UTAH LAKE - BRIMHALL - MERRITT
Turley

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# THE GEOLOGY OF UTAH LAKE: IMPLICATIONS FOR RESOURCE MANAGEMENT

Willis H. Brimhall[1]

LaVere B. Merritt[2]

## A B S T R A C T

Utah Lake is a remnant of Lake Bonneville from which it originated about 8,000 years ago.

Analysis of sediment cores reveals significant variations in lake salinity and sedimentation rates. Notable examples are a very dry, high-salinity period between 5000 and 6000 years ago; a major freshening, wet period between 2700 and 3000 years ago; and a very dry, high-salinity period between 1400 and 2600 years ago. Smaller variations are interspersed through the lake's history.

Long-term sedimentation rates are generally about 1 mm (0.039 in) per year in most of the lake but post-colonization rates appear to be about 2 mm (0.079 in) per year. Faults in the lake appear to be lowering the lake bottom at about the same rate as sediment has been filling it. Bottom sediments consist of about 60 percent calcium carbonate in the lake proper, much of which precipitates from the water itself.

The lake bed faults are similar in character to those of the Wasatch Fault which bounds the valley and mountains a few miles to the east. Lake bottom springs and seeps are localized, in the most part, along the eastern and northern lake margins where all major tributaries occur and groundwater recharge is largest. Only limited spring activity appears to be associated with the faults.

In a geological sense, Utah Lake is an old lake — shallow, turbid and slightly saline — and has been since its "birth" with the demise of Lake Bonneville approximately 8,000 years ago.

[1]Professor of Geology, Brigham Young University, Provo, Utah 84602.
[2]Associate Professor of Civil Engineering, Brigham Young University, Provo, Utah 84602.

# GEOLOGIC HISTORY AND SETTING OF UTAH LAKE

Utah Valley, of which Utah Lake occupies more than one-fourth, lies near the junction of three of the great physiographic provinces of North America. To the west stretches the Great Basin, a vast expanse of arid intermontane valleys extending from the Wasatch Mountains to the Sierra Nevadas. To the east lies the western portion of the Rocky Mountains, expressed in central Utah by the high peaks of the Wasatch Mountains rising above the Wasatch Fault, one of the largest of the fractures of the earth's crust in North America. Not far away to the southeast is the colorful Colorado Plateau Province. The rich and varied physiographic setting of the valley and its lake suggests that they are heirs of a rich and varied natural history, the principal parts of which, for present purposes, is that associated with the past 30,000 years.

Utah Valley and its companions in the Great Basin were born in the aftermath of convulsions which seized the crust in central Utah some 70 million years ago as North America moved westward and collided with the lithosphere of the western Pacific Ocean. Huge sheets of sedimentary rock, crumpled in paroxysm, formed the ancestral Rocky Mountains of the region. Later, some 30 million years ago, the crumpled rocks began to be blocked into intermontane valleys by high angle faults, one of the most famous of which is the Wasatch Fault which bounds Utah Valley on the east (Fig. 1). Recurrent movements on these faults continue to the present time, and thus maintain the intermontane basins in spite of erosion and infilling of sediments from the highlands.

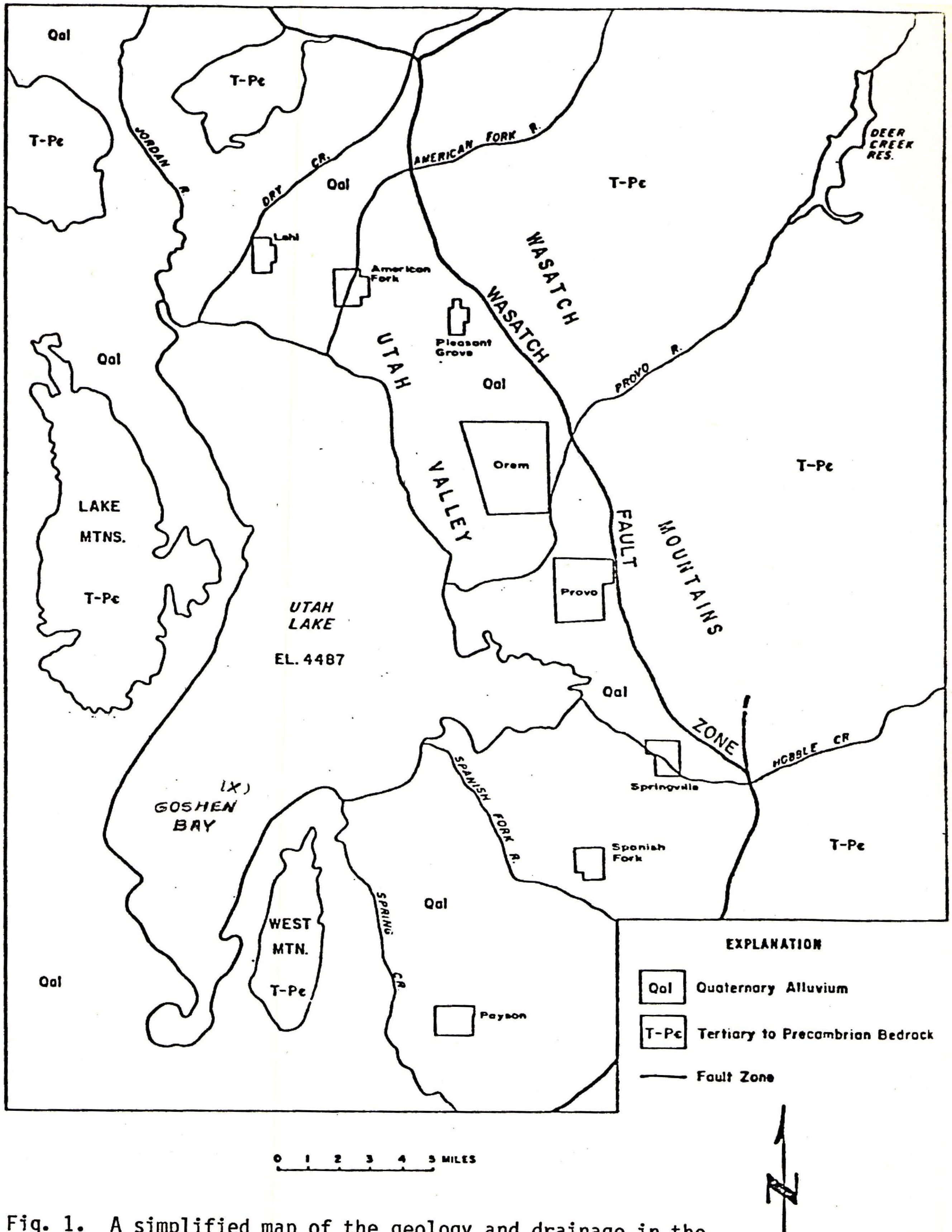


Fig. 1. A simplified map of the geology and drainage in the vicinity of Utah Lake (modified from Fuhriman et. al. 1980).

Note (x) marks the approximate location of the core taken in Goshen Bay.

The high angle faults are the principal structures contributing to the intermontane physiography. Rock waste eroded from the rising mountains has been transported downward and deposited in the valleys. Probably sediment as thick as several thousand feet occupies the central portions of Utah Valley (Cook~~, K. L.,~~ and Berg~~, J. W.,~~ 1961); similar thicknesses of rock have been worn away from the ever-rising mountains. A dynamic equilibrium seems to have been maintained for some 30 million years between the uplifting of the mountains and the downdropping of the valley on the one hand, and of erosion and infilling on the other.

Lake Bonneville (Fig. 2), the ancestor of Utah Lake and the Great Salt Lake, occupied the intermontane basins to a greater or lesser extent from about 75,000 years ago to about 8,000 years ago (Gilbert~~,~~ 1889; Bissell~~,~~ 1968). Lake Bonneville coincided in time with Wisconsinan Stage of the Pleistocene Epoch; that is, with the last stage of the Great Ice Age which so profoundly affected planet Earth during the past 1 million years or so.

The size and depth of Lake Bonneville is recorded in the layers of sediments accumulated on its margins and floor. The lake was largest during times of cool, wet climates; smallest in times of warm, dry climates (Bissell~~,~~ 1968). The level and extent of the lake fluctuated through three principal levels, designated the Alpine, Bonneville, and Provo substages (Fig. 3). At its highest level, some 30,000 years ago, Lake Bonneville spilled over into the Snake River drainage at Red Rock Pass near Preston, Idaho (Fig. 2), and quickly dropped from about 1555 meters (5200 feet) above sea level to about 1460 meters (4800 feet)

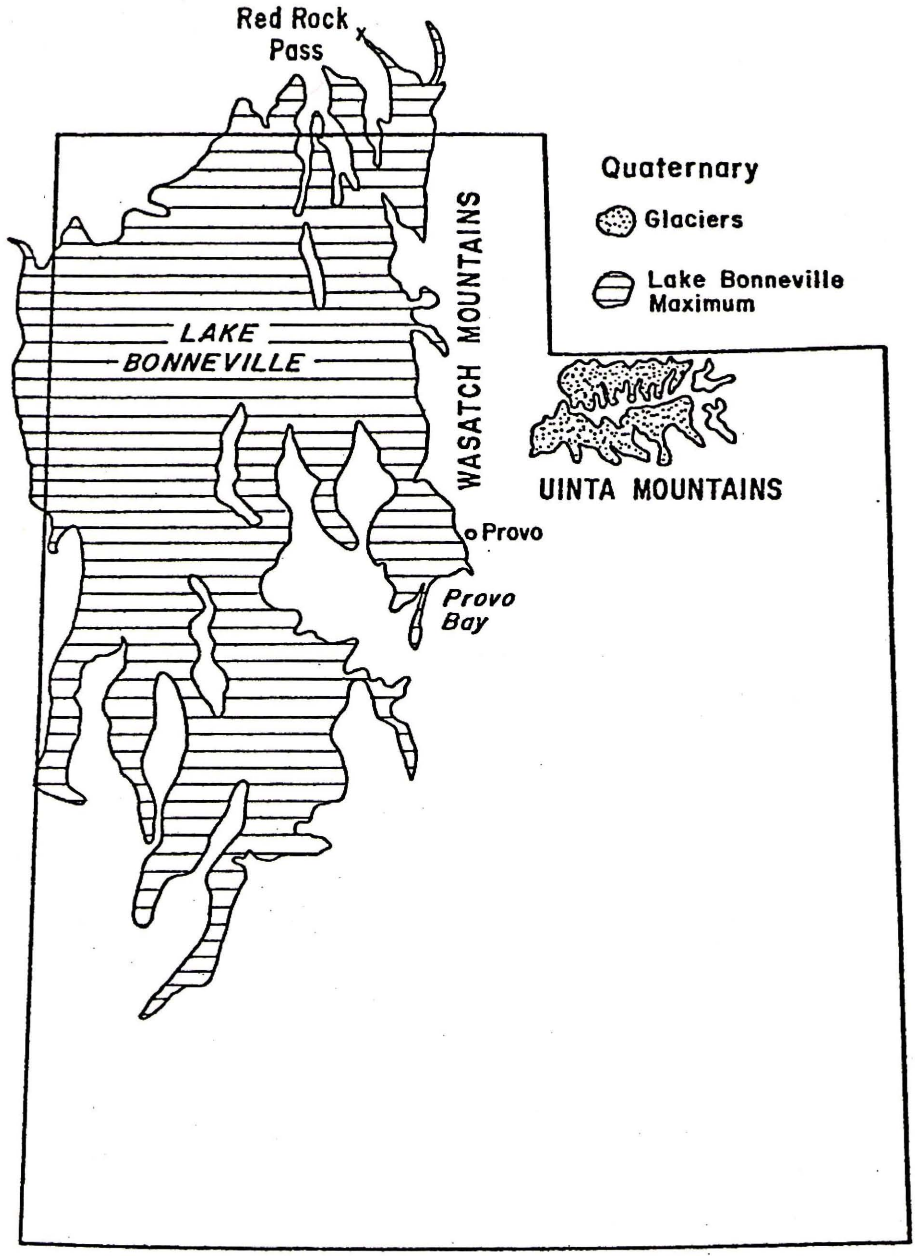


Fig. 2. The distribution of Lake Bonneville at its maximum size. (Adapted from Bissell, 1968)

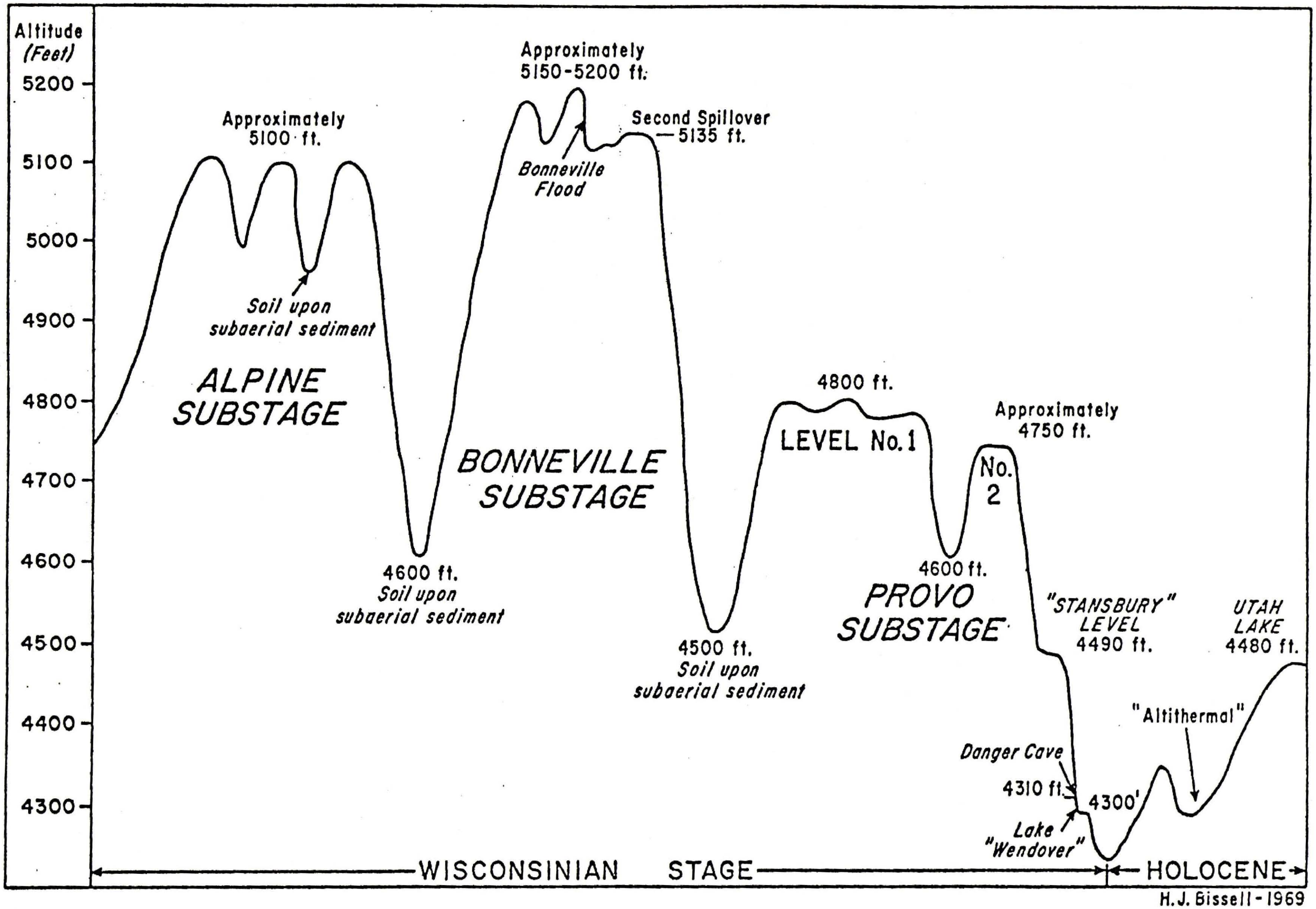


Fig. 3. Elevations associated with the principal substages and lesser fluctuations of Lake Bonneville. Lake Bonneville dried up and passed from existence at the end of the Wisconsinian Stage, some 10,000 years ago. Utah Lake originated in the aftermath of Bonneville's passing, and is associated with the Holocene Epoch, 10,000 years ago to the present. (Adapted from Bissell, 1968)

where the lake stabilized at the Provo substage, with fluctuations, until about 8,000 years ago.

