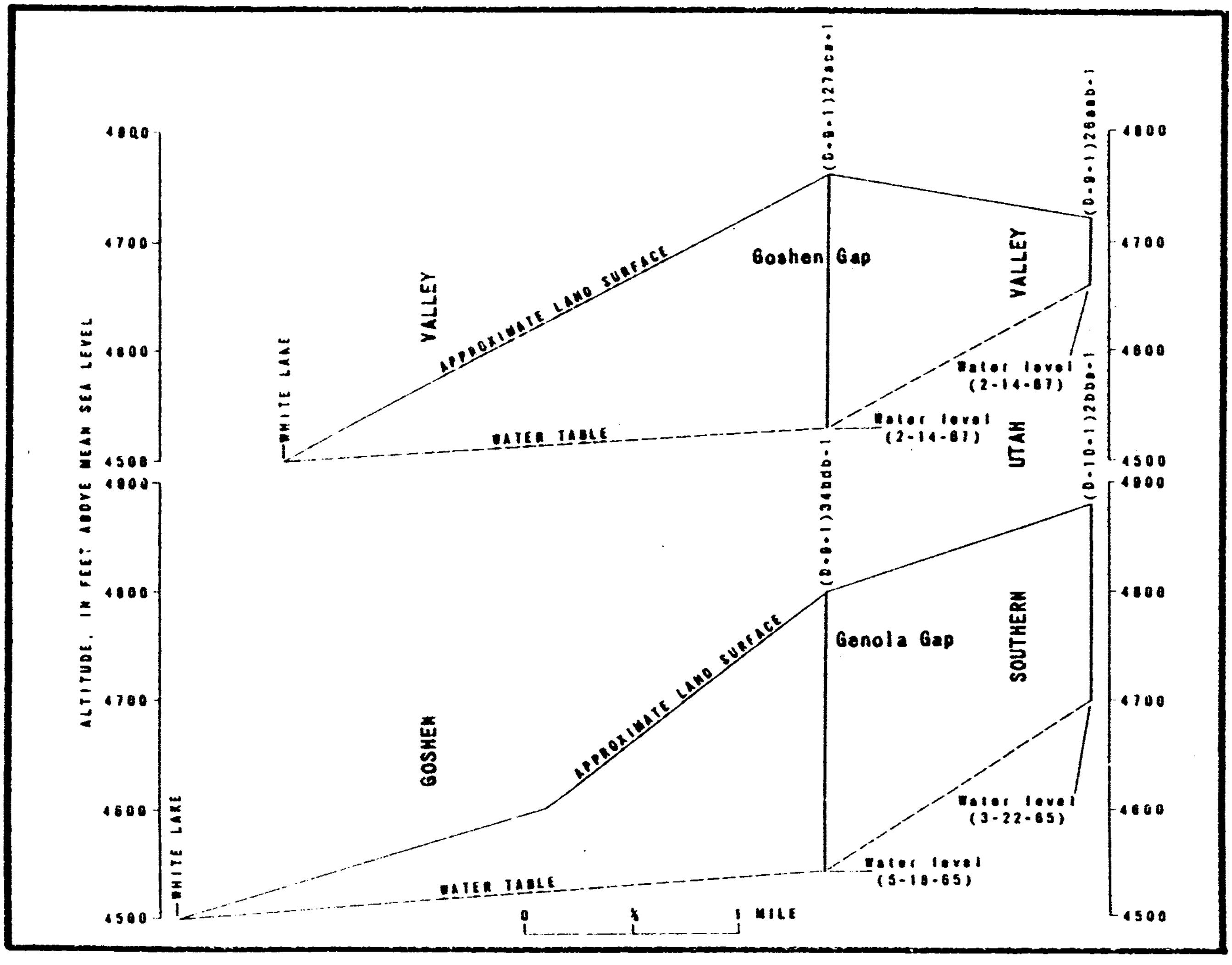


Figure 16. Profiles of the water table in the Goshen Gap and Genola Gap areas (reproduced, with permission, from Cordova, 1970).

Destination of Basin Ground-Water

Ground-water 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 the hydraulic gradient is reduced to zero. This "zero point" occurs within Utah Lake for most of the subsurface flows in the study area, but ground-water in Cedar Valley may discharge elsewhere, and some limited northern Utah Valley ground-water may flow out through the Jordan Narrows.

Cedar Valley water

Water leaves Cedar Valley in four areas (figure 12): 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. Feltis (1967, p. 13) conducted aquifer tests through mid-Cedar Valley (north-south) and then calculated the horizontal discharge through the valley fill at approximately 10,000 acre feet (12.3 x 10^6 m^3) per year. His water budget calculations, however, indicated closer to 19,000 acre feet (23.4 x 10^6 m^3) per year flowing outward from the Oquirrhs (p. 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 x 10^6 m^3) per year, a significant loss is indicated. If some of this "loss" water does exit Cedar Valley via natural pathways in Lake Mountain, then it must also exit Lake Mountain at some point or points. The nature of the rock, the alignment of the synclinal axes, and the strike and dip of the bedding planes in both the 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. Until this study, however, no major discharges into the west side of Utah Lake had been identified.

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 and others, 1953; Cordova and Subitsky, 1965). However, 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 piezometric contours, make it appear that only a minor proportion of subsurface water is lost to the north.

SISTER BASINS

One of the most intriguing aspects of the Utah Lake basin hydrogeology is the apparent upward migration of water through the overlying confining layers. The hydrogeology of the Weber Delta District and Cache Valley was investigated for evidence of a similar phenomenon.

Weber Delta District

The Weber Delta 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 geology and hydrogeology are very similar to those of the Utah Lake basin.

A hydrologic investigation within the district revealed that 20,000 acre feet (24.6 x 10^6 m^3) of discharge per year could not be accounted for (Feth and others, 1966, p. 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 were 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 groundwater 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 Great Salt Lake causeway connecting Syracuse, Utah, to Antelope Island. The 127 foot (39 meter) well, located about 0.75 miles (1.2 kilometers) northeast of the northern tip of the island, produced fresh water artesian flow of 10 gpm (6.31 x 10^{-4} m^3/s) from a depth of 97 feet (30 meters). One year later, a second well drilled about 400 yards (370 meters) west of the first well to a depth of 481 feet (147 meters) encountered two artesian aquifers. 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 aquifer 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, p. 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 (p. 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 (p. 18).

