PHYSICAL CHARACTERISTICS AND QUALITY OF WATER FROM SELECTED SPRINGS AND WELLS IN THE LINCOLN POINT - BIRD ISLAND AREA, UTAH LAKE, UTAH

by Robert L. Baskin, Lawrence E. Spangler, and Walter F. Holmes

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
foot	0.3048	meter
foot per day	0.3048	meter per day
inch	25.4	millimeter
	0.0254	meter
mile	1.609	kilometer
square mile	2.59	square kilometer
cubic foot per second	28.32	liter per second

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$^{o}F = 1.8\ (^{o}C) + 32$$

Temperatures reported in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by the following equation:

$$^{o}C = 0.56\ (^{o}F - 32)$$

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Chemical concentration and water temperature are given only in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is given in microsiemens per centimeter (µS/cm) at 25 degrees Celsius. Radioactivity is expressed in picocuries per liter (pc/L), which is the quantity of radioactive decay producing 2.2 disintegrations per minute in a unit volume (liter) of water. Chemical concentration in terms of ionic interacting values is given in milliequivalents per liter (meq/L). Meq/L is numerically equal to equivalents per million.

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ABSTRACT

From February 1991 to October 1992, the U.S. Geological Survey, in cooperation with the Central Utah Water Conservancy District, investigated the hydrology of the Lincoln Point - Bird Island area in the southeast part of Utah Lake, Utah. The investigation included measurements of the discharge of selected springs and measurements of the physical and chemical characteristics of water from selected springs and wells in the Lincoln Point - Bird Island area.

This report contains data for twenty-one distinct springs in the study area including two springs beneath the surface of Utah Lake at Bird Island. Data from this study, combined with data from previous studies, indicate that the location of springs in the Lincoln Point - Bird Island area probably is controlled by fractures that are the result of faulting. Measured discharge of springs in the Lincoln Point - Bird Island area ranged from less than 0.01 cubic foot per second to 0.84 cubic foot per second. Total discharge in the study area, including known unmeasured springs and seeps, is estimated to be about 5 cubic feet per second.

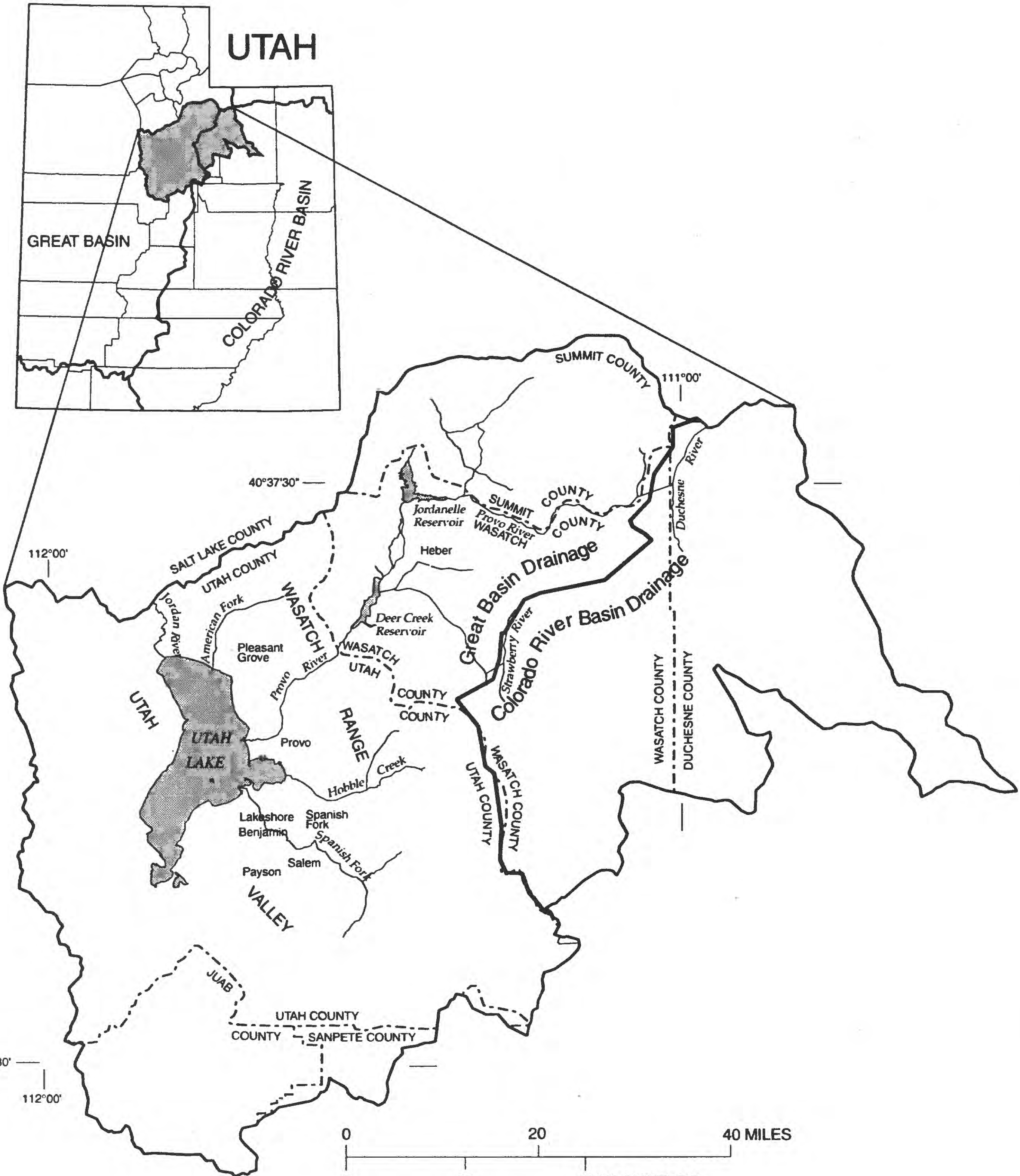
Reported and measured temperatures of water from springs and wells in the Lincoln Point - Bird Island area ranged from 16.0 degrees Celsius to 36.5 degrees Celsius. Dissolved-solids concentrations ranged from 444 milligrams per liter to 7,932 milligrams per liter, and pH ranged from 6.3 to 8.1. Physical and chemical characteristics of spring and well water from the west side of Lincoln Point were virtually identical to the physical and chemical characteristics of water from the submerged Bird Island springs, indicating a similar source for the water. Water chemistry, isotope analyses, and geothermometer calculations indicate deep circulation of water discharging from the springs and indicate that the source of recharge for the springs at Lincoln Point and Bird Island does not appear to be localized in the Lincoln Point - Bird Island area.

INTRODUCTION

The Central Utah Project (CUP) is a Federal/State project to develop water in the Colorado River Basin of eastern Utah for diversion to, and use in, the Great Basin of western Utah (fig. 1). Utah Lake, in Utah Valley, will be used to store some of the Colorado River Basin water developed by the CUP. Some of the streamflow to Utah Lake will be diverted directly for municipal and industrial uses in northern Utah County and Salt Lake County. As a result of this diversion of water from Utah Lake, the salinity of the lake is predicted to increase (Central Utah Water Conservancy District, 1989, p. 4).

In an effort to keep the salinity of Utah Lake at its current level, the Central Utah Water Conservancy District (CUWCD), the operator of CUP, would like to control and divert the sources of saline-water inflow to Utah Lake including several warm, saline springs in the vicinity of Lincoln Point and Bird Island (fig. 2). The Lincoln Point - Bird Island springs are reported to "contribute a relatively large percent of salts to the lake, but a very small percent of the flow" (Central Utah Water Conservancy District, 1989, p. 10). The potential diversion of these springs is predicted to decrease the dissolved-solids concentration of Utah Lake by about 350 milligrams per liter (Central Utah Water Conservancy District, 1989, fig. 21).

From February 1991 to October 1992, the U.S. Geological Survey, in cooperation with the Central Utah Water Conservancy District, studied the hydrology of the Lincoln Point - Bird Island area. The investigation was designed to describe the physical characteristics and quality of water from selected



Base from U.S. Geological Survey digital data, 1:100,000, 1979 and 1980
Universal Transverse Mercator projection,
Zone 12

Figure 1. Location of Central Utah Project area contributing to Utah Lake.