The relatively long period of stability of Lake Bonneville at the Provo substage led to the formation of some prominent benchlands, such as those at Orem, Mapleton, and Spanish Fork. These alluvial benchlands, formed where the rushing rivers met the lake, are among the most striking topographic features of Utah Valley.

The climates of North America generally became warmer and drier at the end of the Pleistocene (Great Ice Age) Epoch some 10,000 to 12,000 years ago. Ice sheets formerly occupying much of the northern portions of the continent began to retreat. In the Great Basin, Lake Bonneville passed from existence, and in the aftermath the Great Salt Lake and Utah Lake were formed.

Utah Lake, born and orphaned of Lake Bonneville, records its nearly

8,000

10,000 years of history in its sediments. ~~G. H.~~ Hansen (1934) was first to recognize that variations of sand, silt, clay, and plant remains, including wood, exposed in a test pit northwest of the mouth of Provo River, associate with strong changes of the level of the lake and of changes of climate in the region during the past few hundred to thousands of years. Hansen did not assign ages to the variations; the carbon 14 dating method was not available at the time.

Bolland (1974) collected a core sample, 500 cm (197 in.) deep, at a point about 2.5 km (1.6 miles) west of Geneva in the late summer of 1970, to study the presettlement history of Utah Lake by means of sediment changes and variations in fossil diatoms. The core (Fig. 4) consisted of nearly

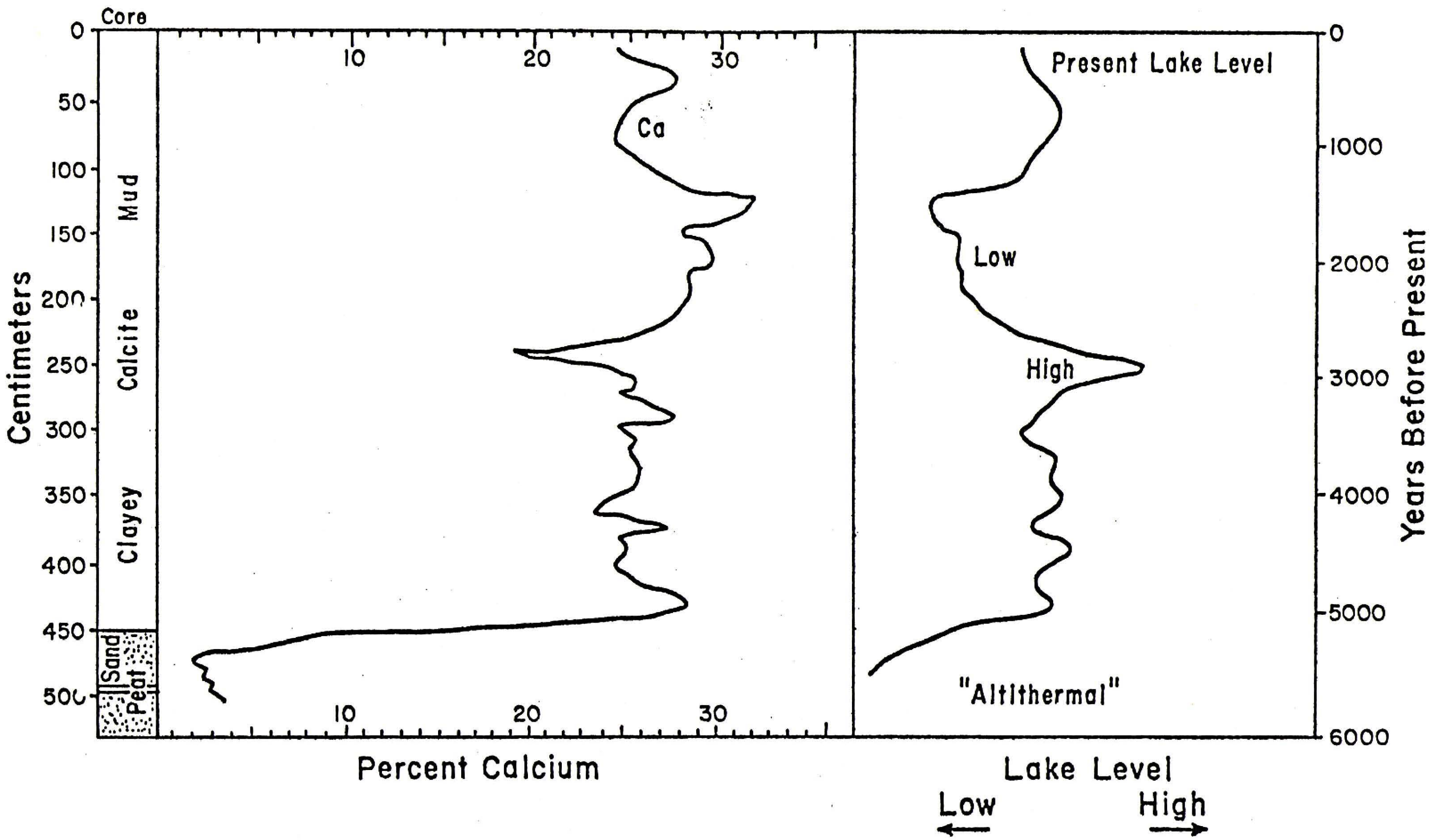


Fig. 4. Characteristics of a core sample of Utah Lake sediments collected approximately 2.5 km west of Geneva. High concentrations of calcium (calcite) are believed to associate with low levels of the lake as compared to recent levels. The sand and peat layers below 450 cm are believed to correlate with the altithermal, a time of extreme aridity described by Antevs (1948). (Adapted from Brimhall, 1973).

uniform gray silt to a depth of 450 cm. (175 in.) Below that depth, to 510 cm (201 in), the core consisted of fine quartz sand with a small layer of peat at 490 cm (193 in). The change from silt to sand and to peat clearly indicates that at some time in the distant past, Utah Lake was much lower and smaller than at present, since the sand and peat must associate with an ancient shoreline which must have persisted over a considerable period of time. Bolland submitted a sample of the peat, weighing 1.8 grams (0.004 lb.), to Radiocarbon Ltd., Spring Valley, New York, for dating. The result was 11,400 ± 800 years.

Brimhall (1973) performed a chemical analysis of the major constituents of the core and assigned some time lines based on apparent inputs of iron from the steel plant, phosphorus from sewage, and other criteria, but evidence obtained during the summer of 1975 (Brimhall, Bassett, and Merritt~~,~~ 1976) make these data appear to be in error. ~~It is~~ We believe~~d by the present writers~~ that the 11,400 ± 800 year old dating of the peat layer is at least twice too large. Contamination of the sample with small amounts of detrital calcite could cause the result to be too high.

Based on data from the latter study, and reassignment of time lines in the core, it is presently believed that the sand layer at the bottom of the core correlates with a very dry period recognized in the Great Basin some 4,000 years ago (Antevs~~,~~ 1948). The beginnings of Utah Lake are believed to associate with sediments about 4 m~~eters~~ deeper than the bottom of the core sample, as shown in acoustical profile (Fig. 5). If this assignment is correct, as we believe, then approximately 8.5 m~~eters~~ (28 feet) of sediment have accumulated since the beginning

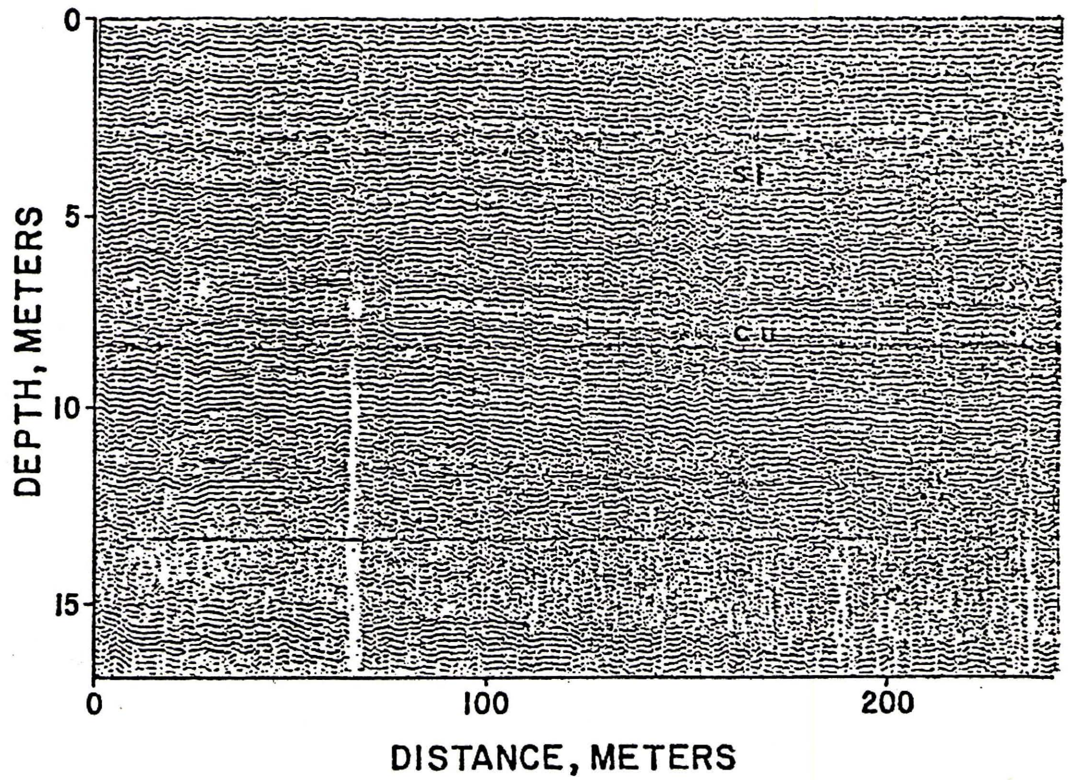


Fig. 5. Acoustical profile of sediments in the vicinity of the sample collected and analyzed by Bolland (1974) and Brimhall (1973). The reflection at about 4 meters is believed to correlate with the sandy layer (sl) described by the above workers, and the second, stronger reflection at about 8.8 meters is believed to correlate with the clay unit (cu) of the Provo Formation, deposited in the waning stages of Lake Bonneville.

of Utah Lake. The average rate of accumulation of sediment is approx-mately 8.5 m~~eters~~ (28 feet) in 10,000 years, or 0.00085 m~~eter~~ (0.033 inch) per year (0.85 mm per year).

Assuming a linear rate of deposition, the sane layer with its contained peat was deposited between 5300 to 6000 years ago during a long, dry period called the "altithermal" by Antevs (1948).

Variations of the calcium content of the cores between 18 and 32 (X) percent (Fig. 4) are believed to associate with fluctuations of lake level caused by short-term wet and dry cycles of several years' duration, not as large as those associated with the sandy and peat layers. Rises in calcium content associate with decreased inflow during dry periods, continued large evaporation loss from the lake surface; and thus, an increased concentration of salts in the lake, including calcium and car-bonate, hence, increased precipitation of calcite (calcium carbonate). Under natural conditions, lake level could vary at least 2 m ~~two meters~~ (6.6 feet) since the flow rate in the outflowing Jordan River is a function of lake level. The lake level is a function of inflow, outflow, and evaporation over time.

Inspection of the calcium profile ~~in~~ (Fig. 4) reveals some pronounced variations of concentration in the upper half of the core. Unusually high concentrations occur between 120 and 220 cm (47 and 87 inches), and unusually low concentrations are present between 230 and 250 cm (90 and 98 inches). Assuming that the high concentrations correlate with low lake level and size, and the low concentrations with high lake level and size, and assuming an average sedimentation rate of 0.85 mm/year (0.033 in/yr) to be approximately true, then the lake was small and shallow between 1400 and 2600 years ago, and larger and deeper between 2700 and 3000 years ago.

The profile also reveals that the level of the lake has fluctuated to a lesser extent than the above extremes during the past 1000 years. The sharp peak at about 25 cm (9.8 in) is believed to associate with a very dry period in the southwestern U.S. some 400 years ago, based on tree ring data (Schulman, 1956). It should be noted, however, that the upper 10 cm (3.9 inches) ~~centimeters~~ of the core sample was imperfectly obtained since the sediment-water interface was not sharply defined.

Reports have been made commonly in the news media in recent years that Utah Lake was a clear blue lake in precolonization times, but the geological aspects of the lake as reflected in its sediments, make the claim seem doubtful. Most of the reports by early settlers of the pristine quality of Utah Lake associate with diary accounts in which observers viewed Utah Lake from such distant points as Point-of-the-Mountain, or from nearshore localities where rivers emptied into the lake. Under these conditions, it is understandable that observers would conclude that the lake was clear. But the sediments in the lake, most of which were accumulated well before the coming of man into the valley, record that the lake has been a geologically old lake for a long time, stretching back to Lake Bonneville, and perhaps beyond. It is believed that geological factors are still the controlling factors in the lake, although human interaction and impact on the lake are important in some local areas of the lake, particularly along the eastern shoreline.

Although Utah Lake has existed less than 10,000 years, a relatively short time in the span of geologic time, it is nevertheless an old lake from a geological point of view. The chief characteristic contributing to its senescence is its shallowness. At present, its average depth is about 2.7 meters (9 feet) (Fig. 6), which contributes greatly to its turbidity, large evaporation losses, hence slightly saline waters, and warm summer temperatures, hence abundant communities of algae.

In summary, the geological setting and history of Utah Lake is rich and varied. The lake lies in one of the most scenic regions of North America. Climatic changes occurring in the region over the past 75,000 years, and especially the past 10,000 years have been spectacular, for they range from very wet to very dry, and the record of these changes is ~~recorded~~ preserved in the sediments of the lake as well as in other natural systems such as tree ring growth.

It is clear that these prehistoric changes occurred essentially independent of the influence of man except in the past century or so. Natural forces still appear to dominate the lake as a whole although some man-caused influences are locally important. ~~and~~ The potential exists, under the influence of continuing growth of populations in the surroundings, ~~to cause~~ for man-made influences to dominate. Whatever the outcome in the future, the geological history of Utah Lake will continue to give a useful perspective on the management of the lake and its resources.

# SEDIMENT CHARACTER AND TRENDS IN UTAH LAKE

Previous Work. Bissell (1942) published a preliminary report on the character of the sediments in Utah Lake. Sonerholm (1973) has described the broad outlines of the mineral compositions of the sediments of the lake, and their distribution. Bingham (1975) has described the major trends of the particle sizes contained in the sediments, and their distribution through the lake. Brimhall (1973) has studied the character of sediment in a core sample, 520 cm deep, to determine the broad outlines of the Holocene (recent) geologic history of the lake, and Brimhall, et. al., (1973) conducted a reconnaissance study of the sediments of Utah Lake, Holocene to upper Pleistocene age, by means of an acoustical profiler. The latter investigation yielded significant information, heretofore unavailable, on the character and distribution of deep-water springs and of the geologic faults in the lake floor, both of which are of importance to resource management.

Sediment Types. Utah Lake is characterized as a carbonate-type lake because the principal constituent of its sediment is calcium carbonate, $CaCO_3$, whose mineral name is calcite. The compound as found in the lake is not pure, but carries small concentrations of magnesium, strontium, and other impurities. Quartz and other forms of silica is generally the next most abundant constituent, followed by clay minerals of the illite and montmorillonite and mixed layer types.

Locally, near the mouths of the major rivers joining the lake and near the existing shorelines where wave action if vigorous, quartz is concentrated in long, narrow ribbons of sand.

The shallowness of the lake intensified the interaction of the water with sediment. During heavy storms the waves generated on the lake have sufficient amplitude to stir much of the lake floor, which contributes to the strong turbidity of the water, which in turn imparts the impression of pollution although this turbidity results from a natural process. The sediment-water interface on the lake floor is not generally sharply defined, but is gradational. Core samples collected during the summer of 1975 indicate that the transition zone from water to sediment is usually about 0.5 m~~eter~~ (1.6 feet). The consistency of the sediment in the transition zone ranges from thin to thick soup. The upper margins of these sediments are frequently stirred by storms and by bottom-dwelling organisms. This is a leading factor in the turbidity (quality) of the water; and the condition is due in the main to natural rather than man-caused processes. Based on the character of sediment core samples and the configuration of the valley floor, it appears that this condition has existed throughout the life of the lake.

Distribution of Calcium Carbonate. Sonerholm (1973) collected 140 samples of bottom sediment from localities spaced on a 1-mile grid, and analyzed them chemically to determine the ~~chemical~~ composition of individual samples and the distribution of the elements throughout the lake. From these data, he determined the mineral constituents and trends for the lake as a whole. The contour map of calcite content ratio shown in Figure 7 is a statistical trend surface map which shows only the broad patterns present in the data.