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 in Cache Valley are very thin compared to those in the Utah Lake basin. The difference in elevation between the two areas make it likely that eroding drainage from Cache Valley during most of Pleistocene time accounts for the thinness of these sediments. Most of the valley fill is 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 prevalent over a large part of the valley (Williams, 1962, p. 131-152). Conditions are not identical but are nonetheless very similar to those in the Utah Lake basin.

In 1962, 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 and others, 1942, p. 11-15). Piezometers were installed at different depths in wells and water pressure was measured simultaneously at each depth. 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.

NEW INVESTIGATIONS

Thermal Imagery

To substantiate the hypothesis that there is significant subsurface inflow in Utah Lake, it was necessary to locate the areas where this inflow occurs.

Aerial infrared imagery has been successfully used to detect such areas of inflow as shown in the study of fresh-water springs of Hawaii by the U. S. Geological Survey (USGS) in 1963 (Fischer and others, 1966), where researchers used infrared photography to positively identify some 219 previously unidentified spring discharges. The Idaho Air National Guard (ANG) (flying RF-4C aircraft out of Boise, Idaho) made preliminary thermal imagery scans of Utah Lake in conjunction with regularly scheduled training flights. Results of this initial flight were very encouraging.

A second thermal imagery scan made on November 13, 1977 from an altitude of 5,000 feet (1,524 meters) above the surface of the lake found other major thermal areas, including "Big Spring", and distinct thermal gradients evident in several other areas of the lake (figure 17). A radial pattern emanating from Lincoln Point is easily explained by the thermal springs on the point. Similarly, a 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 freshwater springs in the north shore area could produce the gradient detected there. A 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.

On December 13, a U. S. Forest Service Beechcraft King Air equipped with a special thermal scanning unit used in forest fire detection flew a complete scan of the lake from an altitude of 3,500 feet (1,067 meters) 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. Actual water temperature measurements were made at the Saratoga Boat Harbor 39°F (3.9°C), the American Fork Boat Harbor 38°F (3.3°C), the Provo Boat Harbor 37.5°F (3.1°C), and Lincoln Point 38.5°F (3.6°C) for reference purposes.

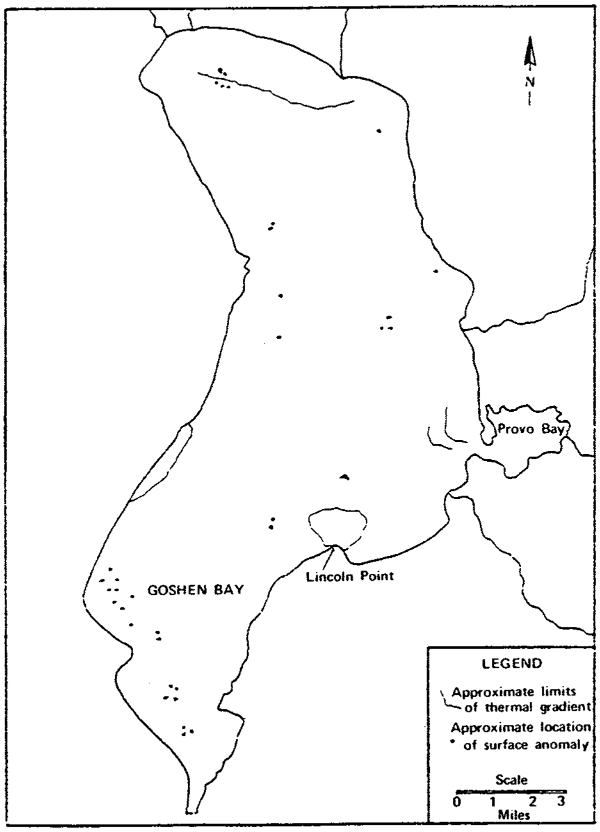


Figure 17. Indications of the 13 November 1977 ANG thermal scan.

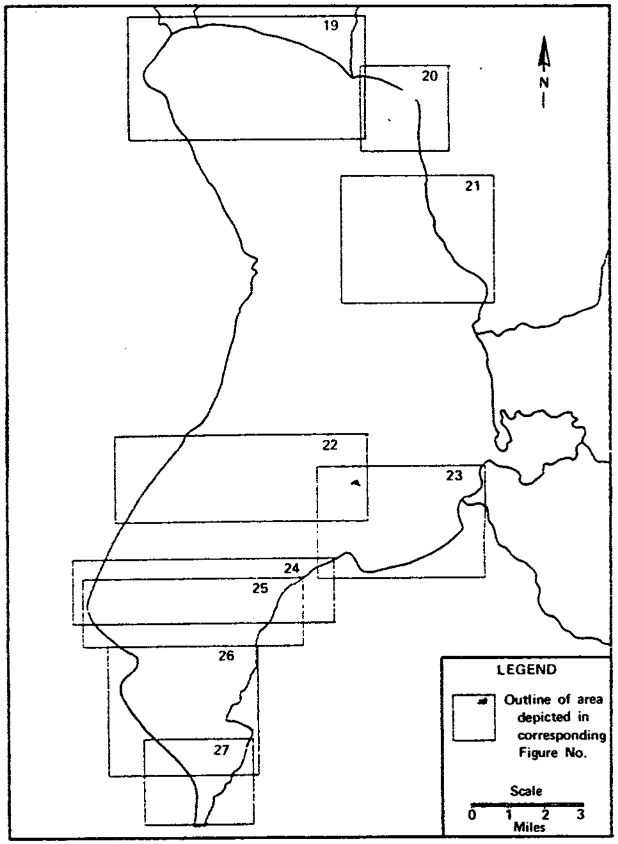


Figure 18. Areas depicted in figures 19 through 27, December 13, 1977 scan.