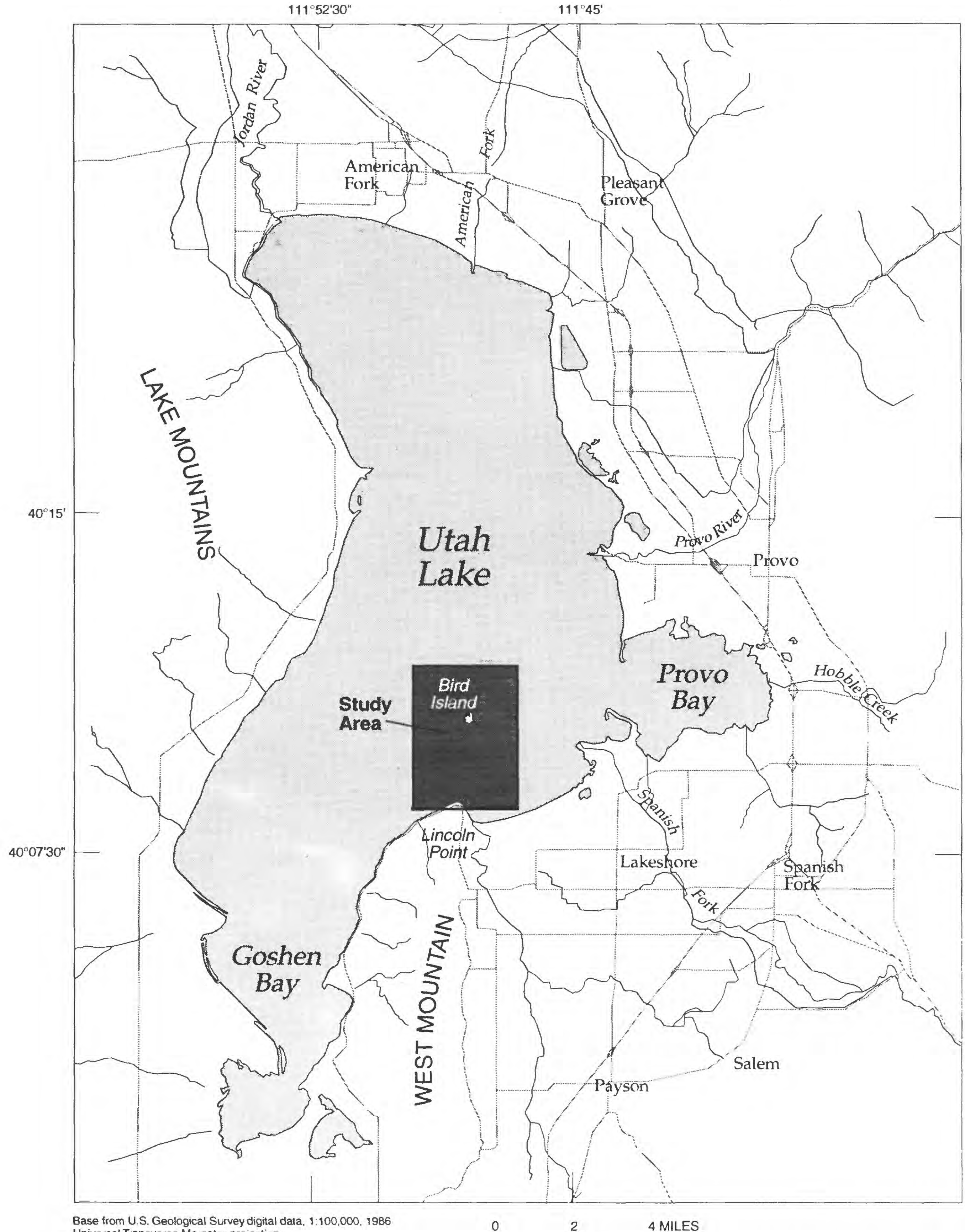


Figure 2. Utah Valley and location of study area.

springs and wells in the Lincoln Point - Bird Island area; to obtain the locations of measured springs and wells; to measure the discharge of known warm, saline springs; and to determine, if possible, the geologic source and path of the warm, saline water discharging from the springs. The results of this investigation are being used by the Central Utah Water Conservancy District to refine the water and chemical budgets of Utah Lake and to provide information that can be used to manage the surface water and ground-water resources of Utah Valley.

Purpose And Scope

This report describes the methods of investigation and results of surveys and tests done by the U.S. Geological Survey in the Lincoln Point - Bird Island area between February 1991 and October 1992. The report also summarizes water-quality and discharge data for springs referenced in previous studies. Relations between spring discharge, water quality, ground-water movement, and geologic structures in the Lincoln Point - Bird Island area also are discussed.

Previous Investigations

Site-specific data for springs in the Lincoln Point - Bird Island area are included in reports by Clarke and Chatard (1884), Richardson (1906), Decker and Maw (1933), Subitzky (1962), Viers (1964), Milligan and others (1966), Bradshaw and others (1969), Cordova (1969, 1970), Mundorff (1970), Dustin (1978), and Central Utah Water Conservancy District (1990). These reports primarily contain information about the water quality or discharge of water from warm springs in the area. Other reports, such as those by Fuhriman and others (1975), Goode (1978), Dustin and Merritt (1980), Davis and Cook (1983), and Central Utah Water Conservancy District (1989), used data from these reports to examine the distribution of springs, salt loads, flows, and water quality of the springs in the Lincoln Point - Bird Island area.

Topographic and bathymetric data for the Lincoln Point - Bird Island area are contained in a series of maps produced by the U.S. Bureau of Reclamation (1963a, 1965a, 1965-66, 1982, and no date). These include Goshen Bay Dike East Abutment Topography (1965a, 2 sheets), West Mountain Borrow Area Topography (1965, 1966, 13 sheets), Goshen Bay Dike East Abutment Topography (1982, 14 sheets), and Utah Lake Area Topography (no date, 73 sheets). Topography for the Bird Island area is found in Utah Lake Bird Island Topography (1963a, 1 sheet) and on a Central Utah Water Conservancy District map generated from photography (unpub. data, November 17, 1989). Bathymetric data for Utah Lake are found in Jensen (1972).

Numbering System for Hydrologic-Data Sites in Utah

The system of numbering springs and wells in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the site, describes its position in the land net. By the land-survey system, the State of Utah is divided into four quadrants by the Salt Lake Base Line and the Salt Lake Meridian. These quadrants are designated by the upper case letters A, B, C, and D, which indicate respectively, the northeastern, northwestern, southwestern, and southeastern quadrants. Numbers that designate the township and range (in that order) follow the quadrant letter, and the three are enclosed in parentheses. The number after the parentheses indicates the section, and is followed by three letters that indicate the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section—generally 10 acres[1] for regular sections. The lower-case letters a, b, c, and d indicate, respectively, the northeastern, northwestern, southwestern, and southeastern quarters of each subdivision. The number after the letters is the serial number of the site within the 10-acre tract. The letter 'S' preceding the serial number denotes a spring. For the purposes of this report, the designation letter 'F' preceding the serial number denotes a flume installation. Thus, (D-8-1)3dda-1 designates the first well constructed or visited in the northeastern 1/4 southeastern 1/4 southeastern 1/4 Sec. 3, T. 8 S., R. 1 E. The numbering system is illustrated in figure 3.

DESCRIPTION OF STUDY AREA

The Lincoln Point - Bird Island study area, along the southern edge of Utah Lake, north of West Mountain, in Utah County, Utah (fig. 2), encompasses about 10 square miles. The lake surface constitutes about 95

[1]Although the basic land unit, the section, is theoretically 1 square mile, many sections are irregular. Such sections are subdivided into 10 acre tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