Throughout most of the lake calcium carbonate exceeds 50 percent (dry weight) of the sediment. In two principal areas, the concentration exceeds 70 percent. The first and largest of these extends from the middle of the lake opposite Provo Boat Harbor to the western midportion of Goshen Bay. The second and smaller area lies in the northwestern portion of the lake between Pelican Point and Saratoga Springs. The pattern observed is easy to explain. Calcium is transported to the lake by surface waters and by sub-surface waters. The valley and mountains surrounding the lake, and the sediment and bedrock beneath the lake are composed in the main of limestones and, to a larger extent, sandstones, or combinations. Most of the calcium arrives in solution, but some arrives as particular matter suspended in surface waters. Calcite is precipitated from lake water as evaporation increases the calcium and carbonate concentrations and by calcite depositing algae and other micro-organisms abundantly present in the interior of the lake. The particles thus formed are tiny, ranging in the silt and clay size (from less than 1/16 mm to submicroscopic dimension). Such particles are too small to settle readily in the near-shore regions where wave action is vigorous. Consequently, they accumulate more in the central parts of the lake.

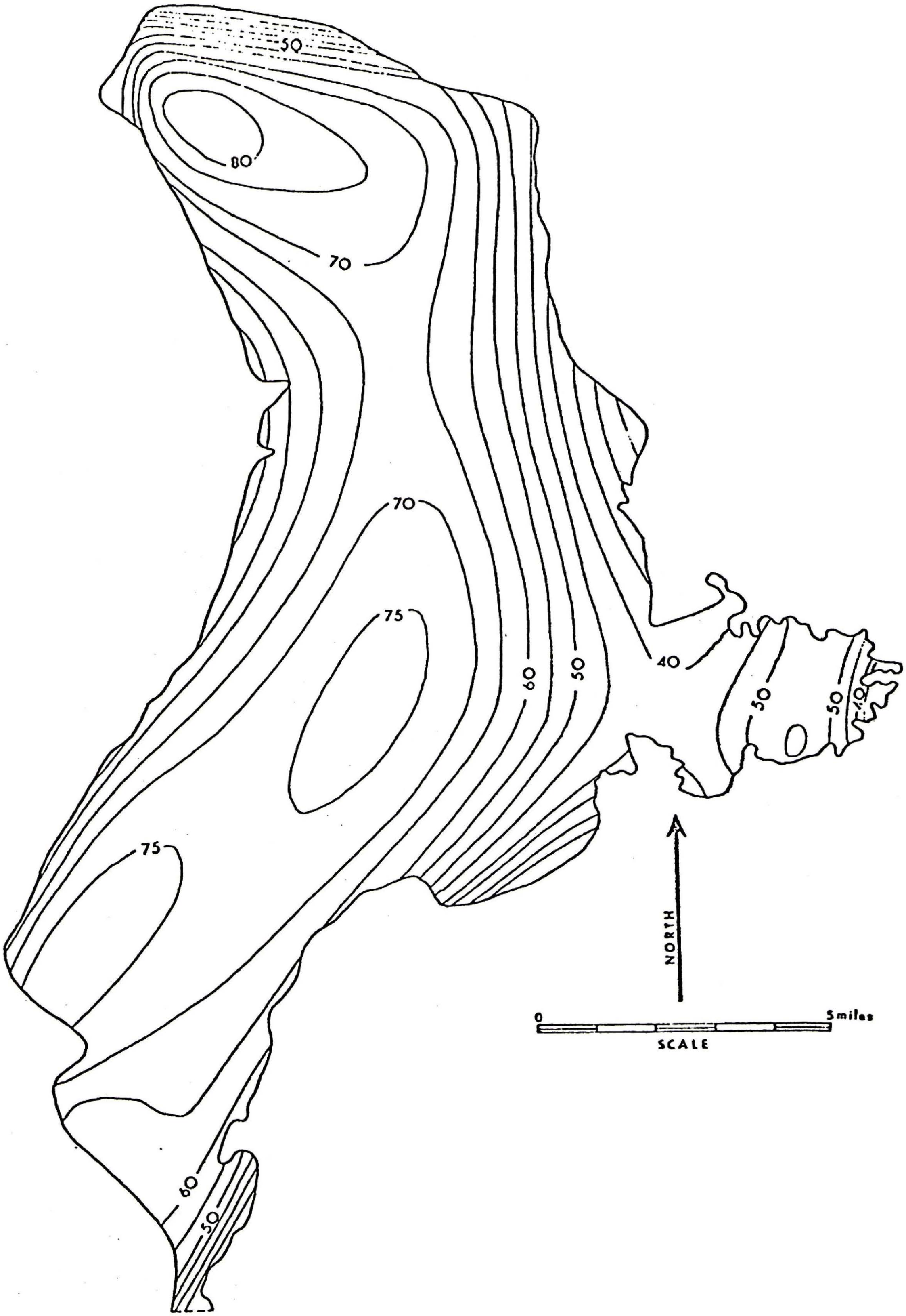


Fig. 7. Sixth degree trend surface map of calcite concentrations in Utah Lake sediments. Contours are in weight percent, dry sediment. (Adapted from Sonerholm, 1973)

~~are too small to accumulate largely~~ settle readily ~~in the nearshore regions where wave action is vigorous.~~ ~~Consequently, they accumulate~~ more ~~in the central parts of the lake~~.

The unusually high concentration of calcite in the northwestern portion of the lake associates with ~~[illegible]~~ thermal springs, striking faults (see later section of this paper), and with an unusually large concentration of organic matter in the sediments, presumably derived from ~~[illegible]~~ higher biologic activity in the area (Bingham~~,~~ 1975).

Distribution of Silica. Silica, as used in this report, means any of the several forms of silicon dioxide present in the lake sediments. These may include quartz, $SiO_2$, or hydrated and/or amorphous forms of variable composition which may be associated with organisms such as diatoms which gather silica from water and sediment to form their shells.

Inasmuch as calcium carbonate generally exceeds 50 percent of the sediment, and silica comprises most of the remainder, the distribution of silica shows an inverse pattern to that of calcium carbonate; in short, the carbonate dilutes the silica. Silica ranges from near 50 percent of the dry weight of sediment in the nearshore regions to less than 15 percent in the regions occupied by high carbonate concentrations.

No ¶ Again, the pattern is not difficult to explain. Quartz is a hard, durable mineral, as are the other forms of silica, when compared to calcium carbonate. Moreover, the individual grain sizes tend to be larger than those associated with carbonate. These two factors, plus the input of quartz in sediment from the major rivers, and wave action nearshore tends to deposit the ~~substance~~ calcium carbonate in the nearshore portions of the lake. ~~Moreover, the~~

~~energy of the waves in the nearshore tends to concentrate the silica at the expense of carbonate because the size of the silica grains is generally larger and less susceptible of transport to the deeper sections of the lake.~~

Distribution of Clay Minerals. The term "clay" is used commonly in two different meanings, both of which are used in literature bearing on this report, so a clarification must be made as to the meaning of the term. Clay on the one hand refers to any natural inorganic substance whose constituent particles are less than 1/256 mm in size. Clay, on the other hand, refers to any of a family of mineral aluminosilicates whose constituent elements are structures in sheets and whose individual particles are typically less than 1/256 mm in size. In this paper, the term clay refers to the latter definition.

NoP The clay minerals of Utah Lake, ranging generally between 5 and 10 percent (dry weight), belong to the illite, montmorillonite, and mixed layer types.

The pattern of clay mineral distribution in Utah Lake is not easily defined because, among other things, it is a minor constituent diluted by carbonate and silica. Areas of high concentration, 9 percent or more, are located in the vicinity of the delta of the Spanish Fork River, and near the mouths of the Provo and American Fork Rivers (Sonerholm, 1973). It is clear that the source of the clay minerals is the detritus carried by the major rivers emptying into the lake. Longshore currents tend to disperse the clay minerals to the deeper waters adjacent to the shorelines.

Bingham (1975), studying the distribution of particle sizes of sediment, reports that most of the sediment of the interior of the lake is composed of particles in the silt and clay size range. He, of course, uses the term clay in the first of the senses described above. It is clear that much of Bingham's "clay" is in reality very fine grained calcium carbonate.

Minor Constituents. Minor constituents of the sediment of Utah Lake are numerous, but in the main, they consist of calcium sulfate, probably as gypsum, iron oxides and/or sulfides, and organic material of varying kinds.

No? Of course, water is a major constituent of the natural sediment. It ranges from a few percent to as much as 75 percent or more, depending on sediment type and location.

An area of relatively large organic concentration is present to the southeast of Saratoga Springs (Bingham, 1975). Provo Bay carries a large concentration of organic material due to natural and man-caused biologic activity. Powell and Benjamin Sloughs also bear large concentrations of organic matter.

Summary Statement on Sediment-Community Relationships. Bingham (1975) concludes that available evidence leads to the conclusion that plant communities of the lake do not associate with specific sediment types. Invertebrate animals, he says, tend to be more selective. Worms, midge flies, gastropods, bivalves and ostracods prefer the carbonate muds of the open lake. Small crustaceans are found in the small, local exposures of tufa, hard rock deposits of calcium carbonate, in the vicinity of Bird Island and Lincoln Beach.

The present writers believe that a detailed study would reveal a stronger association between sediment types and various plant and animal communities. The properties and distribution of sediments, in broad outline, have only been learned in the past few years, and much remains to be learned of the plant and animal communities present in the lake.

Sedimentation Rates. Accumulation of one stratum upon another in sequence of time permits the calculation of an average rate of sedimentation when the absolute age of two different strata can be determined. In the instance of the core samples from Utah Lake, the uppermost stratum associates with the present time. The age of older, deeper layers may be determined by radiocarbon dating, by association with known geological or climatological events in the past, by introduction of components such as chemical contaminants or pollen grains from plants introduced by man, etc.

Sedimentation rates in geologically young lakes (deep and not subject to large sediment inflows) are typically a few tenths to a few hundredths of a millimeter per year. In Utah Lake, a shallow and geologically old lake, sedimentation rates are expected to be much higher, probably in the range of ~~one millimeter~~ 1 mm to ~~one centimeter~~ 1 Cm per year, depending on the portion of the lake under consideration. Rates are likely to be highest in the vicinity of the mouths of the major rivers, and in the deeper parts of the basin where gravity pulls the soupy water-sediment mixture

Acoustical profiling during the summer of 1975 (Brimhall, Bassett, and Merritt, 1976) permitted the recognition at depth of a very persistent layer, the upper surface of which ranges between ~~eight~~ 8 and ~~fifteen~~ 15 m~~eters~~ (26 and 49 feet) deep, and whose thickness appears to range between 5 and 10 m~~eters~~ (16 and 33 feet). The stratum is believed to associate with a dark gray, silty clay which was found at that depth during exploratory drilling for the proposed Goshen Bay dike (U.S. Bureau of Reclamation, 1964). The position and lithology of the stratum suggest that it is the clay unit of the Provo Formation (Hunt, Varnes and Thomas, 1953; Bissell, 1963), deposited in deep water some 10,000 years ago just before the demise of Lake Bonneville. If the assignment is substantially correct, and the age is likewise correct, the average sedimentation rate in the deeper portions of the lake ranges between 0.8 and 1.5 mm (0.031 and 0.059 inches) per year. These values are consistent with rates observed in similar lakes, and with the known inputs of clastic and dissolved material to the lake (Fuhriman, et al., 1975).

The average sedimentation rate, 3.3 cm/year (0.13 inches/yr), calculated by Brimhall (1973) is now believed to be ~~about ten~~ more than 10 times too large. Most of the data presented in that paper can be reconciled with the rates tentatively assigned above by reassigning the times given to the upper 25 cm (9.8 inches) of sediment instead of the upper 250 cm (98 inches). It must be emphasized that all of these assignments are tentative, but the latest assignments are most consistent with new knowledge gained in 1975, and with comparison of Utah Lake with similar lakes. One of the most urgent problems associated with the lake is the matter of establishing its pre-settlement history by means of taking several core samples to 20 m~~eters~~ (66 feet) deep, to delineate that history. In the meantime, the sedimentation rates and history of the lake must remain known only within ~~very~~ broad terms.

During the summer of 1975, ~~seventeen~~ 17 shallow core samples, ranging from 30 cm to 120 cm (12 to 47 inches), were collected in various parts of the lake. Cores taken lakeward from the Geneva waste pond showed a mixture of cinder or slag with sand and lime silt. The relative proportions indicate an average sedimentation rate, for the natural components of the sediment, of about 5 mm (0.2 inches) per year. Another core taken southeast of Saratoga Springs in organically rich sediment showed a highly organic layer at a depth of 400 mm (15.7 inches). Tentatively, this layer is assigned to a low level of the lake thought to exist about 400 years ago when drought conditions persisted over the region (Schulman~~,~~ 1956). If the assignment is correct, the average sedimentation rate at this locality, is about 1 mm (0.039 inches) per year.

No ¶ Features in the other cores are not easily recognized, and so no additional information is available from them at this time.

GEOLOGIC STRUCTURES IN LAKE SEDIMENTS

Previous Work. Two geologic maps of the bedrock and alluvial deposits in Utah Valley have been published. That of Hunt, Varnes, and Thomas (1953) describes the northern half of the valley whereas that of Bissell, (1963) describes the southern half. Neither of these maps show faults or geologic structures in the vicinity of Utah Lake or of the rest of the valley except for the Wasatch Fault at the base of the Wasatch Mountains. The absence of the structures from the maps does not mean that these investigators concluded that none exist, but rather that erosional processes make them unrecognizable.

The measurement and description of gravity anomalies in the vicinity of Utah Valley lead Cook and Berg (1961) to recognize the probable existence of faults in the floor of Utah Lake. Stokes (1962) plots three inferred faults extending in a general northwestward direction along the east side of Utah Valley. The first of these stretches between the east side of West Mountain to the vicinity of Saratoga Springs. The second, from Payson to the middle of Utah Lake, and the third, from the mouth of Spanish Fork Canyon to Orem, American Fork, and Lehi. Markland (1964) demonstrates the probable existence of a fault near Arrowhead Resort.

Cluff, Brogan, and Glass (1975) investigated the Wasatch Fault in Utah Valley with respect to land use planning. Cluff, Hintze, Brogan, and Glass (1975) have also investigated the Wasatch Fault in northwestern Utah as regards recent to current seismic activity and recent fault displacements in Pleistocene strata. Geomorphic evidence, as well as tree ring data, indicate that recent faults in the zone of the Wasatch Fault may be no older than a few hundred years.

Faults. As an outgrowth of a reconnaissance study of the deep-water springs of Utah Lake by means of a sonar-like device (Brimhall et. al. ~~Bassett and Merritt,~~ 1976), an unusual opportunity was afforded to study the faults and other geologic structures present in the strata underlying the lake to a depth of as much as 25 ~~meters~~ m (82 feet). The faults beneath the lake are sometimes remarkably displayed (Fig. 8) by the reflection profiles obtained by sending pulses of sound waves into the lake floor, and by recording the reflections, or "echoes" from the strata and structures beneath.

Heretofore, geologic structures of this kind, less than 10,000 years old (Pleistocene to Holocene age), have only been inferred to exist in the lake floor by extensions of faults observed in bedrock or alluvium in the lake surroundings, and by geophysical measurements such as gravity anomalies. Now, for the first time, the existence, character, and distribution of the faults in the lake floor have been observed. This section sets forth these findings and reports their significance as they apply to the history of Utah Valley and the management of the resources of the lake and its surroundings.