Figures 19-27 are positive prints of imagery 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 shoreline seeps and thermal spring areas near Saratoga are quite visible on figure 19. The influence of the group of 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 water mixing action caused by breezes. A gradient "arc" across the north end of the lake is evident here, indicating a source of "warmer" water from the north end of the lake. To the east (figure 20) 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. Thermal imagery of the Powell Slough area shows more evidence of seeps and springs (figure 21).

The areas to the west of Bird Island and north of Lincoln Point appear lighter than the surrounding water (figure 22 and 23), 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; the lightest contrast is found closest to shore and the width of the light area tends to increase toward the south.

The Lincoln Point springs and their influence are quite obvious, although Vier's (1964) spring number six does not show up. This is most likely due to submergence. 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 (figure 23).

Warmer zones exist along the east shore line of Goshen Bay, most likely due to the seeps noted by previous investigators (figures 24 through 27). A warmer area also exists in the large bay just east of the old Mosida townsite (figure 28). 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 (figure 17).

Gradients depicted over the main body of the lake in the 13 December film were pretty much as had been

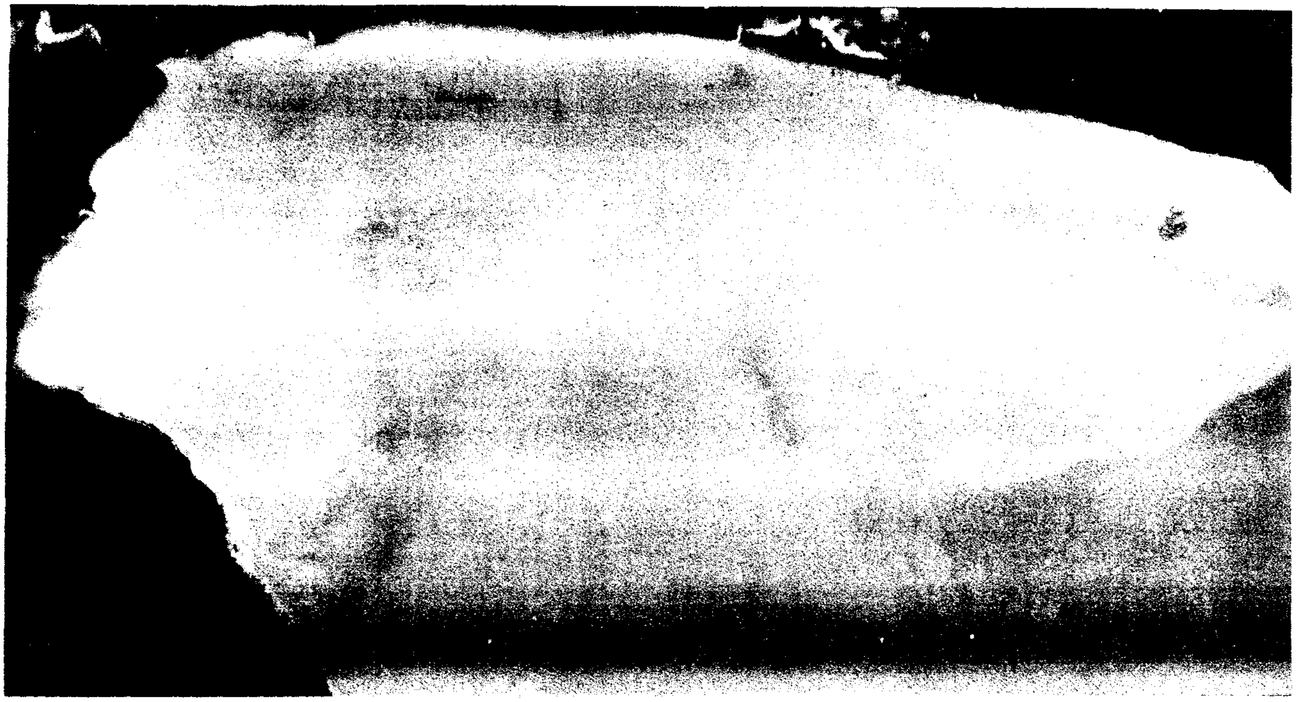


Figure 19. Thermal image of the north end of Utah Lake (USFS), (see figure 18 for location) Figures 21 - 27.

Figure 20. Thermal image of Geneva area (USFS).

expected, but the patterns along the western shoreline south of Pelican Point and in Goshen Bay were sufficiently interesting to justify another flight in an attempt to get concentrated coverage of the Goshen Bay area. On this flight the altitude was reduced to 750 feet (229 meters) AGL where equipment sensitivity increased to less than one degree centigrade and the scan width decreased from approximately 2.5 miles (4 kilometers) to less than 1,300 feet (396 meters). Unfortunately, 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, Utah, and are available for inspection and further study by interested parties. Film from the USAF flights has been donated to the Department of Civil Engineering at Brigham Young University).

Aerial Reconnaissance

In January 1978, the authors made aerial reconnaissance flights along the Utah Lake shores. Ice was just beginning to form but it was broken by 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. Numerous small sand boils were spotted 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.