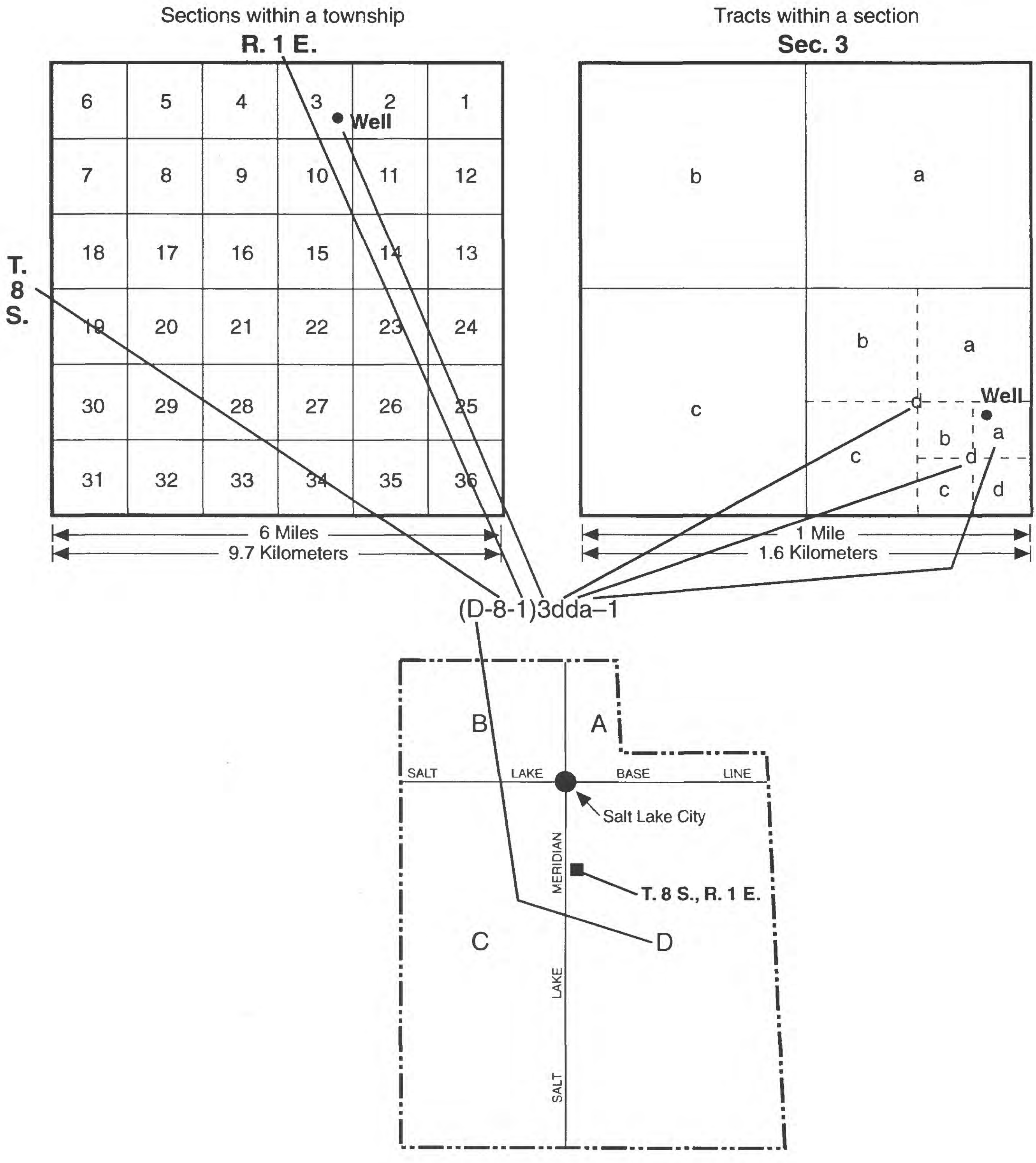


Figure 3. Numbering system for geohydrologic-data sites in Utah.

percent of the total area. The actual percentage of lake surface in the study area varies because of seasonal and long-term fluctuations in the level of Utah Lake. Most of the land surface in the study area consists of travertine deposits, including Bird Island and the shoreline at Lincoln Point. Utah Lake, which surrounds and makes up most of the study area, is at the eastern edge of the Basin and Range Province (Fenneman, 1931) and is a remnant of Lake Bonneville of Pleistocene Age (Gilbert, 1890).

The maximum altitude in the study area is about 4,540 feet along the northern edge of West Mountain. The minimum known altitude is about 4,463 feet at the bottom of a depression in lake-bottom sediments beneath the surface of Utah Lake, west of Bird Island. This depression is caused by discharge from a spring that prevents the accumulation of sediment over the spring orifice. The mean altitude of the lake bottom within the study area is about 4,477 feet.

Geohydrologic setting

Water-bearing formations in the Lincoln Point - Bird Island area include fractured conglomerate, travertine and tufa, and unconsolidated lake deposits (U.S. Bureau of Reclamation, 1965b). The movement of water through these formations is influenced by geologic structure, ground-water head gradients, and the altitude of the surface of Utah Lake. The study area can be divided into three distinct geohydrologic sub-areas: Lincoln Point, Bird Island, and the bottom sediment of Utah Lake, each with characteristic geohydrology.

Lincoln Point is at the north end of West Mountain, a complex north and south trending, steep-sided, isolated horst formed by large-scale displacement faulting (U.S. Bureau of Reclamation, 1965b). Older bedrock formations of West Mountain are folded and broken by many faults, and consist of limestone and quartzite of the Oquirrh Formation of Paleozoic age. The dip of the bedding at West Mountain ranges from about 30 degrees to 90 degrees, and some beds have been overturned.

Overlying the older bedrock formations in the Lincoln Point area is the North Horn Formation of Cretaceous and Tertiary age, a moderately cemented, rounded sand and gravel conglomerate with a red clay matrix (U.S. Bureau of Reclamation, 1965b). This conglomerate is fractured, yields water from well LPW-3 (fig. 4), and is exposed along the break in slope at Lincoln Point.

Overburden in the Lincoln Point area consists almost entirely of slopewash characterized by rounded, clayey gravel with varying amounts of subangular boulders derived from weathering of the conglomerate, limestone, and quartzite formations to the south (U.S. Bureau of Reclamation, 1965b). Springs along the shore at Lincoln Point discharge warm, saline water from rounded gravel at the edge of the overburden.

The area along Lincoln Point below an altitude of about 4,485 feet consists of travertine and tufa deposits interbedded with unconsolidated lake sediment. The travertine and tufa deposits extend about 1 mile to the east of Lincoln Point and about 3 miles to the west into Goshen Bay. The travertine and tufa deposits generally are irregular and thinly bedded. These deposits frequently occur as cementing material in the gravel along the Utah Lake shoreline. Travertine deposits have been encountered in drillhole PRG-1 (fig. 5) at a depth of 19.5 feet below lake bottom, about 2,000 feet northwest of the shoreline at Lincoln Point (U.S. Bureau of Reclamation, 1963b), and may extend farther into Utah Lake.

Bird Island is a small island (about 0.05 square mile when the water level in Utah Lake is at an altitude of 4,486 feet) about 2 miles north-northeast of Lincoln Point. It is composed of travertine and tufa deposits with wave-worked, rounded travertine and tufa gravel along the island beaches. Warm, saline springs discharge along the edge of the island and beneath the surface of Utah Lake in embayments formed by deposition of travertine from spring water.

Lake-bottom sediment in the study area consists primarily of calcium carbonate mud containing small concentrations of magnesium, strontium, and other impurities (Brimhall and Merritt, 1981, p. 30). Drillers' logs (U.S. Bureau of Reclamation, 1963b) reported interbedded clay, silt, and sand in drillholes PRG-2, PRG-3, PRG-4, PRG-21, PRG-22, and PRG-23, all of which are in the study area (fig. 5). In the areas immediately surrounding Lincoln Point and Bird Island, travertine and tufa deposits are exposed at the bottom of the lake and are reported to be interbedded with lake sediment (U.S. Bureau of Reclamation, 1965b, p. 3).

Climate

No specific climatologic data are available for the Lincoln Point - Bird Island study area. Data are available for the Provo BYU weather station (Brough and others, 1983), about 10 miles northeast of the study area and about 90 feet above the surface of Utah Lake. Data