Three major faults (Fig. 9) are herewith designated as the Bird Island Fault, the East Goshen Bay Fault, and the West Goshen Bay Fault, which along with several minor faults and a few folds which were discovered, mapped and characterized by acoustical profiling in the

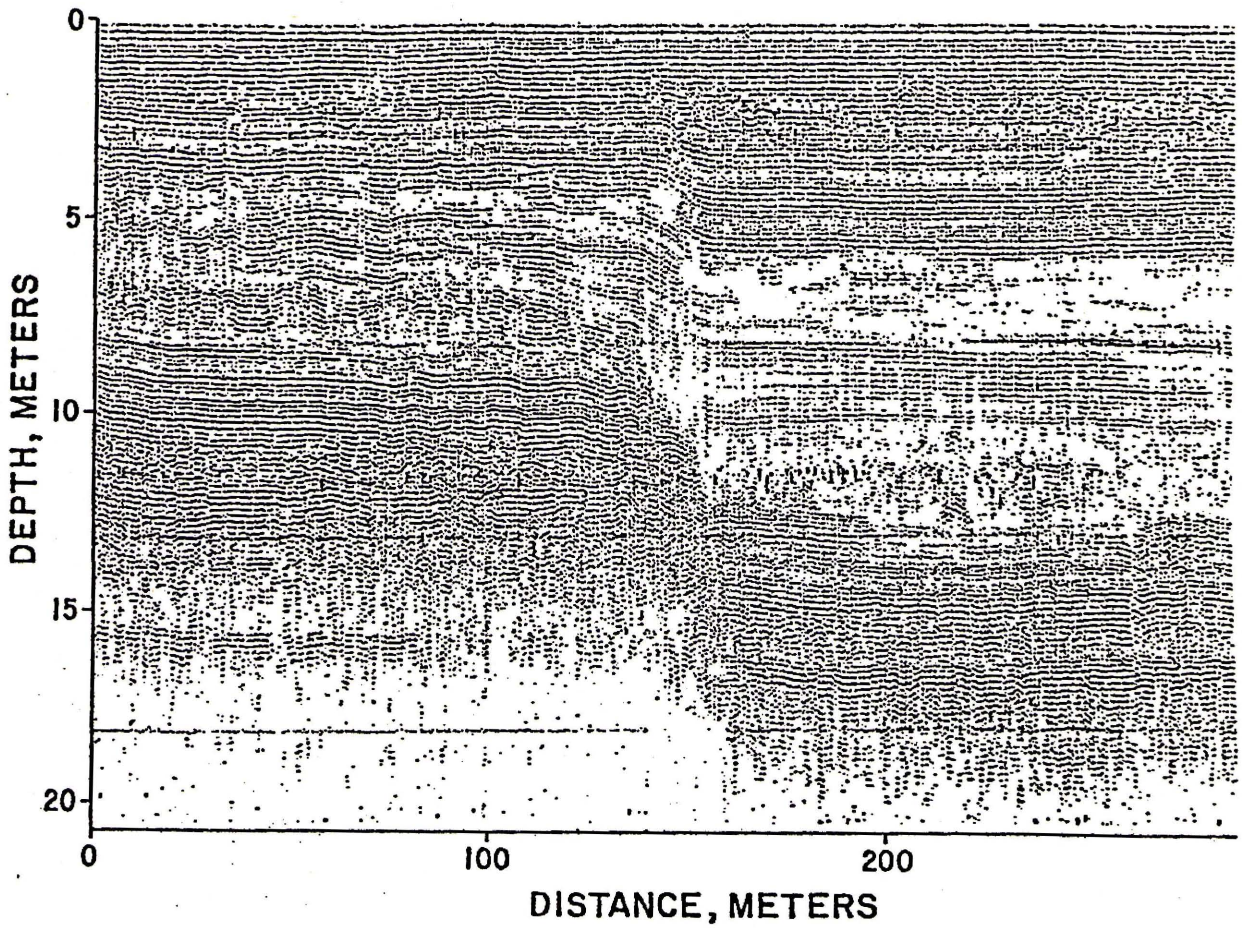


Fig. 8. The East Goshen Bay Fault, 2.4 km west of Lincoln Point. The top of the profile marks the present lake floor. The lower, dark layer on the left, whose top is 8 meters below the floor, is offset on the right by about 5 meters to a depth of 13 meters. This stratum, a persistent marker stratum throughout the profiles, is believed to be the clay unit of the Provo Formation, uppermost Pleistocene age.

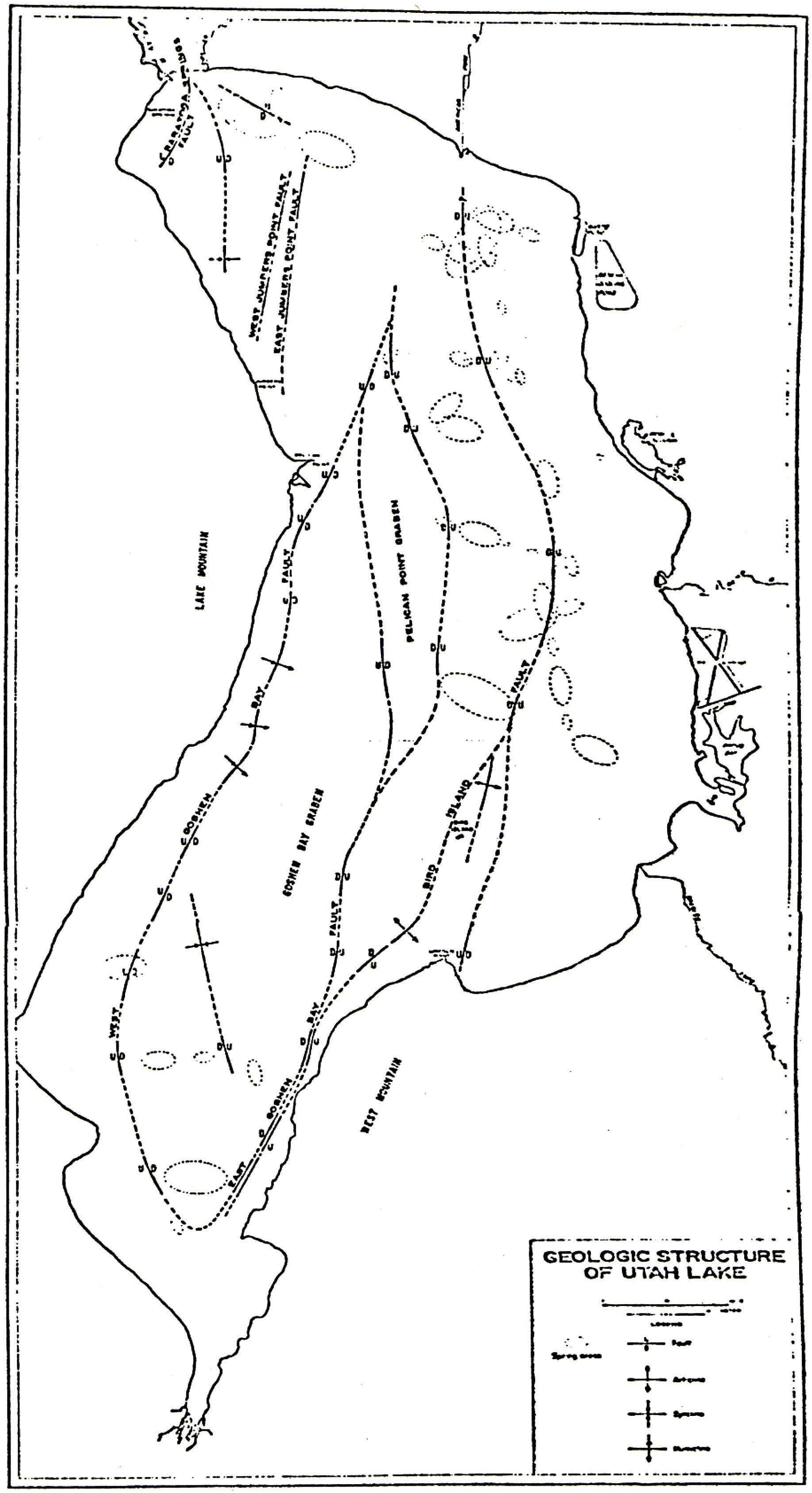


Fig. 9. The principal geologic structures present in the floor of Utah Lake, and the location of the presently known spring areas. (Adapted from Brimhall, Merritt and Bassett, 1976)

summer of 1975. These structures exhibit characteristics which are consistent with faults mapped elsewhere in the valleys by previous workers, and they add considerable detail to the knowledge of the structural geology of these valleys.

No ¶ The faults are furthermore of considerable interest as regards resource management inasmuch as some of the major areas of the lake appear to be controlled to some degree by the distribution of faults in the lake floor.

Bird Island Fault. Bird Island Fault (Fig. ~~10~~ 9) extends northeastward from the eastern part of Goshen Bay to the west side of Bird Island. It then continues northward opposite the mouth of Provo River, and then passes slightly west of north to the vicinity of the mouth of the American Fork River.

No ¶ The western side of the fault is downthrown relative to the eastern side. Observed Holocene displacements (past 10,000 years) range from ~~two meters~~ 2 m (6.6 feet) to less than ~~one half meter~~ 0.5 m (1.6 feet). Generally, the larger displacements occur at the extremities of the fault.

The eastern fork of the Bird Island Fault leaves the main fault and passes southward about 3 ~~kilometers~~ km (1.9 miles) north of Bird Island, and is inferred to pass to the west of the Island toward the east side of West Mountain. The fault is clearly evident in the acoustical profiles just eastward of Lincoln Point. Since the eastern side of the fault is downthrown nearly ~~two meters~~ 2 m (6.6 feet), it is clear that the block including West Mountain and Bird Island stands structurally high (horst).

One could be lead to believe that the coincidence of the northern portion of the Bird Island Fault where thermal springs exist with a major spring ~~area~~ zone on the eastern side of Utah Lake (Brimhall, ~~Bassett, and Merritt,~~ et. al., 1976) accounts for the location of the springs, but the writers are of the opinion that the fault is at most only a contributing factor. Hydrologic and sedimentation factors are thought to be dominant because only a minority of the spring areas is shown to be directly associated with the fault.

East Goshen Bay Fault. The East Goshen Bay Fault forks at a point about ~~two and one-half kilometers~~ 2.5 km (1.6 miles) west of Bird Island (Fig. ~~10~~ 9). The main portion extends southward from the juncture to a position west of, and parallel to, the Bird Island Fault in the eastern section of Goshen Bay. Adjacent to West Mountain the two faults are in such close proximity that they may be expressions of a compound fault rather than two separate, distinct faults.

No ¶ Westward of Lincoln Point, the fault exhibits approximately ~~five meters~~ 5 m (16 feet) of displacement. The western side of the fault is downthrown to form a portion of the Goshen Valley Graben.

From the juncture, the east fork of the East Goshen Bay Fault passes first northeastward then northwestward through the approximate midsection of the lake to a point about ~~five kilometers~~ 5 km (3.1 miles) northeast of Pelican Point. The west fork of the fault passes northward of the juncture to the vicinity of Pelican Point where it appears to rejoin its partner northeast of Pelican Point.

The interior block bounded by the two forks of the fault is displaced downward relative to the other blocks; hence, the interior block is a graben designated as the Pelican Point Graben. It represents the lowest point of Utah Valley from a structural standpoint.

Displacements of the faults bounding the graben range from about 1 m ~~one meter~~ (3.3 feet) to less than 0.5 m ~~one-half meter~~ (1.6 feet). The larger displacements are found on the southern side of the graben. In general, the displacements are smaller than those associated with the Bird Island Fault.

The section of the lake occupied by the Pelican Point Graben appears to have very little spring activity associated with it (Brimhall~~,~~ et. al.~~,~~ 1976). Spring activity along other portions of the fault likewise appear to be slight.

West Goshen Bay Fault. The West Goshen Bay Fault extends from the southern portion of Goshen Bay, where it may converge with and join the East Goshen Bay Fault (Fig. 9), to the vicinity of Pelican Point where it appears to join the east and west branches of the East Goshen Bay Fault. The eastern side of the fault is displaced downward which makes the block bounded by West Goshen Bay Fault and its partner to the east, a graben which is designated as the Goshen Bay Graben. Displacements on the fault range from approximately 2 m ~~two meters~~ (6.6 feet) to less than 0.5 m ~~one-half meter~~ (1.6 feet). Southward of Pelican Point 5 ~~five~~ or 6 km ~~six kilometers~~ (3.1 or 3.7 miles), the fault is replaced with a monocline which dips gently to the east.

Spring activity along the fault is very weakly expressed as shown by the reconnaissance study of Brimhall, et. al (1976).

<u>Minor Faults</u>. The East and West Jumbers Point Faults, through minor faults in terms of lenth, exhibit some of the most spectacular displacements to be found in the lake. Figure 10 shows the acoustical profile obtained over the northern portion of the West Jumbers Point Fault. A similar fault is displayed on the southern section of the East Jumbers Point Fault. Displacements on the faults ranged from about 5 m ~~five meters~~ to about 1 m~~eter~~ (16 to 3.3 feet). The eastern blocks are displaced downward relative to the western. The unusual offsets on these faults indicate that the section of the lake occupied by these faults is active tectonically. The only other fault to compare is the East Goshen Bay Fault just west of Lincoln Point (Fig. ~~ure~~ 8).

None of these faults, as observed in profile, exhibited spring activity at the several points transected, although it is entirely reasonable to suppose that there are springs at places along the faults.

Another small fault, named the Saratoga Springs Fault, lies about 1 km ~~kilometer~~ (0.6 mile) east of Saratoga Springs Resort. The eastern side of the fault is displaced downward approximately 1 m ~~one meter~~ (3.3 feet) as seen in profile. Almost certainly, some spring activity is associated with the fault, but such activity was not determined conclusively in the acoustical profile transects.

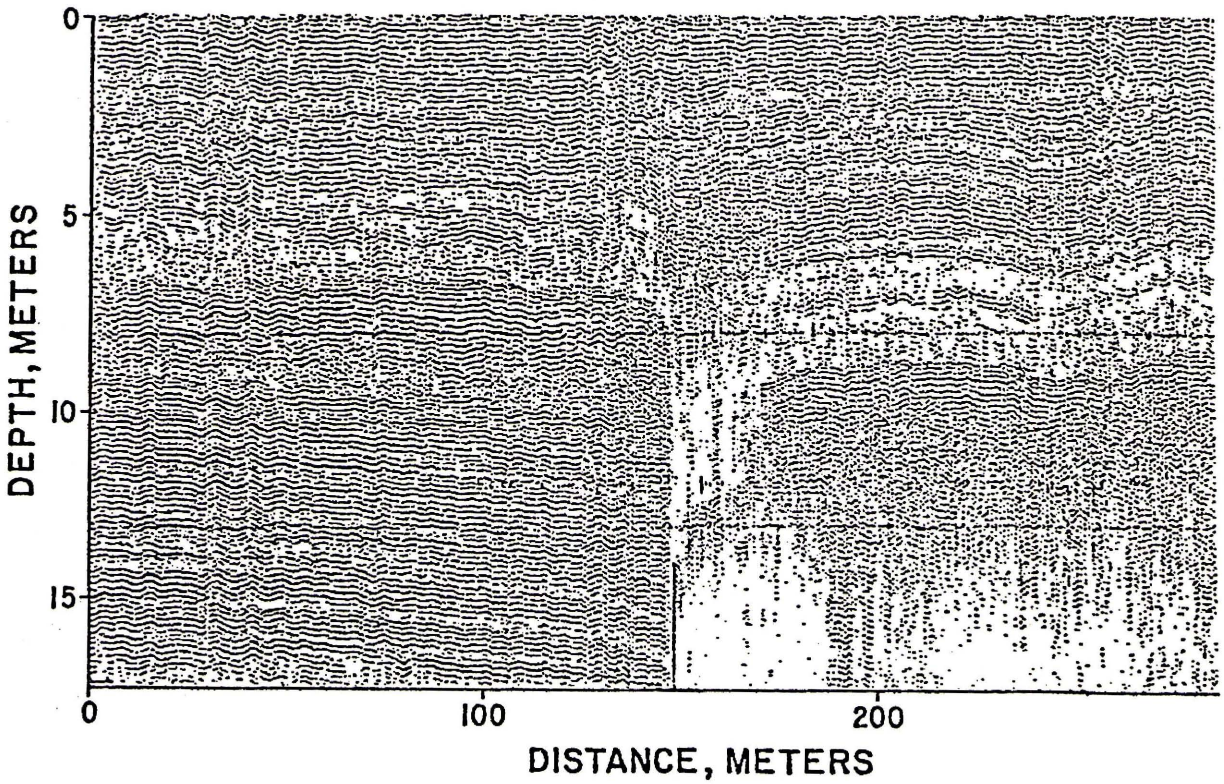


Fig. 10. A spectacular fault on the north end of West Jumbers Point Fault. The right-hand, eastern block is displaced downward about 2.5 meters. The lower dark layer between 7 and 9 meters on the left side, is believed to be the clay unit of the Provo Formation.

# DEEP-WATER SPRINGS OF UTAH LAKE

During the summer of 1975, a 23-transect reconnaisance study of Utah Lake was made by means of a sonar-like device (Brimhall, et. al., 1976). It was possible to infer spring and seep areas from the profiles. The distribution of the areas containing springs is shown in Figure 9.

Inspection of Figure 9 reveals that less than 10 percent of the floor of Utah Lake is associated with springs or seeps. Most are located in a zone 1 to 3 km ~~kilometers~~ (0.6 to 1.9 miles) from shore on the eastern and northern portions of the lake.