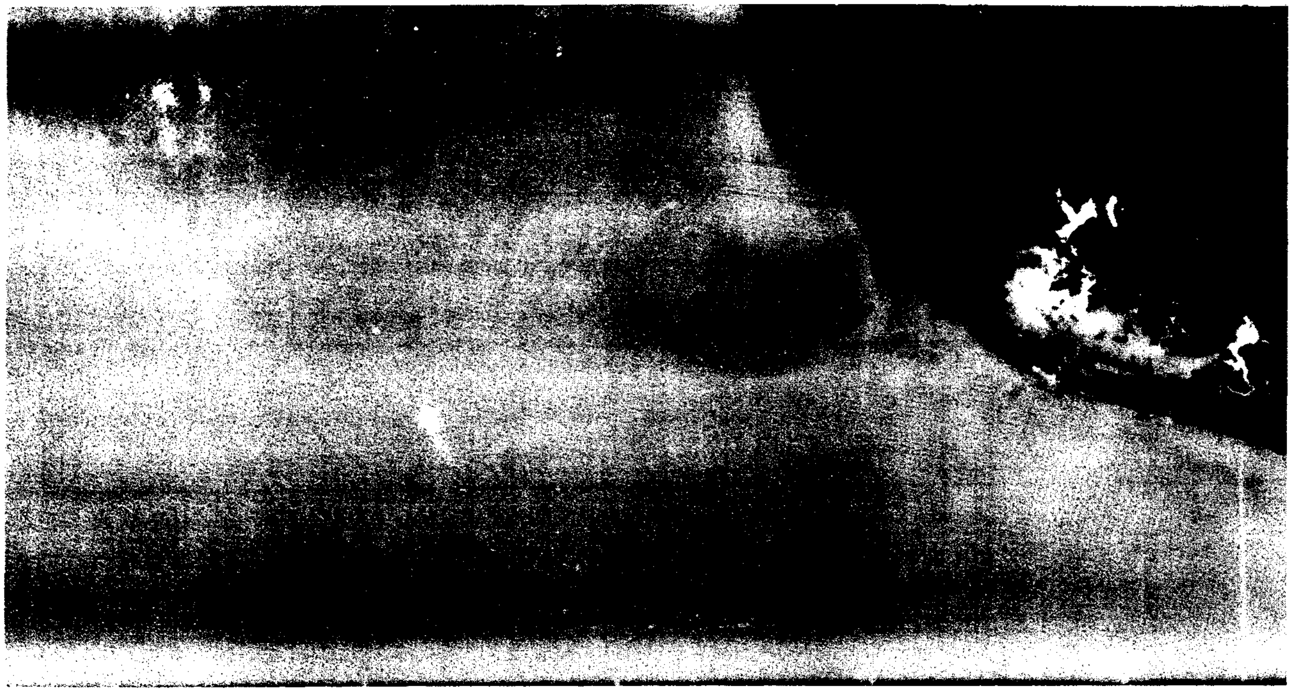


Figure 21. Thermal image of Powell Slough area (USFS).

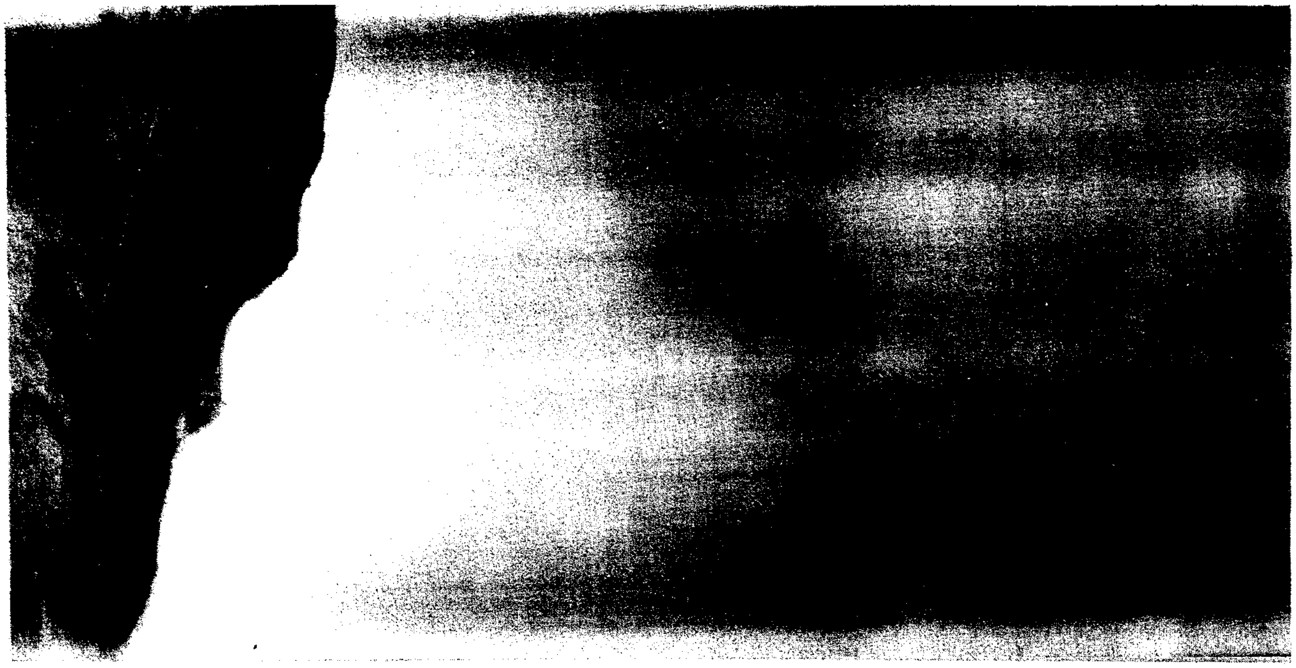


Figure 22. Thermal image of area between West Shore and Bird Island (USFS).

Only two or three small boils were spotted between Saratoga and Pelican Point, but at Pelican Point two plumes, the largest approximately 8 feet (2 meters) across, were spotted 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.

Just south of "The Knolls" was a large open water area of roughly 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

Figure 23. Thermal image of Lincoln Point area (USFS).