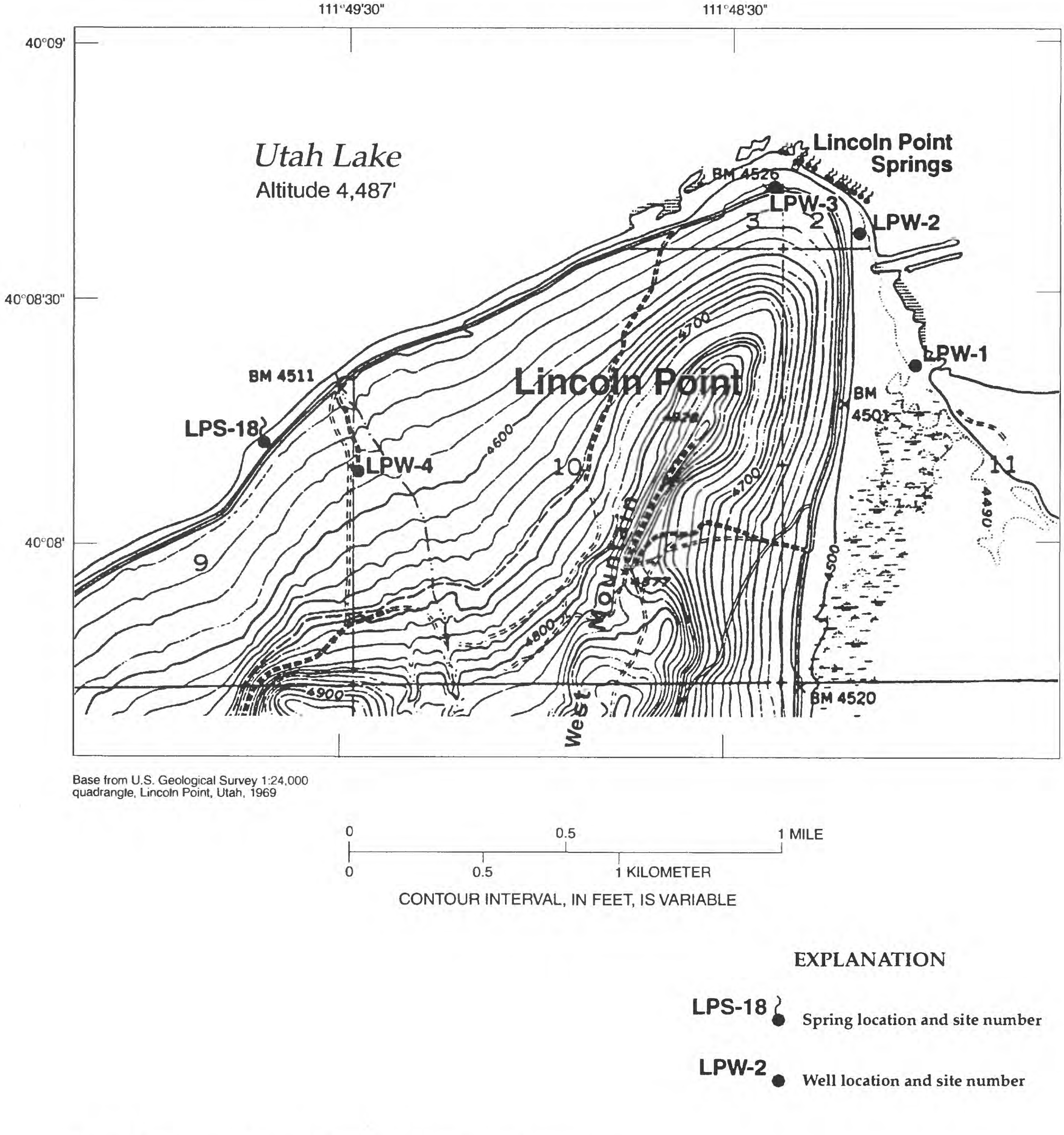


Figure 4. Location of springs & wells in the Lincoln Point area.

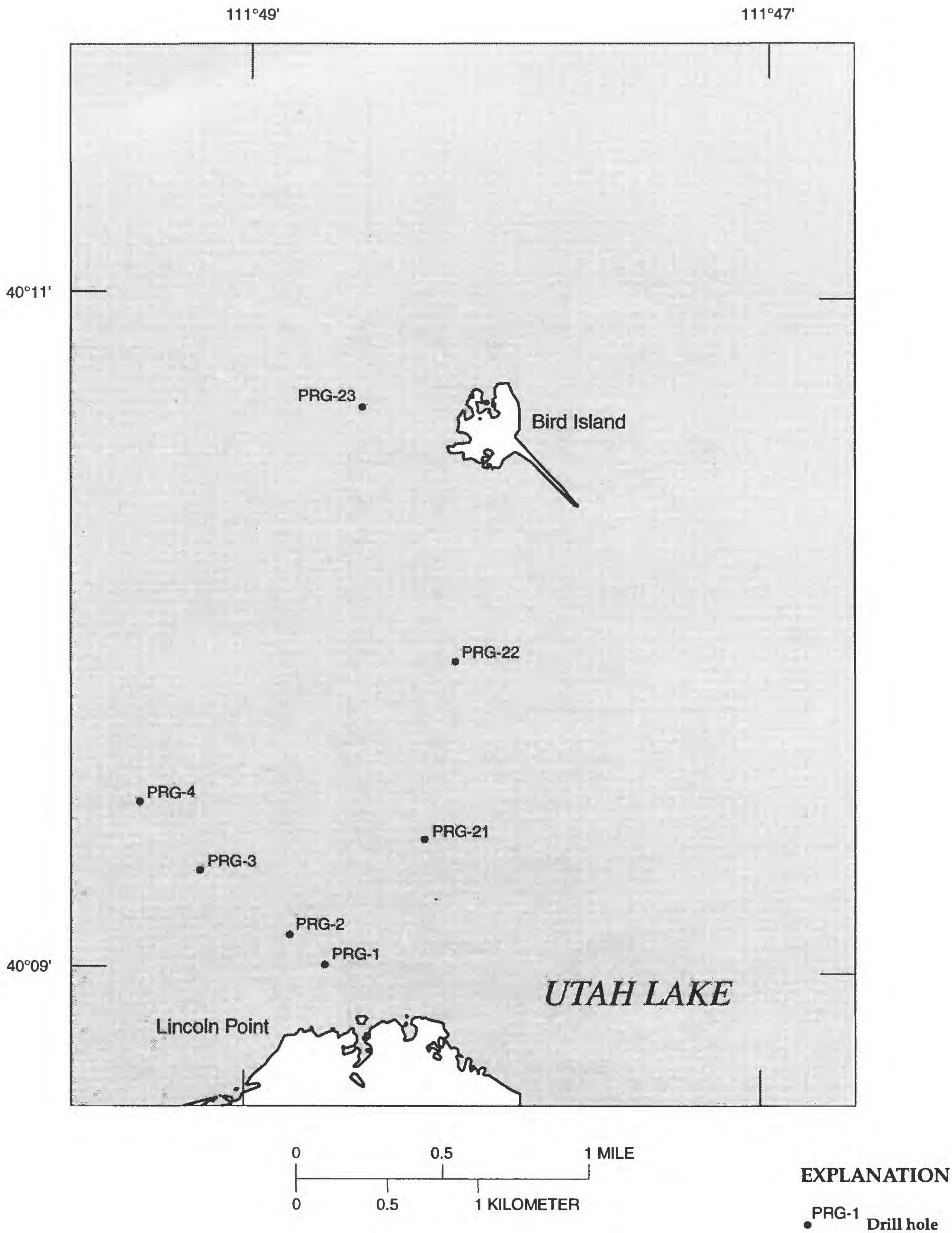


Figure 5. Location of Bureau of Reclamation drill holes (Data from Bureau of Reclamation, 1963b).

also are available for the Utah Lake Lehi weather station (National Oceanographic and Atmospheric Administration, 1987) about 17 miles north of the study area and about 15 feet above the surface of Utah Lake.

The climate of the Utah Lake area is semi-arid (Jackson and Stevens, 1981, p. 9). The 1951-80 normal annual precipitation at the Provo BYU weather station was 14.83 inches. The 1951-80 normal annual precipitation at the Utah Lake Lehi weather station is 10.66 inches. The largest quantity of precipitation falls during April with a 1951-80 normal of 2.11 inches at the Provo BYU weather station and 1.25 inches at the Utah Lake Lehi weather station.

Annual temperature normals (1951-80) range from a low of 36.1 degrees Fahrenheit to a high of 66.0 degrees Fahrenheit at the Provo BYU weather station. Annual temperature normals at the Utah Lake Lehi weather station range from a low of 34.7 degrees Fahrenheit to a high of 62.5 degrees Fahrenheit. The mean daily temperature at the Utah Lake Lehi weather station is 48.6 degrees Fahrenheit. The warmest months for both weather stations are June through August, and the coolest months are December through February.

Estimated pan evaporation at the Provo BYU weather station is 65.47 inches with most evaporation (11.71 inches) occurring during July. Estimated pan evaporation at the Utah Lake Lehi weather station is 70.37 inches with most evaporation (13.02 inches) also occurring during July (Brough and others, 1983).

Surface water

No surface water enters the study area except for a small quantity of runoff from precipitation and direct precipitation to the lake surface. The water level in Utah Lake is controlled primarily by inflow from major streams that have headwaters in the Wasatch Range, by outflow down the Jordan River, by withdrawal from the lake, and by evaporation. Major surface-water contributors to Utah Lake include the Provo, Spanish Fork, and American Fork Rivers, and Hobble Creek (figs. 1 and 2). Major interbasin diversions of water into the Utah Lake drainage come from the Duchesne, Strawberry, and Weber Rivers (Mundorff, 1974). Minor perennial and intermittent streams, drains and sloughs, and runoff from irrigation, sewage effluent, and flowing wells also contribute surface-water inflow to Utah Lake (Mundorff, 1974, p. 1 and 3). Utah Lake provides water for irrigation, culinary use, industry, and recreation, and is classified as a warm-water fishery (Utah Department of Health, 1988, p. 39).

Historic water levels of Utah Lake have ranged from 4,477.22 feet in October 1935 to 4,494.74 feet in June 1984. Lake levels during the period of study for this report ranged from 4,482.67 feet on October 3, 1991, to 4,485.34 feet on June 1, 1991 (David B. Gardner, Utah Lake and Jordan River Water Commissioner, oral commun., 1992).

METHODS OF INVESTIGATION

Springs in the Lincoln Point - Bird Island area were found through on-site surveys of the land areas of Lincoln Point and Bird Island, examination of aerial photographs, investigation of circular travertine embayments, and by examination of thermal differences between lake and spring water near Lincoln Point and Bird Island. Discharge of springs at an altitude above that of the lake surface was measured using a current meter and modified Parshall flumes. Discharge of springs below the surface of Utah Lake was measured using a current meter. Samples were collected for water-quality analysis from springs above and beneath the surface of Utah Lake at Lincoln Point and Bird Island and from wells at Lincoln Point. Topographic and bathymetric surveys were done as part of an effort to define relations between spring orifice location and topographic features in the study area and to obtain accurate locations for springs and wells.