The reason for such a distribution is clear when it is realized that the principal watersheds contributing to the lake occur in the eastern and northeastern zones. The springs/seeps occur in response to availability of water, to the thinning and wedging of permeable, water-bearing strata in a lakeward direction, to the thickening of fine-grained strata to confine the trapped water in a lakeward direction, and to the development of a hydraulic pressure by the aquifers sloping toward the interior of the lake. Thus, the springs/seeps occur principally as the result of prevailing sedimentary and hydrologic conditions.

Occasionally the springs/seeps are clearly controlled by faults, but in general, the pattern is weak. The northern extension of the Bird Island Fault coincides with the concentration of springs/seeps along the eastern side of the lake, but the fault in this section is weak in that its displacement is typically less than 0.5 m ~~one-half meter~~ (1.6 feet) and the springs/ seeps are widely scattered on opposite sides of the fault.

It is noteworthy that the faults showing the greatest displacements, the Jumbers Points Faults, the East Goshen Bay Fault west of Lincoln Point, associate only slightly, if at all, with springs. If a strong association were present, the investigation during the summer of 1975 would have revealed it.

Three separate attempts were made in late August, 1975, to sample water from springs previously located by the acoustical profiler, but the results were inconclusive. Vertical profiles, made with a portable Hydrolab water quality probe, showed no significant variation in conductivity from the surface of the lake to the inferred mouth of the spring/seep areas at three different localities investigated. The quality of water and the quantity of water being discharged from the deep-water springs is still unknown, and awaits further investigation.

# IMPLICATIONS FOR RESOURCE MANAGEMENT

The geology of the lake includes its geologic history and setting, physiography, drainages, groundwater patterns, sediments and strata, and geologic structures (faults). These form a physical base upon which the plant and animal communities, including those of man, live and adapt, and they form the principal boundary conditions, subject to change by interaction, which impose upon the management of the resources of the lake.

The following items summarize some principal implications for resource management imposed by geological conditions known at the present time.

<u>The Life of the Basin</u>. A significant question regarding Utah Lake is this: How fast is the lake basin filling up? What is the expected life of the basin as present constituted and operated? Available geological data indicate a rate of infilling at about 1 mm (0.039 inches) per year over the past 10,000 years, although ~~it is likely that~~ the rate has likely more than doubled with the settlement and urbanization of Utah Valley. It is equally clear, however, from the character of the faults present in the lake floor, that the valley is deepening relative to the mountains, at the same time it is receiving sediment. The displacement on the faults indicate an approximate equality of deepening and infilling, or an approximate state of dynamic equilibrium existing between deepening of the basin by the faults and the infilling of the basin by transport and deposition of sediment derived from the surroundings. This trend is

consistent with the overall geologic history of the region which has been characterized by recurrent movements on the Wasatch Fault since its origin some 30 million years ago.

No ¶ So the depth of the lake, relative to the elevation of the present shoreline, will probably remain constant for the foreseeable future.

No ¶ This does not mean, however, that the resources of the lake could not be improved by artificially deepening the water.

Faults Crossing Proposed Goshen Bay Dike. Although ~~the~~ a proposed Goshen Bay ~~D~~dike will cross some faults and folds, ~~it is~~ we believe~~d by the writers~~ that they do not pose a serious threat to the safety or operation of a ~~the~~ dike. Displacements would likely be no more than a few tens of centimeters, and probably much less, unless an earthquake of catastrophic proportions were to strike the area. Small displacements, if they occur, can be repaired quickly.

The Geological Condition of the Lake. A point commonly, almost pervasively, misunderstood by laymen and many experts as well, is that Utah Lake is a senile lake in the geological sense. It is a very shallow lake. It has a very large surface compared to volume. It is characterized by high evaporation rates. It is characterized by high rates of sedimentation. The exchange of impurities between water and sediment is likewise large.

Many mistakenly believe that the lake can be restored to a pristine state characterized by the waters of the mountain lakes of the region. The essential point missed is that Utah Lake cannot be returned to that condition. The natural history recorded in the sediment cores and profiles show that the lake has been in much the same as its present condition for centuries. This natural evidence opposes statements purportedly derived from diaries and journals of early settlers and observers that the lake was characterized by clear, blue water. Careful analysis of the conditions under which such observations were made indicates that most of them were made from some distant point such as the Point-of-the-Mountain where, even today, the lake has a clear, blue aspect, especially when incident light from the sun bears a critical angle just after sunrise or just before sunset.

No ¶ Reports of clear water and sandy beaches were made mostly in the vicinity of the Provo River or other river inflows where the wide plume of clear water extended away into the lake. Under most of the conditions in which such observations were made, the water would have a clear aspect.

The character and conditions of observations, both from eyewitness accounts and from the natural record left in the sediments of the lake can be reconciled to the effect that the lake is and has been geologically old since its inception, with the water being turbid but which may appear clear locally or completely depending upon the vantage point and conditions under which the lake was observed.

The foregoing should not be construed to mean that there have been no significant changes in the clarity of water in Utah Lake with the changes of level occurring over the past few thousand years; it simply means that the lake has not been a completely clear lake, in the same sense that many mountain lakes are clear, throughout most, if not all, of its history.

<u>Sediment Character and Distribution</u>. Research completed within the past three years has delineated the broad patterns of composition and grain size distributions of minerals being deposited on the lake floor. In all but the nearshore regions, the areas close to the mouths of the major rivers, and in the vicinity of Bird Island, calcium carbonate exceeds 50 weight percent. Silica and clay compose most of the rest. In the same regions occupied by the calcium carbonate, the grain sizes are mostly and about equally in the silt and clay sizes, between 1/16 and 1/256 mm, and less than 1/256 mm, respectively.

No ¶ In the nearshore portions of the lake, silica in the form of sand is the most abundant constituent. Particle sizes are dominantly in the range between 1/16 mm and 2 mm.

~~It is~~ We believe~~d~~ ~~by the writers~~ that these relationships have a larger bearing on the character of the plant and animal communitites than is presently realized, principally by reason of the lack of detailed study necessary to establish the relationships. A very real need for the near future is to map the lithologies of the nearshore regions in detail. When that is done, the base is laid for detailed study of the plant and animal communities. ~~It is believed that the foregoing map could be produced by a senior researcher and two field assistants in the course of a few months.~~

<u>Geologic Faults in the Lake</u>. The geologic faults discovered and mapped in the floor of the lake during the summer of 1975 pose the same kind of threat that other faults pose in the valley, but none beyond those

customarily assigned. That they exist and are consistent in character and distribution with the Wasatch and other faults bordering the valley is interesting and informative.

The faults exhibit displacements up to 5 m ~~five meters~~ (16 feet), during the past 10,000 years or so, but it is unlikely that such displacements were achieved as the result of a single event. It is conceivable that the floor of the lake could be violently heaved by an earthquake, and that large lake waves could be produced, but, even if such did occur, the damage to the shorelines would probably be incidental to the damage wrought elsewhere in the valley by ground vibrations and movements.

The location and character of springs in the floor of the lake is more determined by existing hydrologic and sedimentation factors than by faults. The faults do appear to contribute substantially in a few places, however. In the event of strong earthquakes in the valley, it is not anticipated that the effect on springs in the lake floor would be large.

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Brimhall 

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Order Trichoptera (Continued)
Family Rhyacophilidae
*Rhyacophila pellisa* Ross
*Rhyacophila verrula* Milne

Order Hemiptera
Family Corixidae

Family Gerridae

Family Mesoveliidae

Family Saldidae

Family Belostomatidae

Order Odonata
Family Coenagrionidae

Family Aeshnidae
*Aeshna palmata* Hagen

Family Corduliidae
*Somatochlora semicircularis* Selys

Order Megaloptera
Family Sialidae
*Sialis* sp. Latreille

TABLE 8

AQUATIC INVERTEBRATES OF UTAH LAKE

Phylum Protozoa - one celled organisms

Class Sarcodina

*Amoeba proteus*
*Amoeba limax*

Class Flagellata

*Euglena viridis*
*Heteronema* sp.
*Chilomonas* sp.
*Epipyxis* sp.
Eudorina sp.
*Pleodorina* sp.
*Volvox* sp.
*Ceratium hirudinella robustum*

Class Ciliata

*Holophyra*
*Prorodon* sp.
*Urocentrum* sp.
*Paramecium caudatum*
*Saprophilus*
*Stentor*
*Tintinnidum*
*Gastrostyla*
*Stylonychia*
*Vorticella campanula*
*Charchesium* sp.

Phylum Porifera - sponges

Class Demospongia

*Spongilla lacustris* (L.)
*Meyenia fluviatitis*
This sponge is found along the Lincoln Beach area on the underside of rocks and is very numerous.

Factors to consider in sedimentation rates –

1. Deforestation – removal of veg. cover –
2. Overgrazing – particularly sheep – Sp Fork Canyon
3. Greater mineral concentration – industry, residential wastes,
4. Trenching and draining of lands in close proximity to lake – (reclaiming lands with high water level)
5. also irrigation
6. drawn down of lake
7. Carp.

Bolland 1974 – 300 cm – 1849 $\frac{1970 - 1849}{121}$ 121)300 = 2.48 | 242 | 580 | 484 | 960 | 968 — 2.48 cm/yr dep rate

210 yrs ago – development of qtz sand at 470 cm level — 210)470. = 2.23 | 420 | 500 | 420 | 800 | 630 | 1700 — 2.24 cm/yr

Bolland p. 24. between 1885 + 1970 av. rate sed. 2.82 cm/yr
between 9450 BC + 1885 AD 250 cm accumulated – av. rate 0.02 cm/yr.
between 1935 and 1970 120 cm accum. 3.43 cm/yr
between 1885 + 1970 120 cm accum. 2.40 cm/yr

p. 36 – Mans manipulation of lake's water level – heavily drawn down for agric. purposes after 1910 could have produced floristic changes.

p. 36 Carp introduced into Utah Lake 1800 – added to turbulence + resuspension of substrate materials.

p. 3 frequent great algae blooms of Anabaena + Aphanizomenon

p. 3 In 1885 conflict between land owners and lake water users was somewhat resolved by setting a compromise lake level at 1,368.35 m or 4,489.34 ft above sea level. At compromise level Utah Lake has a surface area of 380 Km² and a shoreline of 132 km.

p. 11 Fig. 3 shows a variation in water depth since 1885 of 17 ft from lowest to highest recorded water level.

p. 11 Fig 3 ~~past~~ 120 cm. level of core there is a marked high increase in the Ca content to 33% low of 2% at the 470 cm. level.

p. 29 Table 1 + p. 31 – Zones of Diatoms

Zone I – 12–24 cm. shallow alkaline waters – eutrophic lake
Zone II 26–176 cm shallow alkaline lake
Zone III 178–~~292~~ cm – warm shallow – low oxygen?
Zone IV 304–370 cm. alkaline water.
Zone V 372–430 cm oligotrophic – mesotrophic
Zone VI 458–464 cm deep cool lake (not necessarily)
Zone VII 486–488 cm. slightly alkaline

UL-26

Cover

Sediment Yield

# CHEMICAL WATER QUALITY

# OF UTAH LAKE TRIBUTARIES

A Project
Presented to the
Department of Civil Engineering Science
Brigham Young University

In Partial Fulfillment
of the Requirements for the Degree of
Master of Civil Engineering

by
K. W. Turley

December 1969

## FIGURES

more polluted except at the point where it is diluted by Diamond Fork Creek. During the summer, the Spanish Fork River is abruptly polluted at the point where irrigation water returns.

INTRODUCTION - In a study[1] of Utah Lake it was concluded that the water quality of the Lake has declined. The biological life of Utah Lake has undergone drastic changes in the past 100 years. Provo Bay, for example, has changed from a good quality fishing area for largemouth bass and cutthroat trout into a carp feeding ground. Jordan River, the Lake's outflow, will no longer support the quality trout fishery that was enjoyed by the early settlers.

The study was not able to detect any definite trend as far as chemical pollution was concerned. However, it found that the biota of the Lake reflected changes that were possibly caused by changes of water chemistry.

OBJECT - This project consisted of investigating the chemical water quality of streams tributary to Utah Lake in order to establish the sources of Utah Lake's chemical pollution. Besides determining the relative quality of tributary streams, the investigation was to identify where two of these streams, the Provo River and the Spanish Fork River, pick up chemical pollutants.

Many other objectives could have been chosen consistent with the data gathered. These objectives include the following: variation of chemical water quality of streams with geological formations and terrain; chemical quality of municipal and industrial water from point of origin to final effluent; variations of specific chemicals in a stream with time of year and with distance along the stream; variations of specific chemicals between all tributary streams; quantities of chemical pollutants (involving discharge measurements); and effect of leaching in northern Utah Lake swamps. Organic pollution studies would also be of value in conjunction with some of the above objectives.

PROCEDURES - Data were obtained from three sources. The first data source was the Brigham Young University Library. The following five publications were found: Water, Wastewater--Chemical and Radiological Analyses, 1965 Tabulation; A Compilation of Chemical Quality Data for Ground and Surface Waters in Utah; Records of Selected Wells and Springs, Selected Drillers' Logs of Wells, and Chemical Analyses of Ground and Surface Waters, Northern Utah Valley, Utah County, Utah; and Irrigation Waters of Utah, Their Quality and Use.

The second source of data was direct inquiry of agencies involved in water quality. The Utah State Engineer's Office in the State Capitol had no information. The Utah State Division of Health on 72 East 400 South in Salt Lake City (care of Louise Slack) were able to furnish subsequent copies of Water, Wastewater--Chemical and Radiological Analysis. Mr. Cordova of the U.S. Geological Survey located in the Federal Building in Salt Lake City reported that they had no data which the author did not already have. The Provo office of the U.S. Bureau of Reclamation produced a large amount of unpublished data.

The third source of data was from the chemical analysis of water samples by the author. A water testing kit obtainable from the Hach Chemical Company; Box 907; Ames, Iowa 50010, was used according to the accompanying explicit instructions for determining the following items: pH, turbidity, total alkalinity as $CaCO_3$, chloride, dissolved oxygen, total hardness as $CaCO_3$, nitrate, nitrite, phosphate, and sulfate. Large inaccuracies were detected in the determination of low concentrations of nitrate ions unless a larger percentage of sample water than suggested was used. Total dissolved solids were determined by utilizing the electrical ovens, dessiccator, and analytical balance belonging to the Civil Engineering Department. Conductivity was determined by utilizing the BYU Agronomy Department's resistivity meter. Resistivity values were recorded in terms of electrical conductivity at 25°C by the following conversion equation:

$$EC_{25} = K \times f_t \div R_t$$

K = the conversion factor constant for a particular resistivity cell.

$EC_{25}$ = electrical conductivity at 25°C in units of mhos per centimeter.

$R_{25}$ = resistivity at 25°C in units of ohms.

$f_t$ = a temperature convestion factor as found on the table in Appendix A.

The K factor for the resistivity meter that was used was found by determining $R_{25}$ by this meter for several samples, determining $EC_{25}$ for these same samples on Dr. Raymond B. Farnsworth's direct indicating conductivity meter, and then using this equation: $K = EC_{25} \times R_{25}$

RESULTS - The analysis was made in terms of micromhos per centimeter since electrical conductivity is a measure of the total ion concentration. For water of low or intermediate salt content the approximate relationship between conductance and parts per million of ions to water by weight is as follows:[2]

$$EC \times 10^6 = \frac{ppm}{0.70}$$

where $EC \times 10^6$ = electrical conductivity in micromhos per centimeter

and ppm = parts per million of ions to water by weight.

The streams tributary to Utah Lake shown in Figure 1 have been analyzed; the conductivity values at the mouths of these streams is shown in Figures 2 and 3. Figures 4, 5, 6, 15, and 18 show the variability of this data. Notice the great variation between streams.

The Spanish Fork River and some of its tributaries were given special study. Figure 7 shows the conductivity values obtained for the tributaries. Notice that the values increase and then decrease along the length of Diamond Fork Creek. Figure 8 shows the annual variation of conductivity along the length of the Spanish Fork River and at the mouths of two tributaries. Notice the shape of the family of curves, and observe that the Spanish Fork River at its mouth does not fit this family very well. The variability of the data is shown in Figures 9 through 15.