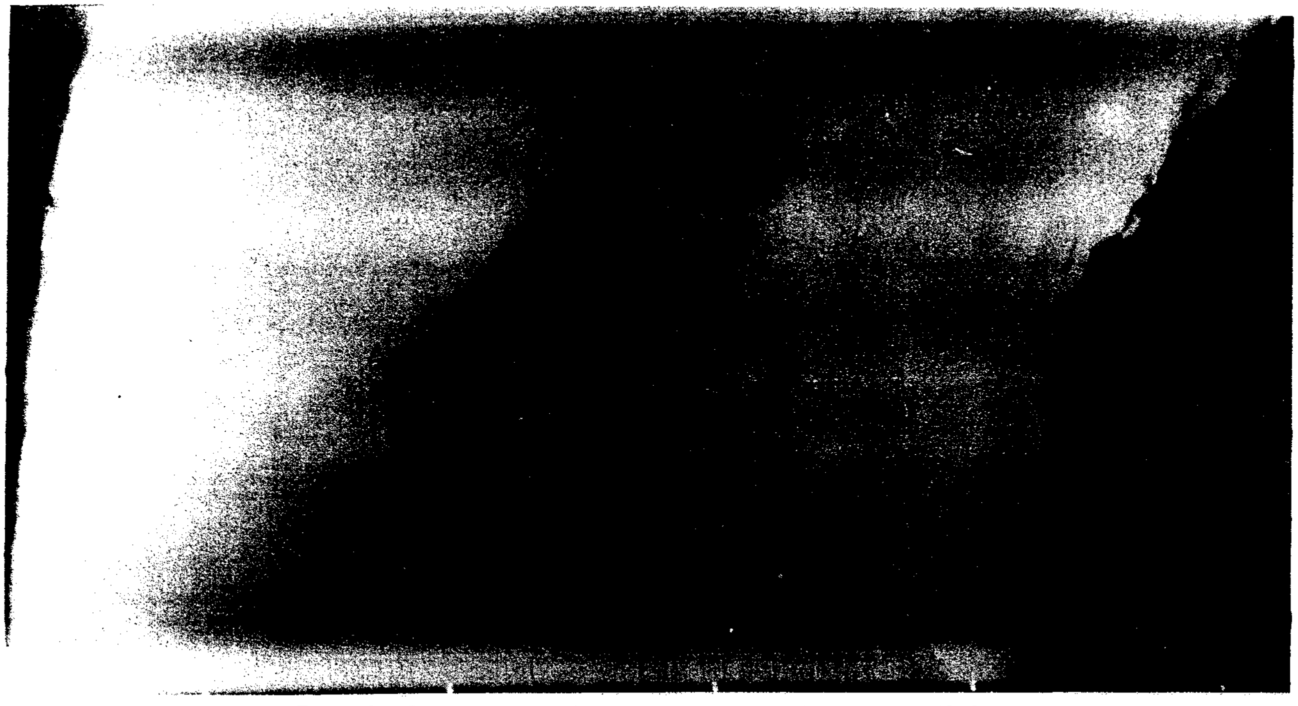


Figure 24. Thermal image of northern portion of Goshen Bay (USFS).

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.

At the large cove just east of the old Mosida townsite, midway along the western side of Goshen Bay, which was dubbed "North Mosida Cove" (figure 28), the largest single concentration of sand boils in the lake was spotted. 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.

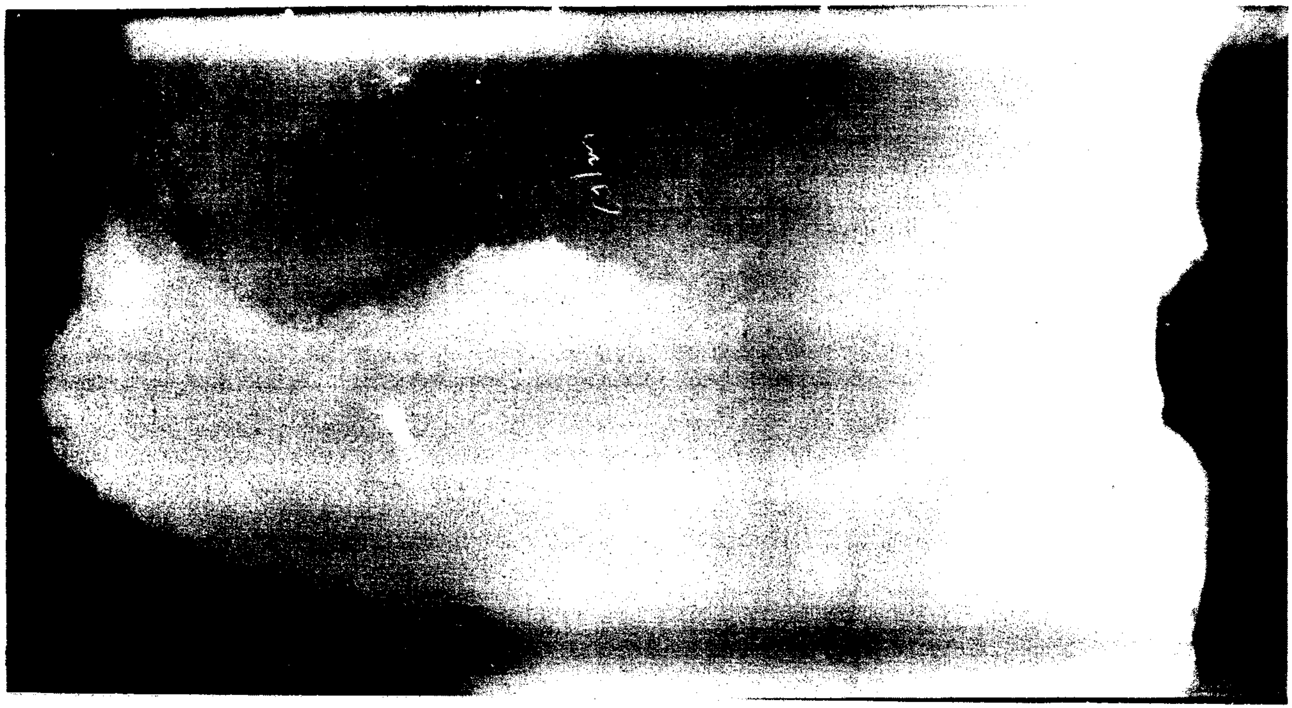


Figure 25. Thermal image of mid-Goshen Bay (USFS).

Figure 26. Thermal image of southern Goshen Bay (USFS).

Two large plumes were spotted about 1,200 yards (1,097 meters) out from the tip of "Mosida Point" (figure 28). 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.

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

Figure 27. Thermal image of south tip of Goshen Bay (USFS).