Locating springs and wells

An areal reconnaissance was done for the Lincoln Point - Bird Island area during March 1991 to identify spring-discharge locations, inventory wells, and to locate and record geologic features associated with the springs. Spring and well locations, relations of the springs and wells to surface topography, physical characteristics of spring orifices, and the approximate discharge of springs were recorded during the reconnaissance. Information was collected on the construction of wells, water levels in wells, and the location of survey markers.

Aerial photographs were obtained for the Lincoln Point - Bird Island area from the archives at the U. S. Department of Agriculture Agricultural Stabilization and Conservation Service (ASCS) Aerial Photography Field Office in Salt Lake City, Utah, and from low-altitude flights during the study. These data were collected to determine the distribution of springs in each area, locate any previously unknown springs, record changes in the shoreline related to lake-level fluctuations, determine if submarine springs could be visually identified aerially, and to provide a photographic record of the area.

Photographs taken on July 27, 1965, were obtained for Lincoln Point, and photographs taken on August 22, 1988, were obtained for the Lincoln Point - Bird Island area from the archives at the ASCS Aerial Photography Field Office. Photographs of Lincoln Point and Bird Island were taken April 9 and October 5, 1991, and February 24, 1992, and are available for inspection at the U.S. Geological Survey, Water Resources Division, in Salt Lake City, Utah.

Springs beneath the surface of Utah Lake at Bird Island were found by investigating circular travertine embayments and by using thermal differences between the spring water and lake water. Depressions in lake-bottom sediments in these embayments and warmer temperatures near the springs enabled divers to locate the springs. Submarine springs could not be visually identified on the available aerial photography.

For the purposes of this report and to avoid any confusion with springs described in previous reports, springs identified during this study in the Lincoln Point area were labeled LPS, wells located in the Lincoln Point area were designated LPW, and springs located in the Bird Island area are designated BIS.

Measuring discharge of springs

Discharge was measured at selected springs above the level of Utah Lake in the Lincoln Point area and at springs beneath the lake surface at Bird Island. Spring discharge data for the Lincoln Point and Bird Island areas also were compiled from past investigations (Milligan and others, 1966). Measurements of discharge for this study were made using U.S. Geological Survey-approved field-measurement techniques (U.S. Geological Survey, 1977).

Spring-discharge measurements above the surface of Utah Lake were obtained using a current meter and modified Parshall flumes. A current meter was used when flume installation was not possible. The water level of a spring-fed pond was measured using a staff gage, and during an interference test, using a pressure transducer calibrated to the staff gage. Location of flume measuring sites in the Lincoln Point area are labeled LPF for the purposes of this report.

Determination of spring discharge beneath the surface of Utah Lake involved measuring the velocity using a current meter and measuring the area of the spring orifice. For measurement using a current meter, one blade of a calibrated Hoff meter was marked and the meter was inserted into the spring orifice and moved through the plane of discharge. Revolutions of the Hoff meter blades were counted by a diver and checked to provide an average velocity for the discharge. The area of the orifice was measured using a folding rule.

Collection of water samples

Water-quality data were collected during the latter one-half of the 1991 water year and the 1992 water year from springs and wells on Lincoln Point above the lake surface and from springs beneath the lake surface at Bird Island. All water samples from springs were collected at the point of discharge from the spring orifice. Water-quality data also were compiled from past investigations (Decker and Maw, 1933; Subitzky, 1962; Milligan and others, 1966; Cordova, 1969; Dustin, 1978; and Dustin and Merritt, 1980).

Water-quality samples collected from springs beneath the surface of Utah Lake were obtained by lowering flexible tubing into the orifice and pumping the sample directly from the spring to the surface of the lake using a peristaltic pump. Water temperature was taken at the orifice by a diver, and specific conductance and pH were measured after the sample was pumped to the surface of the lake. To obtain an uncontaminated sample, the peristaltic pump was flushed with spring water for at least 15 minutes before specific conductance and pH were measured and the sample for water-quality analysis was taken.

Water samples from wells were obtained by pumping water from the well. Submersible pumps were installed in each of the sampled wells and operated for a period sufficient to remove at least 5 casing volumes of water from the well before the sample was collected. Temperature, pH, specific conductance, and alkalinity were determined at the well site immediately following collection of the sample.

Topographic and bathymetric surveys

Topographic and bathymetric surveys were done as part of an effort to define relations between spring locations and topographic features. The topographic survey also was used to obtain accurate locations for springs and wells.

Topographic data were obtained for shore and near-shore areas at Lincoln Point and Bird Island using conventional surveying techniques. Surveys were done September 30 through October 4, 1991, using a total-station surveying instrument and three rod persons. Topographic data collected for this study included the location of springs and wells, the location of buildings and other man-made structures, and land-surface (topographic) data. Near-shore topographic data were collected for the bottom of Utah Lake near Lincoln Point and the area immediately surrounding Bird Island. Topographic data collected above and beneath the lake surface were combined with previous surveys (U.S. Bureau of Reclamation, 1963a, 1965a, 1965-66, 1982, and Central Utah Water Conservancy District (unpub. data, July 5, 1989), to produce composite maps (plates 1 and 2).

Bathymetric data were obtained for parts of Utah Lake including the areas between Lincoln Point and Bird Island and the area immediately surrounding Bird Island. Bathymetric data were collected on October 11, 1991, using a global positioning system and a paper-chart depth recorder. Depth data were continuously recorded on a paper-chart depth recorder for each of the 13 survey lines (fig. 6). Position data were obtained along the lines about every 250 meters using a global positioning system, and the position was marked on the paper chart. Depth measurements were manually checked using a graduated rod and recorded at each position fix (fig. 6) to ensure accurate corrections for depth of the transducer beneath the lake surface. Uncertainty in position was estimated to be less than 20 meters (Steve Ault, Magnavox Corporation, oral commun., 1992). The maximum depth recorded during the bathymetric survey was about 6.8 feet or an altitude of 4,475.94 feet. Bathymetric data were subtracted from lake-surface altitude and a contour map of the lake bottom was prepared (fig. 7). Original survey data are on file at the U.S. Geological Survey, Water Resources Division, in Salt Lake City, Utah.

PHYSICAL CHARACTERISTICS OF SELECTED SPRINGS

Springs are present above the Utah Lake shoreline (at about 4,483 feet) in the study area at Lincoln Point and at Bird Island. Springs beneath the surface of Utah Lake have been identified inside circular embayments at Bird Island. Springs discharge from sand, gravel, and rounded cobbles in the Lincoln Point area and from travertine deposits above and below the lake surface at Bird Island. Many of the springs at Lincoln Point discharge at discrete locations; however, diffuse seepage through the unconsolidated surface materials is widespread.

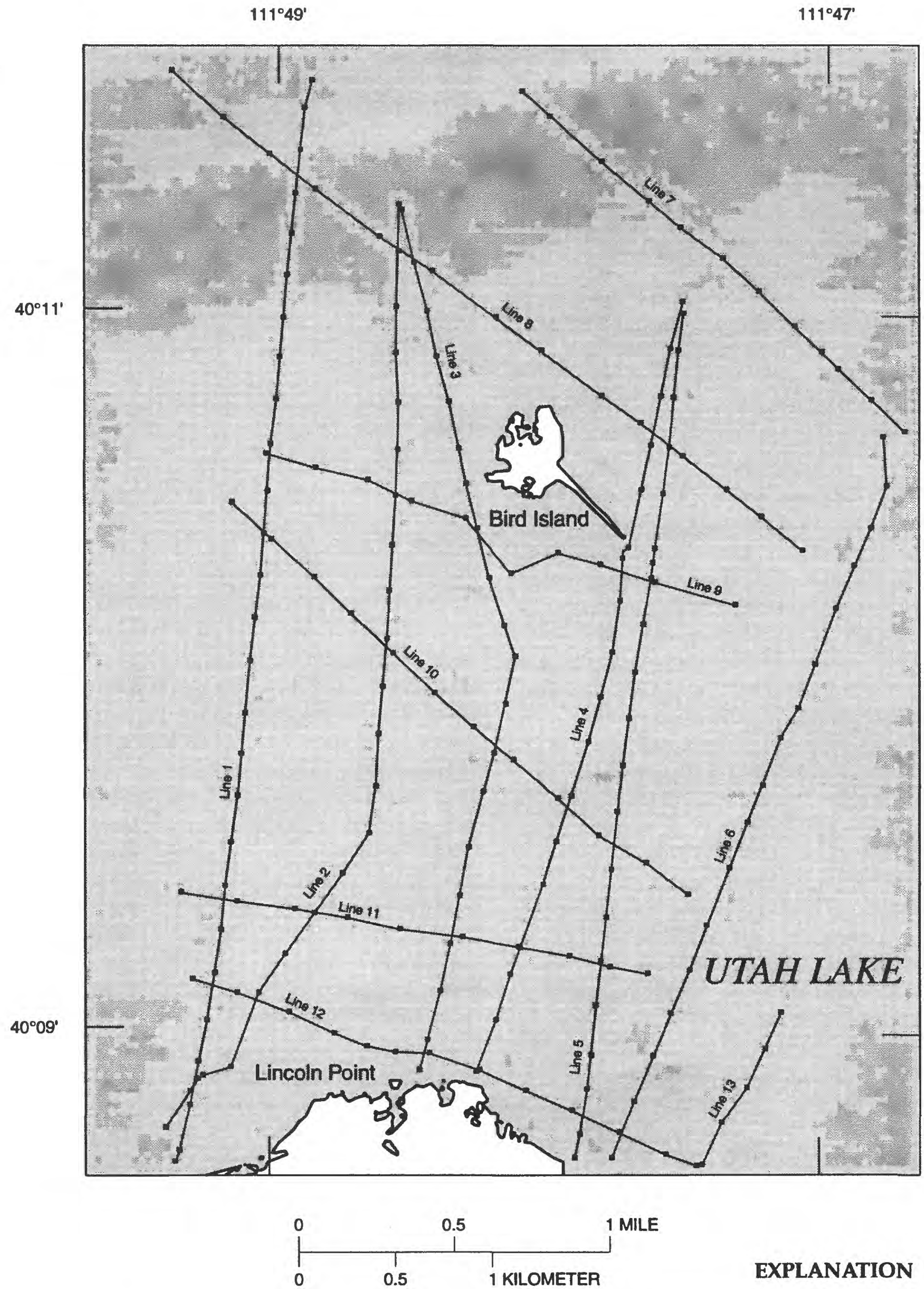
Physical characteristics of springs include the location, orifice characteristics, relation of the spring to topography or structural features, discharge, and the relation of the spring discharge to ground water in the area. These characteristics may change over time as the forces controlling the characteristics change.