A special study was also conducted on the Provo River. Figure 16 shows the peculiar way that the conductivity varies with time and length on this river. Figures 17 and 18 show

FIGURE 1

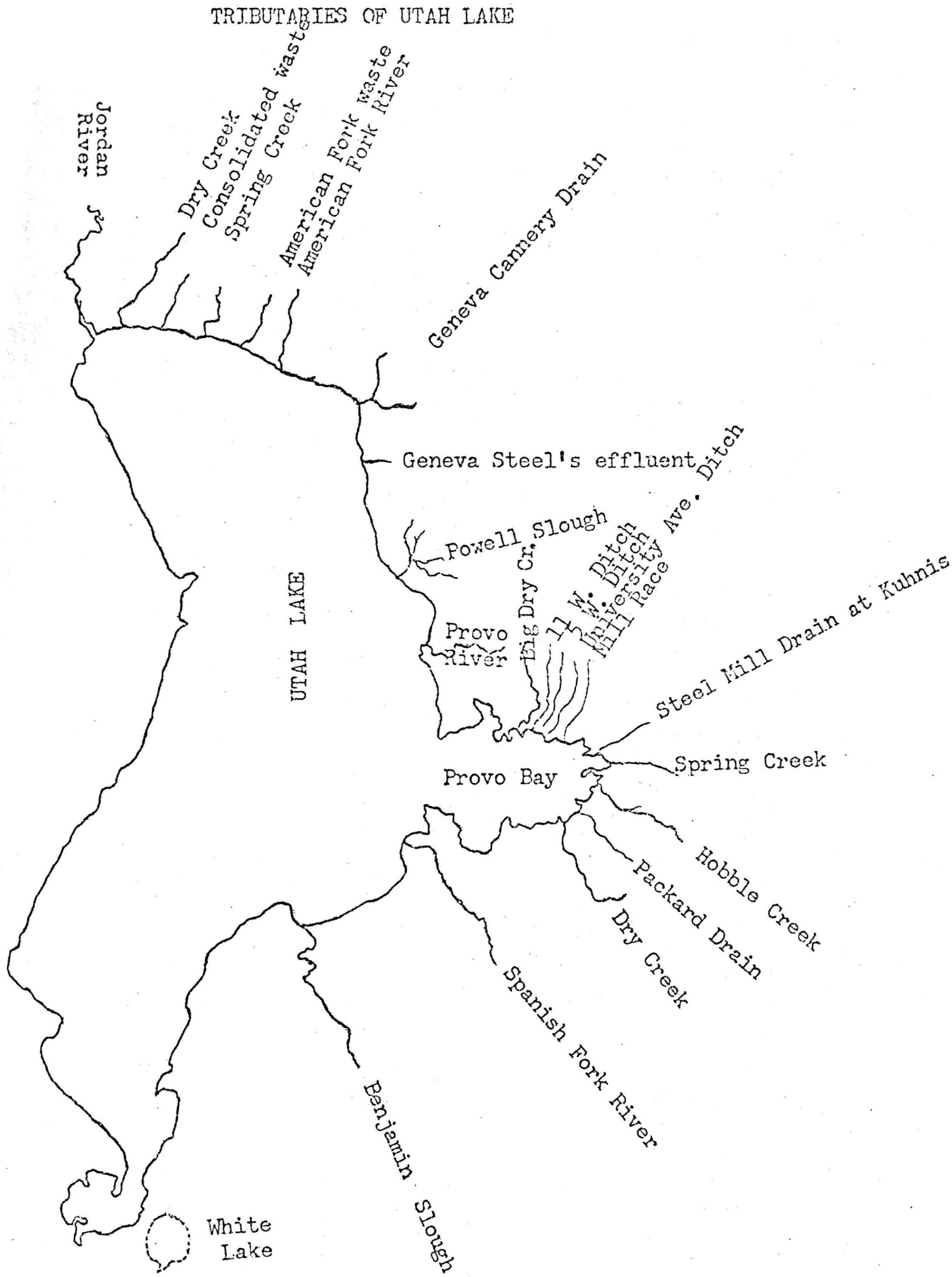
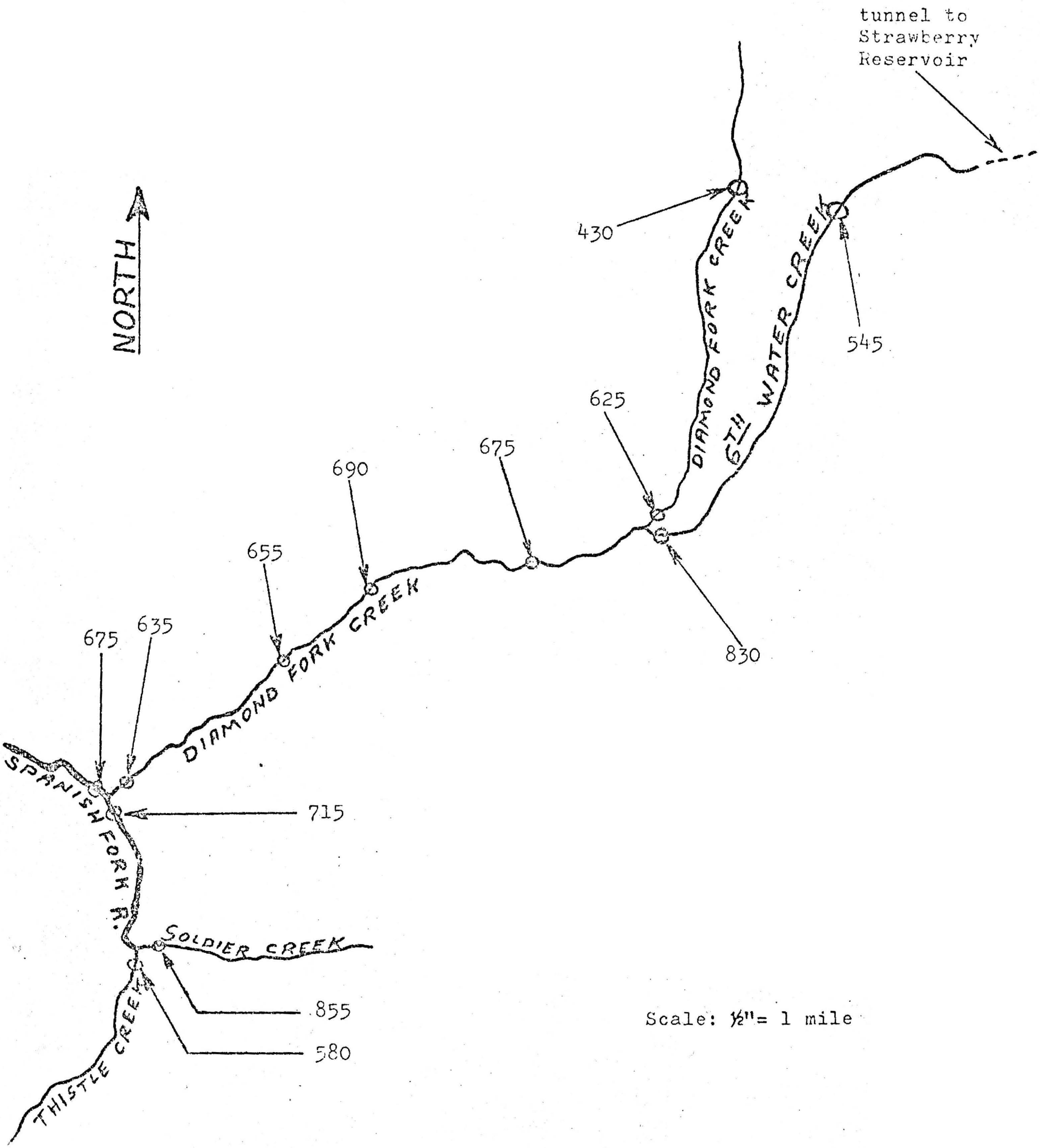

TRIBUTARIES OF UTAH LAKE
Jordan River
Dry Creek
Consolidated waste
Spring Creek
American Fork waste
American Fork River
Geneva Cannery Drain
Geneva Steel's effluent
Powell Slough
Big Dry Cr.
11 W. Ditch
5 W. Ditch
University Ave. Ditch
Mill Race
Provo River
UTAH LAKE
Steel Mill Drain at Kuhnis
Spring Creek
Provo Bay
Hobble Creek
Packard Drain
Dry Creek
Spanish Fork River
Benjamin Slough
White Lake