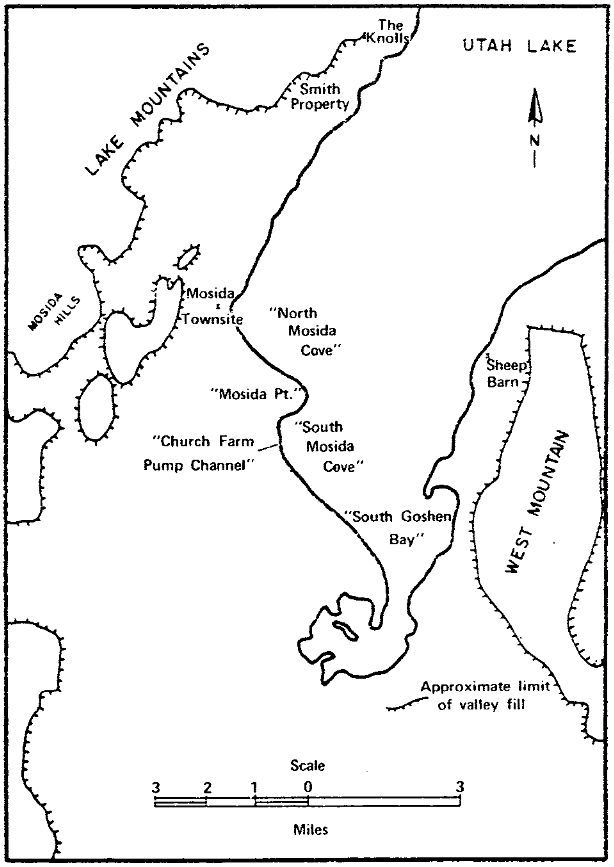


Figure 28. Geographic points in Goshen Bay.

group was located in fairly deep water approximately one mile (1.6 kilometers) out from the east shore (figure 28); the largest of the plumes appeared to be 15 to 20 feet (5 to 6 meters) across.

Two more sand boils were spotted in the area between Lincoln Point and the mouth of the Spanish Fork River in shallow water about 100 yards (91 meters) off shore. They were located approximately 1.5 and 2.5 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.

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. Even a slight breeze affects the turbidity of the lake water, which explains why these sand boils had escaped previous detection and why it would be impossible to spot them from a boat.

The numerous sand boils around the eastern and northern shores indicate that inflow is occurring over a very broad area in the northern end of the lake. In contrast, the plumes along the west side of the lake and in Goshen Bay identify very definite inflows in an area previously thought void of subsurface springs.

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 (figure 5) and with the thermal imagery anomalies for that area. The "islands" discussed in connection with Jensen's (1972) trend maps correspond with the location of the large plumes off "Mosida Point". Many of the anomalies noted on the 13 November USAF film (infrared) correspond closely with many of the sand boil locations.

Samples and Piezometric Profiles

Since most major inflows occur north from the Mosida area and tend to be located in the western half of Goshen Bay, piezometers for collecting hydrostrata data and water samples were installed in the northwestern part of Goshen Valley. Locations of piezometers and wells are shown on figure 29.

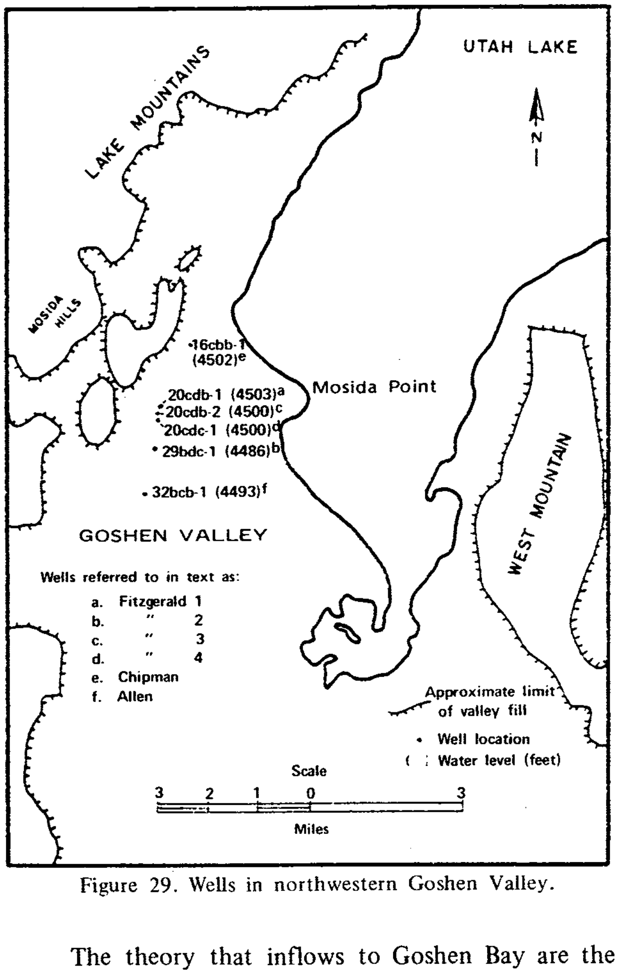


Figure 29. Wells in northwestern Goshen Valley.

The theory that inflows to Goshen Bay are the result of irrigation return flow was rejected for two reasons. The first is that sprinkler irrigation used throughout Goshen Valley is highly efficient and water losses due to surface/subsurface return flow are minimal. The second is that the land is not cultivated any further north than the "Mosida Point" area.

Water levels were checked in several wells in the northwestern part of Goshen Valley (figure 29). A hydraulic gradient away from the "Fitzgerald 1" well, both to the south and to the north, suggests 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 4,502 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 3,000 gpm from "Fitzgerald 4". "Fitzgerald 3" produces 1,902 gpm with only an eight foot drawdown after six hours of pumping. The drillers of "Fitzgerald 4" reported that fractured bedrock with very large water-filled cracks 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 for water from a southern Cedar Valley well, the combined flow of "Fitzgerald 3" and "4", and other Goshen Valley wells south of the Fitzgerald wells, is compared as follows:

1. Calcium and magnesium: 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.

2. Sodium: Fitzgerald wells have slightly higher concentrations.

3. Potassium: There is relatively little difference.

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

5. 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 that of the Cedar Valley sample than the other Goshen Valley samples.