Location and Orifice Characteristics

The location of springs and measuring sites reported in previous reports generally were not accurate enough to locate specific springs. Development efforts and fluctuations in the water level of Utah Lake have affected the location of springs and the topography of Lincoln Point and Bird Island. Consequently, many of the measurements from previous reports cannot be directly compared with measurement data from this study.

Most of the springs in the Lincoln Point area are aligned along a northwest trend, parallel to the northeastern edge of Lincoln Point (fig. 8), and are at an altitude of about 4,488 feet. The springs are at the base of a break in slope (fig. 9) and discharge through wave-worked sand, gravel, and cobbles. Sand, gravel, and cobbles in the Lincoln Point area appear to be remnants of wave-worked travertine, tufa, and slope wash along the edge of Lincoln Point and were probably formed during a period of high lake levels. Some of the springs discharge from areas primarily composed of broken travertine and tufa and are suspected to issue directly from consolidated travertine and tufa deposits beneath the broken surface materials.

Many of the springs in the Lincoln Point - Bird Island area discharge at discrete locations; however, diffuse seepage through the unconsolidated surface materials at Lincoln Point is widespread. Most of the diffuse springs (seeps) discharge from gravel, cobbles, and boulders along the northern edge of Lincoln Point (fig. 10). These seeps are frequently characterized by year-round vegetation. Discharge from these seeps generally cannot be measured because of the small quantity of discharge and widespread dissemination of the flow. Discharge from springs and seeps in the Lincoln Point area generally flows to the north over surface travertine and tufa deposits and into Utah Lake. Some of this flow may re-enter the travertine and tufa deposits before reaching the lake and discharge below the initial spring site.



EXPLANATION

Bathymetric survey line

▪ Location where depth of water was measured with survey rod

Figure 6. Location of bathymetric survey lines and control locations.

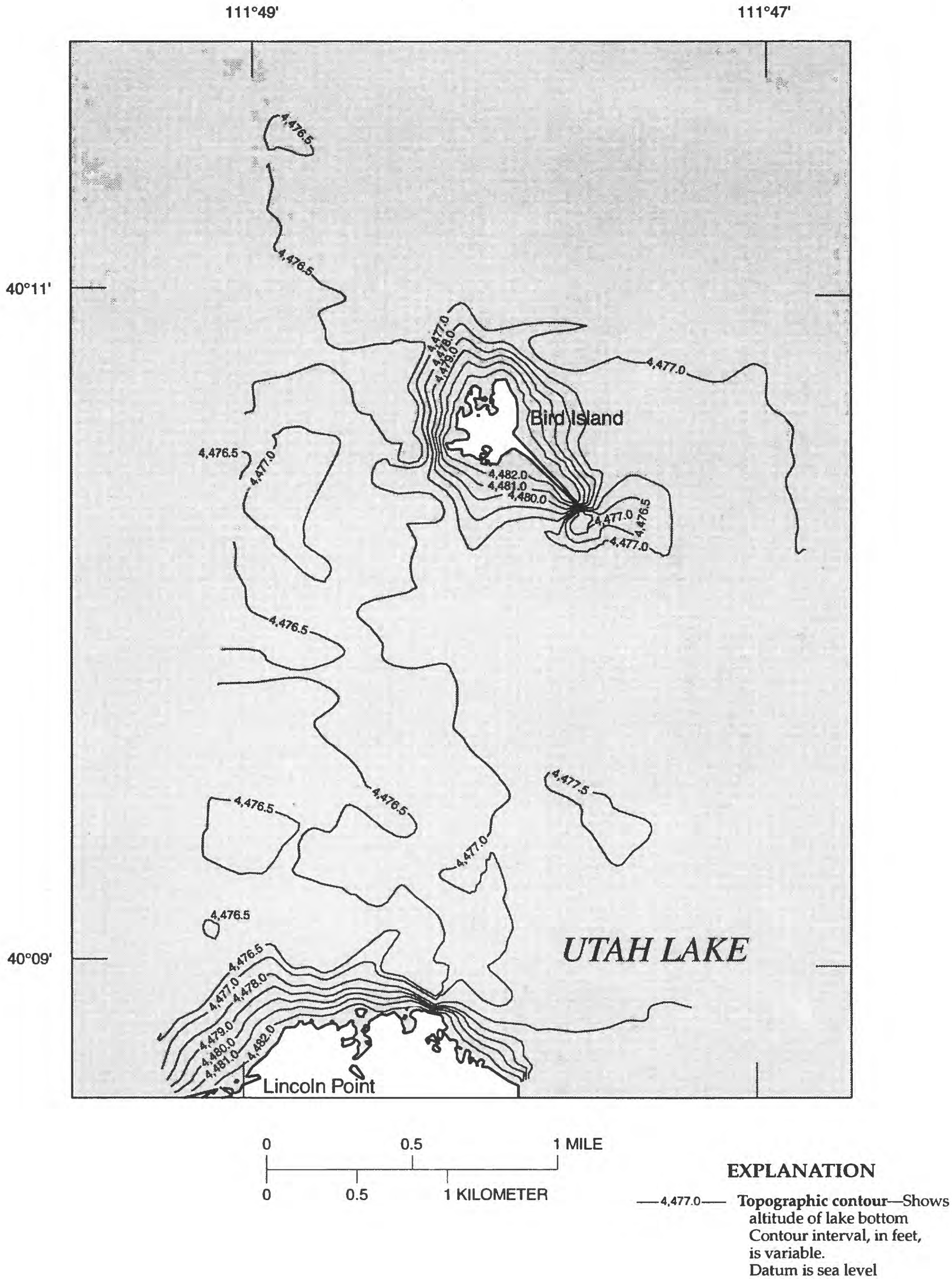


Figure 7. Computer-generated contours of lake-bottom altitude from bathymetric survey.