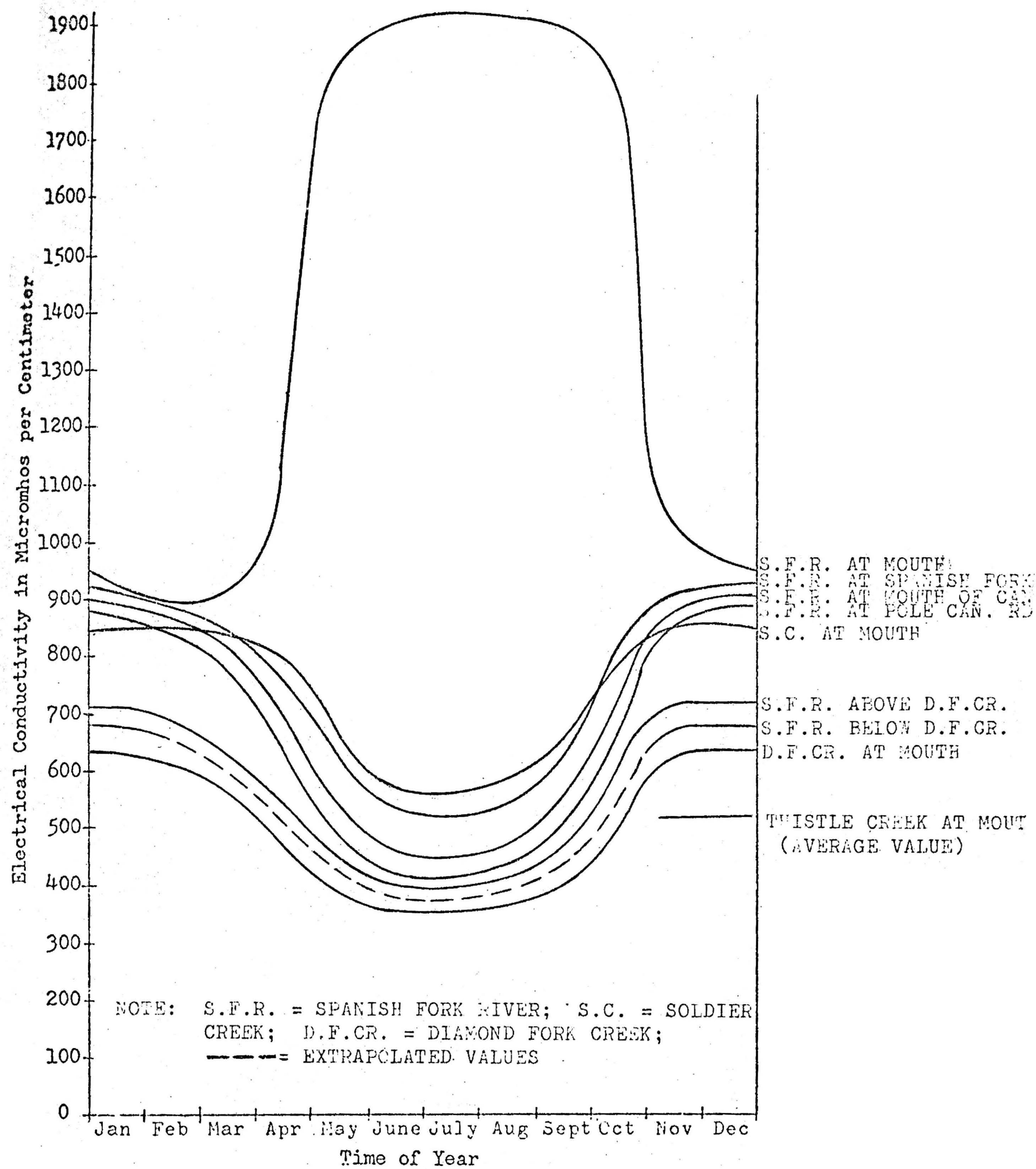
FIGURE 7

NOVEMBER 20, 1969, WATER QUALITY AS
MEASURED BY ELECTRICAL CONDUCTIVITY
IN MICROMHOS PER CENTIMETER



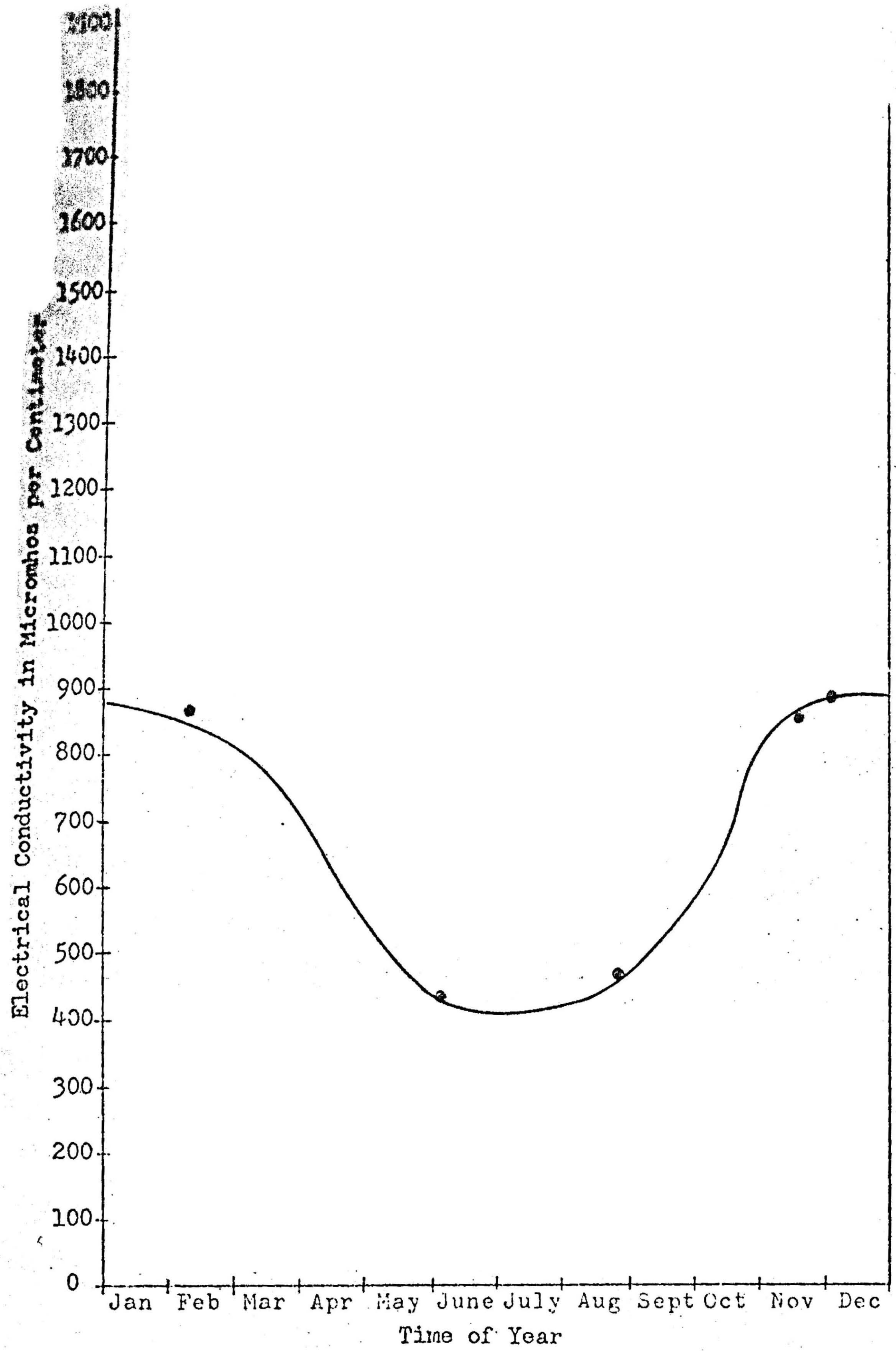
Hamon Influence

FIGURE 8



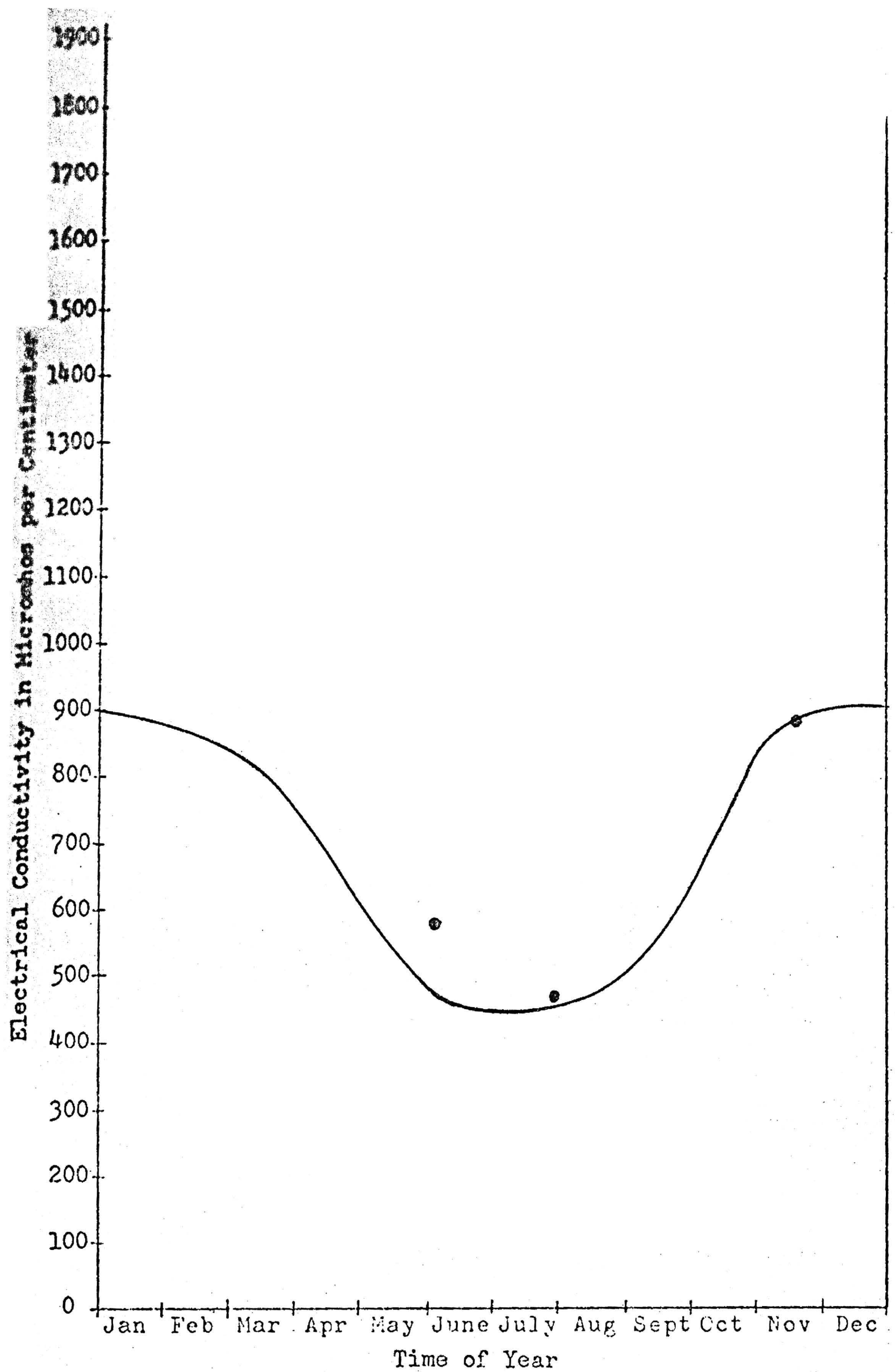

CHEMICAL WATER QUALITY OF SPANISH FORK RIVER AND TRIBUTARIES AS MEASURED BY ELECTRICAL CONDUCTIVITY

FIGURE 12



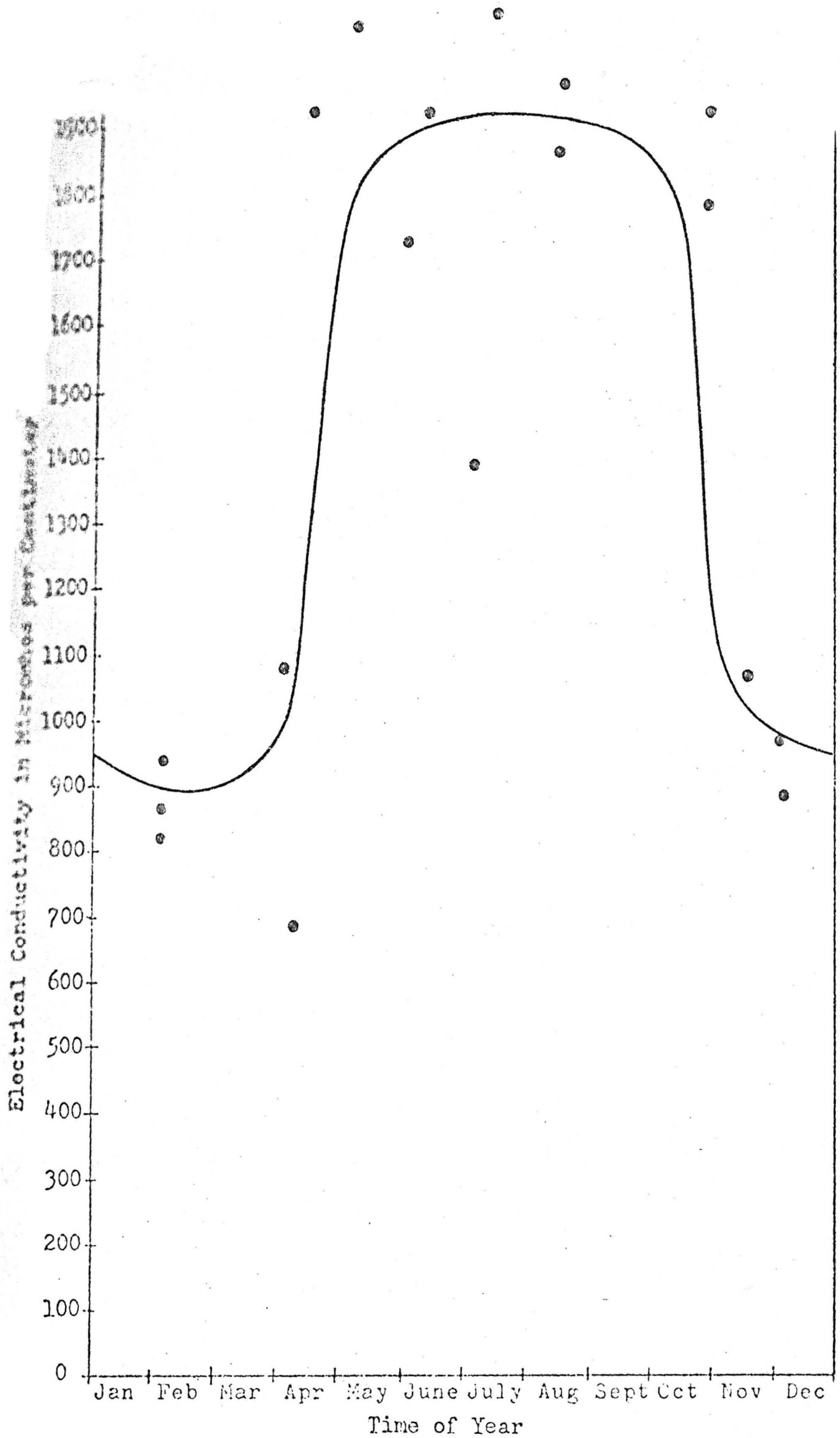

CHEMICAL WATER QUALITY OF SPANISH FORK RIVER AT POLE CANYON ROAD AS MEASURED BY ELECTRICAL CONDUCTIVITY

FIGURE 13




CHEMICAL WATER QUALITY OF SPANISH FORK RIVER AT MOUTH OF CANYON AS MEASURED BY ELECTICAL CONDUCTIVITY

FIGURE 15




CHEMICAL WATER QUALITY OF SPANISH FORK RIVER AT ITS MOUTH AS MEASURED BY ELECTRICAL CONDUCTIVITY

EXACT DESCRIPTION OF SAMPLING POINT: Spanish Fork River near Lake Shore

SOURCE OF SAMPLE: Stream

| DATE OF SAMPLE COLLECTION | LOCAL MILITARY TIME | DISCHARGE IN CFS | TEMPERATURE IN °C | CONDUCTIVITY MICROMHOS/CM @ 25°C | PH | TURBIDITY UNITS | SUBSTANCES IN MILLIGRAMS PER LITER: TOTAL DISSOLVED SOLIDS | TOTAL ALKALINITY AS $CaCO_3$ | BICARBONATE ($HCO_3$) | CALCIUM (Ca) | CARBONATE ($CO_3$) | CHLORIDE (Cl) | DISSOLVED OXYGEN ($O_2$) | HARDNESS TOTAL AS $CaCO_3$ | MAGNESIUM (Mg) | NITRATE ($NO_3$) | NITRITE ($NO_2$) | PHOSPHATE ($PO_4$) | POTASSIUM (K) | SODIUM (Na) | SULFATE ($SO_4$) | INFORMATION SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/11/59 | | | | 2056 | 8.2 | | 1290 | | 422 | 49.2 | 24.3 | 234 | | | 74 | | | | 7.4 | 309 | 377 | 3 |
| 6/19/59 | | | | 1911 | 8.0 | | 1190 | | 468 | 57.0 | 26.1 | 194 | | | 71.6 | | | | 6.3 | 266 | 308 | 3 |
| 7/22/59 | | | | 2095 | 8.0 | | 1314 | | 537 | 80.6 | 12.0 | 222 | | | 71.2 | | | | 8.6 | 293 | 354 | 3 |
| 8/19/59 | | | | 1858 | 8.0 | | 1164 | | 428 | 70.0 | 24.6 | 205 | | | 62.8 | | | | 5.9 | 259 | 310 | 3 |
| 4/23/59 | | | | 1924 | 8.0 | | 1212 | | 480 | 94.4 | 17.7 | 213 | | | 67.8 | | | | 5.5 | 247 | 323 | 3 |
| 11/4/59 | | | | 1796 | 8.4 | | 1158 | | 451 | 93 | 29.4 | 182 | | | 62.2 | | | | 5.9 | 217 | 280 | 3 |
| 2/11/60 | | | | 931 | 8.3 | | 588 | | 290 | 86.6 | 16.8 | 76.7 | | | 28.7 | | | | 5.1 | 74.1 | 123 | 3 |
| 6/3/60 | | | | 1763 | 8.4 | | 1104 | | 394 | 58.6 | 28.8 | 180 | | | 60.4 | | | | 7.4 | 229 | 267 | 3 |
| 7/7/60 | | | | 1395 | 8.4 | | 878 | | 298 | 44.0 | 16.5 | 149 | | | 52.3 | | | | 6.6 | 192 | 258 | 3 |
| 12/8/60 | | | | 879 | 8.1 | | 532 | | 249 | 69.2 | 7.5 | 80.2 | | | 30.7 | | | | 5.1 | 77.3 | 138 | 3 |
| 2/2/61 | | | | 803 | 8.3 | | 517 | | 230 | 64.6 | 0 | 67.8 | | | 29.3 | | | | 4.7 | 68.5 | 137 | 3 |
| 4/5/61 | | | | 1086 | 8.3 | | 700 | | 248 | 61.0 | 11.7 | 95.1 | | | 38.4 | | | | 4.7 | 115 | 171 | 3 |
| 12/7/61 | | | | 971 | 8.1 | | 584 | | 299 | 90 | 10.2 | 83.4 | | | 31.6 | | | | 5.1 | 79.6 | 148 | 3 |
| 4/6/62 | | | | 686 | 8.5 | | 422 | | 255 | 62.4 | 9.9 | 45.4 | | | 24.9 | | | | 4.7 | 48.5 | 72 | 3 |
| 8/7/62 | | | | 1967 | 7.6 | | 1244 | | 587 | 127 | 7.2 | 196 | | | 66.7 | | | | 7.0 | 250 | 359 | 3 |
| 10/31/62 | | | | 1930 | 7.8 | | 1246 | | 512 | 98.0 | 16.5 | 197 | | | 67.2 | | | | 6.3 | 236 | 303 | 3 |

EXACT DESCRIPTION OF SAMPLING POINT: Spanish Fork River near Lake Shore (CONT.)

SOURCE OF SAMPLE: Stream

| DATE OF SAMPLE COLLECTION | LOCAL MILITARY TIME | DISCHARGE IN CFS | TEMPERATURE IN °C | CONDUCTIVITY IN MMHOS/CM@25°C | PH | TURBIDITY UNITS | TOTAL DISSOLVED SOLIDS | TOTAL ALKALINITY AS $CaCO_3$ | BICARBONATE ($HCO_3$) | CALCIUM (Ca) | CARBONATE ($CO_3$) | CHLORIDE (Cl) | DISSOLVED OXYGEN ($O_2$) | HARDNESS TOTAL AS $CaCO_3$ | MAGNESIUM (Mg) | NITRATE ($NO_3$) | NITRITE ($NO_2$) | PHOSPHATE ($PO_4$) | POTASSIUM (K) | SODIUM (Na) | SULFATE ($SO_4$) | IMPORTANCE OF SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | SUBSTANCES IN MILLIGRAMS PER LITER | | | | | | | | | | | | | | | |
| 2/5/63 | | | | 855 | 7.9 | | 536 | | 314 | 78.2 | 6.00 | 63.5 | | | 27.9 | | | | 63 | 60.3 | 86.9 | 3 |

EXACT DESCRIPTION OF SAMPLING POINT: Spanish Fork River near Utah Lake (at the natural gas pipe crossing located 0.5 miles North of 3200 W 4400 S intersection)

SOURCE OF SAMPLE: Stream

| Date of Sample Collection | Local Military Time | Discharge in CFS | Temperature in °C | Conductivity Mhos/CM | PH | Turbidity Units | Substances in Milligrams per Liter: Total Dissolved Solids | Total Alkalinity as $CaCO_3$ | Bicarbonate ($HCO_3$) | Calcium (Ca) | Carbonate ($CO_3$) | Chloride (Cl) | Dissolved Oxygen ($O_2$) | Hardness Total as $CaCO_3$ | Magnesium (Mg) | Nitrate ($NO_3$) | Nitrite ($NO_2$) | Phosphate ($PO_4$) | Potassium (K) | Sodium (Na) | Sulfate ($SO_4$) | Information Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/30/69 | 1730 | | 4 | 1060 | 8.44 | | 514 | | | | | | | | | | | | | | | [illegible] |

EXACT DESCRIPTION OF SAMPLING POINT: Spanish Fork River at Utah State Highway 115 Bridge

SOURCE OF SAMPLE: Stream

| DATE OF SAMPLE COLLECTION | LOCAL MILITARY TIME | DISCHARGE IN CFS | TEMPERATURE IN °C | CONDUCTIVITY MMHOS/CM | PH | TURBIDITY UNITS | SUBSTANCES IN MILLIGRAMS PER LITER | | | | | | | | | | | | | | | INFORMATION SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | TOTAL DISSOLVED SOLIDS | TOTAL ALKALINITY AS $CaCO_3$ | BICARBONATE ($HCO_3$) | CALCIUM (Ca) | CARBONATE ($CO_3$) | CHLORIDE (Cl) | DISSOLVED OXYGEN ($O_2$) | HARDNESS TOTAL AS $CaCO_3$ | MAGNESIUM (Mg) | NITRATE ($NO_3$) | NITRITE ($NO_2$) | PHOSPHATE ($PO_4$) | POTASSIUM (K) | SODIUM (Na) | SULFATE ($SO_4$) | |
| 11/20/69 | 1715 | | 4 | 910 | 8.51 | | 531 | | | | | | | | | | | | | | | 7 |

EXACT DESCRIPTION OF SAMPLING POINT: Spanish Fork River near Spanish Fork, Utah, (at the U.S. Highway 91,6,50 Bridge) just South of Spanish Fork, Utah

SOURCE OF SAMPLE: Stream

| DATE OF SAMPLE COLLECTION | LOCAL MILITARY TIME | DISCHARGE IN CFS | TEMPERATURE IN °C | CONDUCTIVITY MHOS/CM | PH | TURBIDITY UNITS | SUBSTANCES IN MILLIGRAMS PER LITER: TOTAL DISSOLVED SOLIDS | TOTAL ALKALINITY AS $CaCO_3$ | BICARBONATE ($HCO_3$) | CALCIUM (Ca) | CARBONATE ($CO_3$) | CHLORIDE (Cl) | DISSOLVED OXYGEN ($O_2$) | HARDNESS TOTAL AS $CaCO_3$ | MAGNESIUM (Mg) | NITRATE ($NO_3$) | NITRITE ($NO_2$) | PHOSPHATE ($PO_4$) | POTASSIUM (K) | SODIUM (Na) | SULFATE ($SO_4$) | INFORMATION SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/22/56 | | | | 412 | | | 232 | | 196 | 41 | | 15 | | 174 | 18 | 1.4 | | | 20 | | 33 | 2 |
| 11/20/69 | 1700 | | 4 | 910 | | | 634 | | | | | | | | | | | | | | | 7 |

EXACT DESCRIPTION OF SAMPLING POINT: Spanish Fork River at the mouth of the canyon 1.0 miles Southeast of Moark Junction

SOURCE OF SAMPLE: Stream

| DATE OF SAMPLE COLLECTION | HOUR MILITARY TIME | DISCHARGE IN CFS | TEMPERATURE IN °C | CONDUCTIVITY MHOS/CM | PH | TURBIDITY UNITS | SUBSTANCES IN MILLIGRAMS PER LITER: TOTAL DISSOLVED SOLIDS | TOTAL ALKALINITY AS $CaCO_3$ | BICARBONATE ($HCO_3$) | CALCIUM (Ca) | CARBONATE ($CO_3$) | CHLORIDE (Cl) | DISSOLVED OXYGEN ($O_2$) | HARDNESS TOTAL AS $CaCO_3$ | MAGNESIUM (Mg) | NITRATE ($NO_3$) | NITRITE ($NO_2$) | PHOSPHATE ($PO_4$) | POTASSIUM (K) | SODIUM (Na) | SULFATE ($SO_4$) | INFORMATION SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/6/49 | | 276 | | 580 | | | | | 260 | 80 | 8 | 24 | | 220 | 23 | 0.4 | | | 9.7 | 28 | 41 | 2.6 |
| 7/30/49 | | 336 | | 470 | | | | | 213 | 31 | 11 | 15 | | 148 | 17 | | | | 3.9 | 8 | 40 | 2.5 |
| 12/3/54 | | | | 774 | | | | | 252 | 61 | | 37 | | 265 | 28 | 0.9 | | | 47 | 59 | 113 | 2 |
| 11/20/69 | 1620 | | | 895 | 8.48 | | 529 | | | | | | 9 | | | | | | | | | 7 |

EXACT DESCRIPTION OF SAMPLING POINT: Spanish Fork River at the Pole Canyon Road Bridge (T. 9 S., R. 3 E., Sec. 12, S.L.B. & M.)