6. Chloride: The trend is similar to that for sulfate except that Fitzgerald sample is much closer to the Goshen sample than the Cedar Valley sample by a considerable margin.

7. Dissolved Solids: The trend is similar to that for the chloride except the Fitzgerald sample is only slightly closer to the Goshen sample.

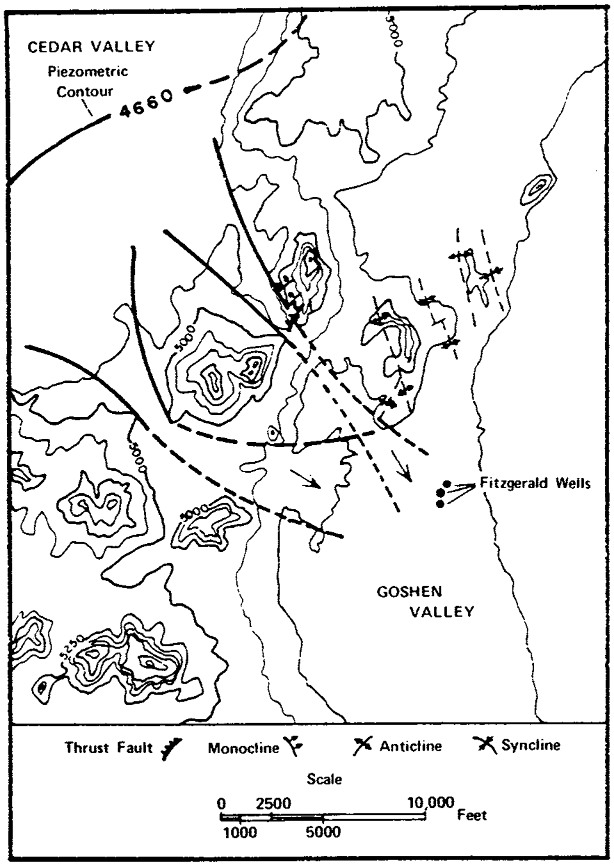


Figure 30. Most likely path for water flowing from southeastern Cedar Valley.

There is insufficient data available at present to firmly establish the source of the water in the Fitzgerald wells but if Cedar Valley ground-water were the source, the most likely path water would follow would be as shown in figure 30.

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

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 separated by thinner (usually less than a foot or .3 meter) layers of hard, cemented sand. Extremely fine sand was encountered at all levels. 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. The piezometer installed in Goshen Bay near the plume off "Mosida Point", showed a totally different situation. 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 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 laden with silt and the flow had reduced to a trickle. The pressure which forced the water up the pipe could have been attributed to the jetting rig, which is unlikely, or to the weight of the overburden, equally unlikely since the sediments are very soft, or to artesian conditions, which is most probable.

A sample was collected from this piezometer soon after sediment started appearing, which 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 1,685 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, however, all the values are comparable. While the chemical data is inconclusive 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 Goshen Bay.

Northwest Goshen Bay

Mr. Delbert Chipman (1978) (who has run sheep in the northwestern part of Goshen Valley for many years) told the senior author 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 tamarisk ". . . about a mile or so south of The Knolls. . ." as a boy.

Mr. Adelbert (Doyle) Smith, who owns the property described above (figure 28), had, a few months prior to our contacting him, 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. 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 S. 26, T. 7 S., R. 1 W. This is the same area in which the large opening in the ice 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 (figure 5). Mr. Smith described these springs as ". . . cold and clear. . ." Several years earlier, he had forced a 55 gallon drum down about three feet (1 meter) over the two northernmost 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 senior 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 lake bed 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 31.

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. It does not appear possible to channelize it for flow measurement, but the water from this beach area does not appear to be thermal. Mr. Smith said that his beach 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 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 as late as November of 1978. As additional evidence of abundant ground-water, this stretch of beach sports one of the heaviest, most luxuriant growth of tamarisk around the lake.

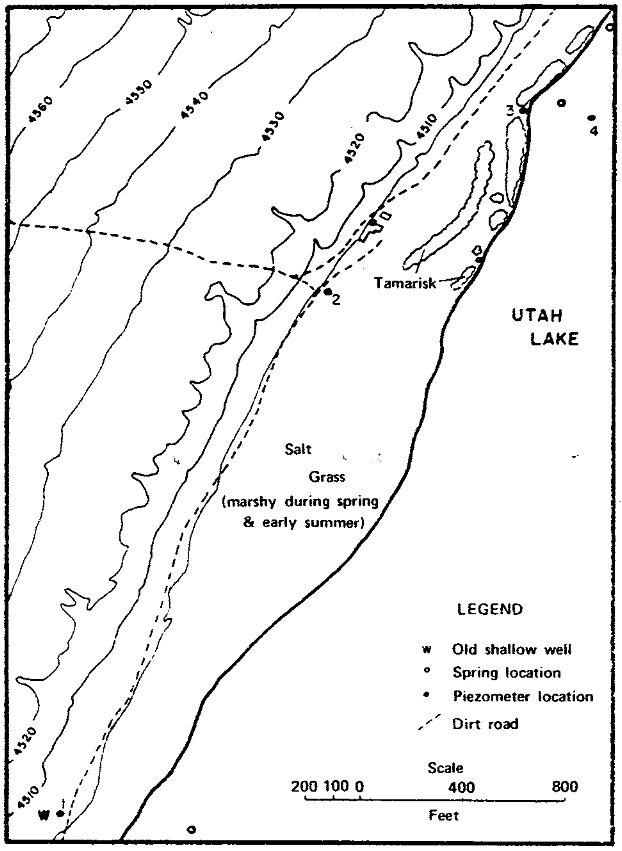


Figure 31. Well, spring and piezometer locations on the Doyle Smith Property–northwestern Goshen Bay (see figure 28 for location).