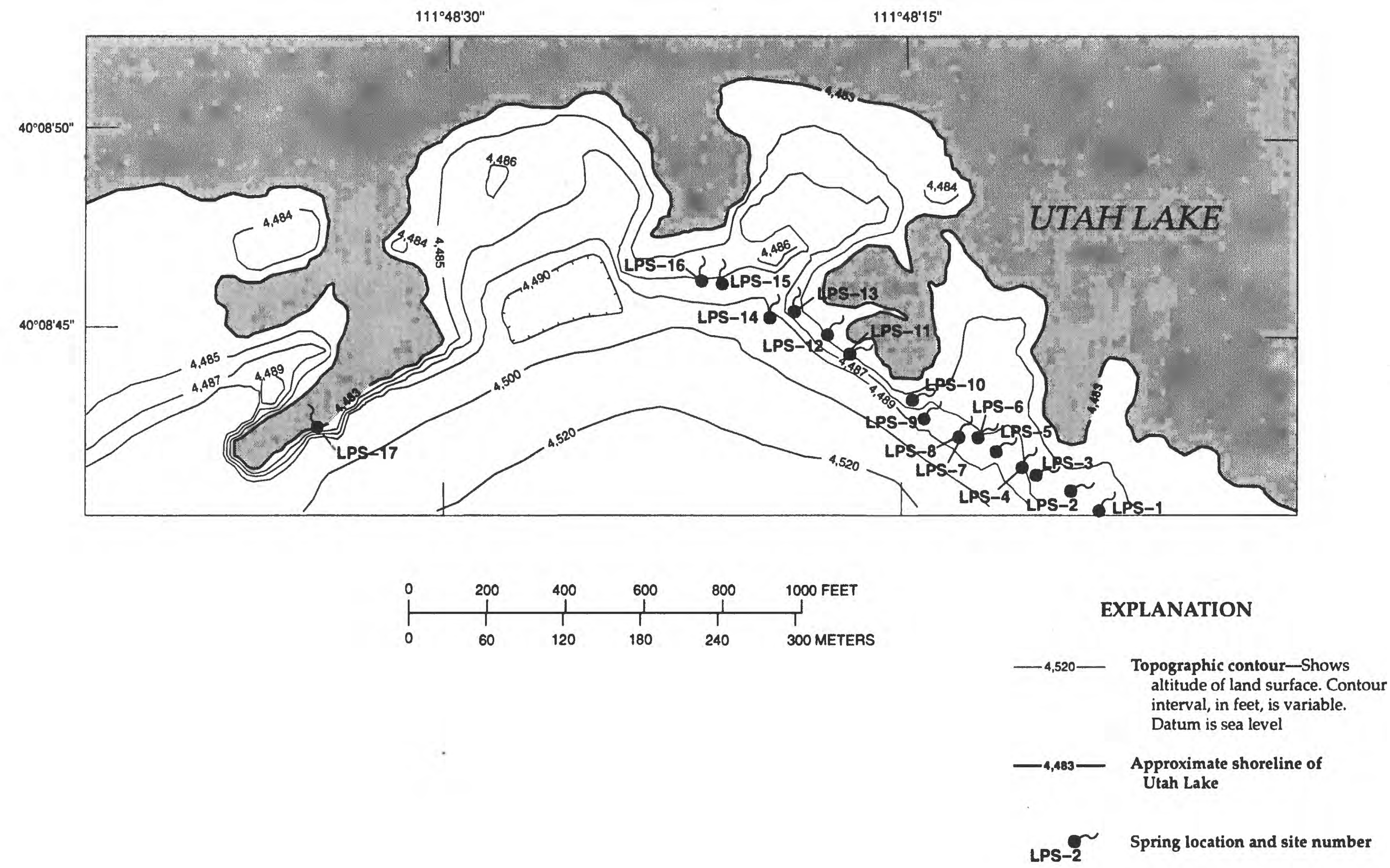


Figure 8. Location and approximate altitude of measured springs in the Lincoln Point area.

Figure 9. Break in slope at Lincoln Point (looking west).

Figure 10. Area of diffuse spring discharge at Lincoln Point.

Development efforts in the Lincoln Point area have changed the physical characteristics of some of the springs. Spring LPS-15 discharges from the end of a man-made dike, and the location of the actual spring orifice is unknown. Spring LPS-17 discharges beneath the surface of Utah Lake in a man-made boat harbor near the north edge of Lincoln Point (fig. 8).

Spring LPS-18 (fig. 4), about 1.1 miles southwest of the northernmost part of Lincoln Point, was included in this report because of the physical and chemical similarities between it and the other springs on Lincoln Point. Spring LPS-18 discharges into a small pond that drains into Utah Lake when the lake level is below an altitude of about 4,481 feet. Excavation of the spring and construction of a dike immediately to the west of the spring, has disturbed the natural topography of the spring area. Spring LPS-18 discharges through clay, silt, and sand as a series of discrete springs. The springs are oriented along a north trending line about 6 feet in length and may discharge from a fracture in travertine, tufa, or bedrock underlying the unconsolidated sediment.

Spring BIS-1 is located in a travertine and tufa embayment at the western edge of Bird Island (fig. 11). The spring discharges at an altitude of about 4,463 feet from beneath a travertine shelf about 22 feet beneath the surface of the lake. The main orifice is about 12 inches wide by 8 inches high and consists of travertine. The area around the spring orifice appears to be broken travertine that has collapsed and sealed off part of an older, larger opening. Looking into the spring orifice from the lake bottom, the orifice opens into a chamber about 4 feet wide by 1 foot high that eventually narrows to about 8 inches in diameter before it changes direction and is no longer visible. Discharge from the spring is to the west and about 75 degrees off vertical.

Spring BIS-2 discharges from travertine in the north embayment of Bird Island (fig. 11). Discharge is from an irregularly shaped travertine orifice about 12 inches in height and 24 inches wide at its largest point. The spring is about 3 feet beneath the surface of the lake at an altitude of about 4,480 feet. Discharge from the spring is to the west and is about 60 degrees off vertical.

Spring BIS-3 discharges above the surface of Utah Lake at an altitude of about 4,483 feet. Discharge is from a nearly vertical, travertine orifice along the southern edge of Bird Island (fig.11). The orifice is rectangular in shape and lies at the north end of a small embayment.

Structural Features Associated With Springs

Naturally occurring structural features associated with spring locations in the Lincoln Point - Bird Island area include inferred faults and joints, embayments, and depressions in lake-bottom sediment. All of the springs in the Lincoln Point - Bird Island study area are near inferred faults or in areas adjacent to faults (fig. 12). Some travertine embayments are associated with springs in the Lincoln Point and Bird Island areas, and depressions in lake-bottom sediment are present at the Bird Island springs.

The location of faults and associated joints may play an important role in the location of warm springs in the Lincoln Point - Bird Island area. Cook and Berg (1961, plate 13) mapped a continuous set of steep gravity anomalies on the east edge of West Mountain, through the center of Utah Lake to the north-northwest and past Saratoga Springs, inferring the presence of a major fault zone. This "Utah Lake Fault Zone" passes close to Bird Island and is an expression of buried fault scarps that mark the west side of the Utah Valley graben (Cook and Berg, 1961, p. 82). Brimhall and Merritt (1976), using data from a reconnaissance study of deep-water springs and strata of Utah Lake (Brimhall, Bassett, and Merritt, 1976), mapped displacements in the sediments of Utah Lake and identified faults passing to the east and west of West Mountain and in the vicinity of Bird Island (fig. 12). Results of the interference test during this study indicated that springs in the Lincoln Point area are hydraulically connected to fractured consolidated rock, implying discharge from a fracture-flow system. The linear orientation of springs along the break in slope in the Lincoln Point area indicates that an abrupt change in subsurface lithology or fracturing of the underlying consolidated materials probably controls the location of the springs.

Travertine embayments are present along the edge of Lincoln Point and at Bird Island. These embayments generally are circular in shape, formed from spring-deposited travertine and tufa deposits, and are characterized by collapsed travertine shelves along the perimeter (fig. 13). The embayments vary in size and are exposed during periods of low lake levels. They are depositional features originally formed from precipitation of calcium carbonate. Some embayments in the Lincoln Point area have been modified by development activities, and the original shape of these embayments is unknown.

No major springs have been found inside the embayments at Lincoln Point; however, numerous