SOURCE OF SAMPLE: Stream

| | | | | | | | SUBSTANCES IN MILLIGRAMS PER LITER | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DATE OF SAMPLE COLLECTION | LOCAL MILITARY TIME | DISCHARGE IN CFS | TEMPERATURE IN °C | CONDUCTIVITY MMHOS/CM | PH | TURBIDITY UNITS | TOTAL DISSOLVED SOLIDS | TOTAL ALKALINITY AS $CaCO_3$ | BICARBONATE ($HCO_3$) | CALCIUM (Ca) | CARBONATE ($CO_3$) | CHLORIDE (Cl) | DISSOLVED OXYGEN ($O_2$) | HARDNESS TOTAL AS $CaCO_3$ | MAGNESIUM (Mg) | NITRATE ($NO_3$) | NITRITE ($NO_2$) | PHOSPHATE ($PO_4$) | POTASSIUM (K) | SODIUM (Na) | SULFATE ($SO_4$) | INFORMATION SOURCE |
| 2/11/60 | | 59 | | 881 | 8.3 | | 533 | | 277 | 79 | 13 | 77 | | 299 | 25 | | | | 4.3 | 70 | 92 | 4 |
| 6/2/60 | | 419 | | 413 | 7.8 | | 251 | | 199 | 41 | 0 | 14 | | 180 | 19 | | | | 1.9 | 17 | 36 | 4 |
| 8/31/60 | | 147 | | 465 | 8.6 | | 258 | | 172 | 48 | 16 | 24 | | 211 | 22 | | | | 2.3 | 25 | 65 | 4 |
| 12/8/60 | | 35 | | 894 | 8.3 | | 537 | | 241 | 71 | 8.1 | 91 | | 288 | 27 | | | | 5.5 | 77 | 118 | 4 |
| 11/20/69 | 1610 | | 4.5 | 870 | 8.5 | | 504 | | | | | | | | | | | | | | | 7 |

EXACT DESCRIPTION OF SAMPLING POINT: Spanish Fork River 100 yards Northwest of the Diamond Fork Road--U.S. Highway 50,6,89 Intersection

SOURCE OF SAMPLE: Stream

| DATE OF SAMPLE COLLECTION | LOCAL MILITARY TIME | DISCHARGE IN CFS | TEMPERATURE IN °C | CONDUCTIVITY MMHOS/CM | PH | TURBIDITY UNITS | SUBSTANCES IN MILLIGRAMS PER LITER: TOTAL DISSOLVED SOLIDS | TOTAL ALKALINITY AS $CaCO_3$ | BICARBONATE ($HCO_3$) | CALCIUM (Ca) | CARBONATE ($CO_3$) | CHLORIDES (Cl) | DISSOLVED OXYGEN ($O_2$) | HARDNESS TOTAL AS $CaCO_3$ | MAGNESIUM (Mg) | NITRATE ($NO_3$) | NITRITE ($NO_2$) | PHOSPHATE ($PO_4$) | POTASSIUM (K) | SODIUM (Na) | SULFATE ($SO_4$) | INFORMATION SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/20/69 | 1545 | | 4 | 675 | 850 | | 427 | | | | | | | | | | | | | | | 1 |

EXACT DESCRIPTION OF SAMPLING POINT: Diamond Fork Creek under U.S. Highway 50,6,89 Bridge (At mouth)

SOURCE OF SAMPLE: Stream

| Date of Sample Collection | Local Military Time | Discharge in CFS | Temperature in °C | Conductivity Micromhos/CM | pH | Turbidity Units | Total Dissolved Solids | Total Alkalinity as $CaCO_3$ | Bicarbonate ($HCO_3$) | Calcium (Ca) | Carbonate ($CO_3$) | Chloride (Cl) | Dissolved Oxygen ($O_2$) | Hardness Total as $CaCO_3$ | Magnesium (Mg) | Nitrate ($NO_3$) | Nitrite ($NO_2$) | Phosphate ($PO_4$) | Potassium (K) | Sodium (Na) | Sulfate ($SO_4$) | Information Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | SUBSTANCES IN MILLIGRAMS PER LITER | | | | | | | | | | | | | | | |
| 6/20/56 | | | | 350 | | | 202 | | 192 | 42 | | 6.5 | | 172 | 17 | 1.6 | | | $\underbrace{9.6}$ | | 24 | 2 |
| 11/20/69 | 1345 | | 7 | 635 | 8.53 | | 329 | | | | | | | | | | | | | | | 1 |

EXACT DESCRIPTION OF SAMPLING POINT: Thistle Creek under the U.S. Highway 89 Thistle Creek Bridge 0.2 miles from U. S. Highway 50.6

SOURCE OF SAMPLE: Stream

| DATE COLLECTED | LOCAL MILITARY TIME | DISCHARGE IN CFS | TEMPERATURE IN °C | CONDUCTIVITY MHOS/CM | PH | TURBIDITY UNITS | SUBSTANCES IN MILLIGRAMS PER LITER: TOTAL DISSOLVED SOLIDS | TOTAL ALKALINITY AS $CaCO_3$ | BICARBONATE ($HCO_3$) | CALCIUM (Ca) | CARBONATE ($CO_3$) | CHLORIDE (Cl) | DISSOLVED OXYGEN ($O_2$) | HARDNESS TOTAL AS $CaCO_3$ | MAGNESIUM (Mg) | NITRATE ($NO_3$) | NITRITE ($NO_2$) | PHOSPHATE ($PO_4$) | POTASSIUM (K) | SODIUM (Na) | SULFATE ($SO_4$) | INFORMATION SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [illegible]/21/50 | | | | 424 | | | 250 | | 226 | 56 | | 13 | | 206 | 16 | 3.9 | | | 12 | | 23 | 2 |
| [illegible]/56 | | | | 536 | | | 332 | | 284 | 51 | | 23 | | 224 | 24 | 1.2 | | | 36 | | 34 | 2 |
| [illegible]/87 | 1410 | | 3.5 | 580 | 8.47 | | 307 | | | | | | | | | | | | | | | 7 |

EXACT DESCRIPTION OF SAMPLING POINT: Soldier Creek 0.25 miles upstream from the U.S. Highway 89 Soldier Creek Bridge at Thistle, Utah

SOURCE OF SAMPLE: Stream

| DATE OF SAMPLE COLLECTION | LOCAL MILITARY TIME | DISCHARGE IN CFS | TEMPERATURE IN °C | CONDUCTIVITY MICS/CM | PH | TURBIDITY UNITS | TOTAL DISSOLVED SOLIDS | TOTAL ALKALINITY AS CaCO3 | BICARBONATE ($HCO_3$) | CALCIUM (Ca) | CARBONATE ($CO_3$) | CHLORIDE (Cl) | DISSOLVED OXYGEN ($O_2$) | HARDNESS TOTAL AS $CaCO_3$ | MAGNESIUM (Mg) | NITRATE ($NO_3$) | NITRITE ($NO_2$) | PHOSPHATE ($PO_4$) | POTASSIUM (K) | SODIUM (Na) | SULFATE ($SO_4$) | INFORMATION SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/20/56 | | | | 565 | | | 338 | | 293 | 42 | | 15 | | 242 | 34 | 1.4 | | | $\underbrace{\quad 34 \quad}$ | | 53 | 2 |
| 11/20/69 | 1420 | | 1 | 855 | 8.49 | | 613 | | | | | | | | | | | | | | | 7 |
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the variability of the data.

The curves on the above mentioned figures were arrived at by a trial and error procedure as follows: first the points were plotted, next a reasonable curve was drawn, then the distances from the line to the points above the line were measured, summed, and compared to the sum of the distances from the line to the points below the line; these two sums were made to be equal by shifting and/or changing the shape of the curve. For simple curves this balance of points was attained for the full curve length. For complicated curves, as in Figure 18, a balance was attained for segments of the curve. Data with too much variability as in Figures 4 and 5 were averaged and shown as a straight line.

DISCUSSION - The results concerning Utah Lake's direct tributaries are shown on Figures 2 and 3. Provo River empties into Utah Lake with a better chemical quality than any other stream, with Hobble Creek being the closest rival. The next few streams in order of highest purity are the northern tributaries of Provo Bay which in reality are mainly Provo River water. It is interesting to notice that Geneva Steel's effluent, which was composed mainly of Provo River water and well water, had twice as much chemical pollutant as did the Provo River at its mouth.

Spring Creek and Steel Mill Drain at Kuhnis have lower ion concentrations during the summer than they have during the winter as shown on Figure 3. This pattern also appears in some of the curves on Figures 8 and 16. The pattern can be extrapolated up Diamond Fork Creek beyond the pollutional influence regions of man. Knowing that this pattern was a natural phenomenon, it was then noticed that the pattern probably varied in some inverse relationship with discharge. This led to the conclusion that the low winter flows which slowly trickle through the rocks and soil leach more ions per unit volume than do the large, swiftly moving summer flows with correspondingly less contact per cubic foot of water. This conclusion leads to the following hypotheses:

(1) A stream with this pattern is one of the following:

(a) a stream chemically unpolluted by man, or

(b) a stream chemically polluted by man in fairly constant amounts.

Steel Mill Drain at Kuhnis and Spring Creek are suspected of being the latter type since all water origins near these creeks have a much higher chemical purity as far as can be detected by the data in Appendix B.

(2) A stream without this pattern is one of the following:

(a) a stream of fairly constant discharge, or

(b) a stream chemically polluted by man at a higher rate during the summer than during the winter.

Many of the streams with straight line graphs on Figures 2 and 3 are suspected of being the latter type.

The results of a special study of Spanish Fork River and tributaries are given on Figures 7 and 8. As shown on Figure 7, Diamond Fork Creek has a sharp increase in conductivity from a point near its origin to a point just above Sixth Water Creek. It is believed that this increase in chemical pollution was due mainly to sulfur springs since the author noticed a few such springs in this stretch of the creek and observed no sulfur springs in any other stretch of this creek. Similarly, Sixth Water Creek shows a large increase in conductivity. It is possible that this increase was also due to sulfur springs, in which case the total number of ions entering Sixth Water remains fairly constant, and a larger volume of water coming down Sixth Water Creek would be correspondingly purer in chemical quality.

As expected, Diamond Fork Creek shows an increase in conductivity after receiving the rather highly chemically polluted Sixth Water Creek. Diamond Fork Creek continues to increase in conductivity until it reaches Palmyra Campground, indicating that the water coming down Monks Hollow, Red Hollow, and Wanrhodes Canyon is as a whole more polluted chemically than Diamond Fork Creek. From Palmyra Campground to its mouth, Diamond Fork Creek decreases in conductivity, indicating that the water coming down Little Diamond Creek and Brimhall Canyon has a better chemical quality than Diamond Fork Creek has. Diamond Fork Creek empties into Spanish Fork River with a typical annual pattern and at a higher chemical purity than the Spanish Fork River.

Referring to the data in Appendix B, Soldier Creek constantly increases in conductivity as it travels downstream. Soldier Creek, with a high conductivity, combines with Thistle Creek, which has a low conductivity, and thus the Spanish Fork River is formed. As is shown on Figure 8, the Spanish Fork River is diluted only at one point--where Diamond Fork Creek enters. The Spanish Fork River shows the same annual pattern from its origin to U.S. Highway 91 at Spanish Fork, Utah. Then the annual pattern changes drastically as shown on Figure 8. The Spanish Fork River at its mouth has the expected conductivity values during the winter, but the summer values, which are expected to be about 600 micromhos per centimeter, are three times this amount. These high values coincide with the irrigation season. Maps indicate that the irrigation return flow enters the Spanish Fork River between Spanish Fork, Utah, and Utah Lake. The irrigation water leaches out a considerable chemical load.

The results of a special study of the Provo River are given on Figure 16. The Duchesne River water is shown to indicate that we are not getting any chemical pollution into the Provo River from a foreign drainage. The Provo River near Hailstone is chemically fairly pure water and has a definite annual pattern.

The Provo River as it leaves Deek Creek Reservoir has two interesting features. First it is noticed that the annual pattern has shifted and is approximately one month behind the pattern at Hailstone. This is due to the delay of the water as it travels through the reservoir. The second feature of this curve is that it indicates a much higher concentration of ions. This is caused partially by evaporation, but the main cause is that most of the other tributaries into Deer Creek Reservoir have higher concentrations than the Provo River has. As seen in Appendix B, the northwestern tributaries of Deer Creek Reservoir are particularly high in conductivity.

The Provo River at Murdock Diversion Dam also shows two features of interest. First it is seen that the water here is chemically purer than it was as it left Deer Creek Reservoir. This occurs since the tributaries in Provo Canyon dilute the Provo River water. The data in Appendix B substantiate this statement. Second it is seen that there is not such a large annual variation at this point in the river as there was above Provo Canyon. One reason for this is that Provo River's tributaries in Provo Canyon have an annual pattern that is out of phase from the Provo River's annual pattern, due to the delay time in Deer Creek Reservoir. The sum of two such curves when out of phase produces a curve with a smaller amplitude and greater wave length.

The final curve in this study is of the Provo River at Geneva Road. This curve indicates that during the entire year a fairly large amount of chemical pollutants enter the river downstream from Murdock Diversion Dam. The small hump in the curve during the summer months, which is similar to the Spanish Fork River situation, indicates returning irrigation water.

CONCLUSIONS

1. Provo River is chemically the purest tributary to Utah Lake.

2. The Provo River is diluted as it travels through Provo Canyon, polluted as it continues toward Utah Lake, and enters the Lake at a chemical purity approximately equal to the Provo River as it leaves Deer Creek Reservoir.

3. It is concluded that the summer increase in chemical pollution in the Provo River is caused by irrigation return flow.

4. Tributaries to Utah Lake in order of chemical purity following the Provo River are: Hobble Creek; the northern tributaries to Provo Bay; Powell Slough; all tributaries north of Powell Slough plus Spring Creek (tributary to Provo Bay); the rest of the Provo Bay tributaries; Spanish Fork River; all Utah Lake tributaries south of Spanish Fork River.

5. Sixth Water Creek chemically pollutes Diamond Fork Creek.

6. Diamond Fork Creek chemically dilutes Spanish Fork River.

7. It is concluded that due to irrigation return flow the Spanish Fork River has a chemical concentration during the summer months of three times the value it would otherwise have.