Piezometers readings. Piezometers were installed in the four locations shown in figure 21. 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. The gravel 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.

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 4,486.61 MSL. The level in the old shallow well was measured at 4,487.7 (1.1 foot difference); 4,487.5 in piezometer 1 (located 13 feet east-northeast of the well); 4,488.0 in piezometer 2; 4,487.7 in 3; and 4,487.9 in number 4. These readings show a water table gradient toward the lake 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. Water samples were collected and analyzed from the old shallow well and from the offshore piezometer. Table 5 compares these analyses with 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. The offshore sample may have been contaminated with lake water and the values shown are probably not representative, but the sample from the shallow Smith well was not diluted and is a representative of unconfined water in this area. The high concentrations of Mg, K and Na correlate with Jensen's findings. Table 5 shows the value for each parameter (except chloride and conductivity) to increase slightly toward the east side of Lake Mountain.

These increases support the theory that water escapes from Cedar Valley through Lake Mountain; such increased concentrations would be expected of water passing through limestone and dolomitic formations. The Smith property is in direct line with the axis of the major Lake Mountain syncline. Whether the groundwater on the Smith property originates in Cedar Valley or as precipitation over Lake Mountain, it seems likely that the synclinal axes direct the flow in a southeasterly direction.

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

SUMMARY

A study was made of the geology and hydrogeology of the Utah Lake basin, including a comprehensive review of the findings of other researchers. Thermal imagery, aerial reconnaissance, piezometric investigations and water chemistry were employed to identify subsurface inflow areas and the 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 confining sedimentary layers by artesian pressures; and water may move from Cedar Valley to 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, and that total annual subsurface inflow may exceed 100,000 acre feet (123 x 10^6 m^3). Most of this inflow comes into the eastern half of the lake from the Wasatch Range. Precipitation over the Oquirrh and Lake Mountains provides an additional source of groundwater to Utah Lake.

In the Goshen Bay area, previously unknown ground-water inflows were identified as a result of evidence from thermal imagery and chemical quality trends. Presence of these 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. These inflows contribute an estimated maximum of 18,000 acre feet (22.1 x 10^6 m^3) of relatively low quality groundwater to the Goshen Bay area. Some of this water originates in the Oquirrh Mountains and moves through Mosida Hills and Lake Mountain from Cedar Valley. These findings justify the consideration of additional ground-water investigations and alternative locations of the proposed Goshen Bay dike of the Bonneville unit of the Central Utah Project.

CONCLUSIONS

These conclusions are presented as answers to the six questions posed in the "problem statement":

1. Based on the hydrogeology of the Utah Lake basin, the annual volume of subsurface inflow may be in excess of 100,000 acre feet (123 x 10^6 m^3). Evidence shows that Fuhriman's latest estimate (1980) of 170 cfs (14,000 acre feet/year or 140.6 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, the presence of sizeable, previously unidentified groundwater inflows has been established 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. Artesian pressures cause diffuse seepage through much of the lake bed. Additional groundwater inflow occurs as mineralized thermal water derived from deep sources. The groundwater source(s) for the inflows discovered in Goshen Bay have not been determined conclusively, but much of this flow likely originates 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 which underlies the shallower groundwater aquifer. Thermal flows in the southern end of the lake contain more mineralization than those in the northern end. Analyses of samples from various mineral springs (Dustin, 1978) agree closely with the results reported by other investigators and indicate a fairly stable quality. The quality of the water entering the lake in Goshen Bay appears to be generally of equal to lower quality than that in the main lake, with higher conductivity and higher concentrations of bicarbonate, calcium, magnesium, potassium, sodium, sulfate, and dissolved solids.

5. A steady influx over a very broad area appears to contribute most of the subsurface inflow volume. The authors estimate that roughly 85 percent of the total subsurface inflow, approximately 102,000 acre feet (125 x 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 x 10^6 m^3) per year, occurs south of the proposed Goshen Bay dike, if 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 assessment of Brimhall's acoustical profiling indications as well as the 10,000 to 19,000 acre feet of "unaccounted for" water which may be leaving Cedar Valley (Feltis, 1967, p. 18-19).

6. The discovery of previously unrecognized groundwater inflows in the area behind the proposed Goshen Bay dike alignment require consideration of the quality of this groundwater to determine whether provisions should be made to segregate or integrate these waters with the main lake water.

RECOMMENDATIONS

Based on the authors findings, investigations in the following areas are recommended:

1. To establish conclusively whether or not Cedar Valley groundwater enters Goshen Valley, at least three test wells should be drilled 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 SE ¼ S. 23, T. 7 S., R. 1 W.; the second well 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.

2. To determine whether an upward gradient exists and to obtain data from which inflow volume calculations might be made, several piezometers should be installed in a line from the highway to the lake (1) on the Smith property, (2) near the old Mosida townsite, and (3) in S. 27 and 28, T. 8 S., R. 1 W., to establish the hydraulic gradients for these areas.

3. To test Brimhall's spring inflow theory and provide additional refinements to it, additional attempts should be made to install piezometers in Goshen Bay in the "plume" area off "Mosida Point", in such a way as to prevent contamination and sanding. The driving of small diameter, fine mesh well points from a stable driving platform may be a solution. At least two and preferably three such piezometers should be installed at each location at varying depths. 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 and others, 1976a).

4. To investigate the possibility of a recharge of percolating waters over Lake Mountain and West Mountain and to make a more accurate determination of hydraulic gradients for these areas, piezometers (wells) capable of penetrating coarse materials and/or bedrock and extending to considerable depths should be drilled.

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

6. To pinpoint other possible groundwater inflow locations in Utah Lake, a densitometric study of the thermal imagery films obtained in 1977 should be made.

7. To consider the effect of isolating the previously unidentified groundwater inflows in Goshen Bay from the main lake, plans for locations of dikes in Utah Lake should be reviewed, including legal implications, pumping provisions, and ponding/channeling arrangements behind the dike.

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