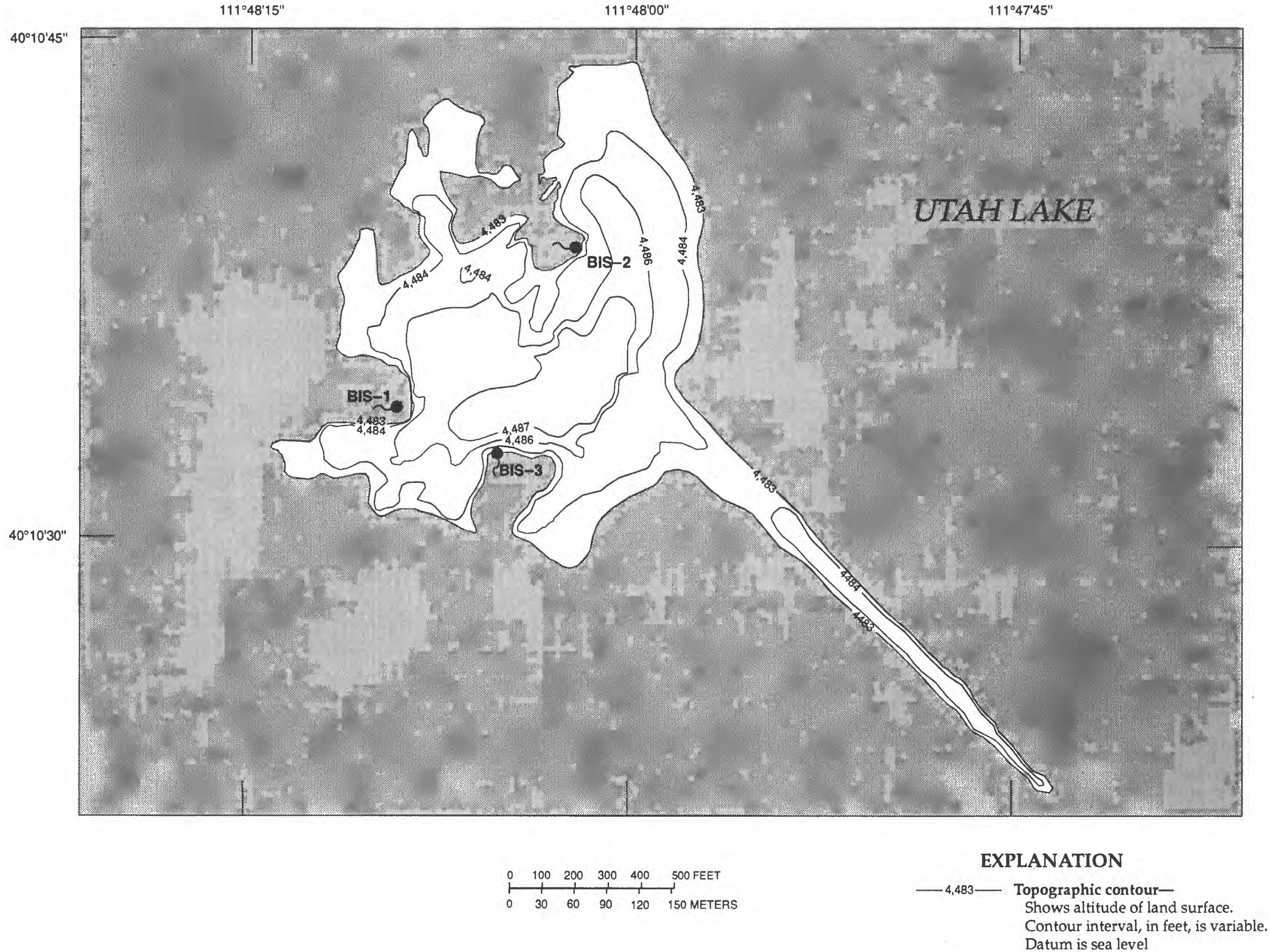


Figure 11. Location and approximate altitude of measured springs in the Bird Island area.

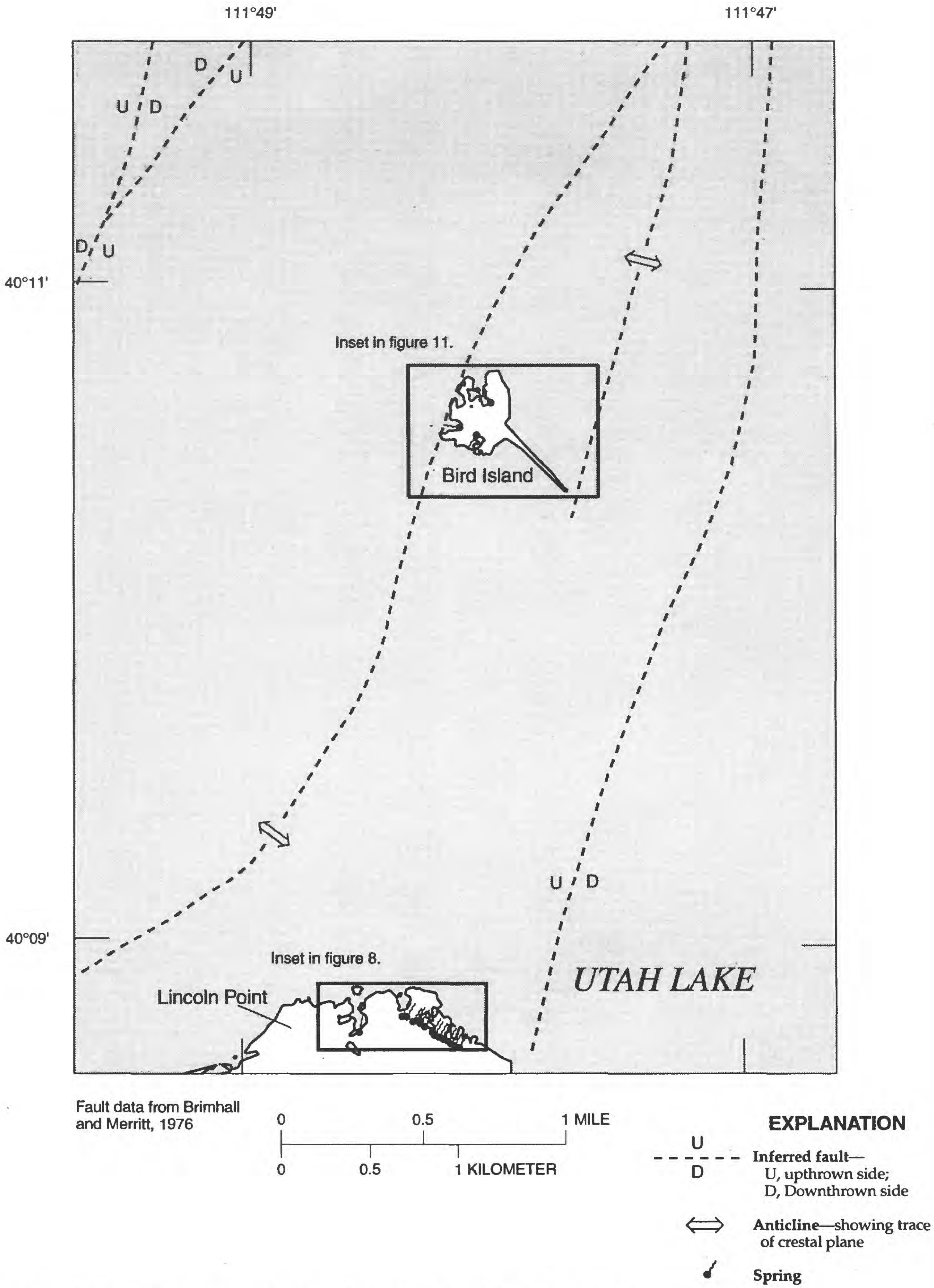


Figure 12. Approximate location of inferred faults and their relation to spring locations.

Figure 13. Edge of travertine embayment at Lincoln Point showing collapsed travertine shelves (looking north).

small springs and seeps can be seen along the edges of the embayments and are visible only when the water level of Utah Lake is sufficiently low to expose their outlets. Most of the springs along the northern edge of Lincoln Point discharge into these embayments and into Utah Lake.

Depressions in lake-bottom sediments are present at Bird Island in two large embayments. These depressions probably are caused by long-term, uninterrupted spring inflow preventing sediment accumulation near the spring orifice. Spring BIS-1 discharges at the bottom of a depression in lake-bottom sediments. This depression is about 14 to 16 feet deep and is estimated to be about 30 feet wide near the surface of the lake. The depression is in the shape of an inverted cone with the walls steepening abruptly near the bottom. The walls of the depression are clay and silt that are compacted near the orifice and become less consolidated toward the surface of the lake. The diameter and exact slope of the depression were not measured because of poor visibility at the bottom of the lake.

Spring BIS-2 discharges at the bottom of a shallow depression on the east edge of the north embayment at Bird Island (fig.11). The density difference between the spring water (greater dissolved-solids concentration) and lake water (lesser dissolved-solids concentration) prevents the spring water from moving toward the surface of the lake and mixing. The spring water flows toward the bottom of the lake and can be traced by temperature differences between the spring and lake water. Discharge from the spring has formed a shallow channel in the bottom of the embayment, beginning at the spring orifice and continuing about 8 feet from the spring. The channel probably is the result of moving spring water that prevents deposition of fine sediment.

Discharge

Numerous springs and seeps discharge warm, saline water in the Lincoln Point - Bird Island area. Twenty-one distinct springs (LPS 1-18, BIS 1-3) were found during this study, including two springs beneath the surface of Utah Lake at Bird Island. Historical estimates and measurements of discharge from the Lincoln Point - Bird Island area ranged from 0.02 cubic foot per second for the North Bird Island Spring to 2.00 cubic feet per second for Lincoln Point Springs No. 1 and No. 4 (table 1)(Milligan and others, 1966). Average total discharge of water from springs in the Lincoln Point area was estimated to be about 2.8 cubic feet per second during the late fall and early winter of 1960-61 (table 1).

Spring-discharge data were collected on April 18, May 3-8, August 12, and October 17-18, 1991, and February 24, August 5, and October 14, 1992, for selected springs above the level of Utah Lake, and on September 18, 1991 and October 14, 1992, for springs beneath the lake surface at Bird Island (table 2). In the Lincoln Point area, discharge measurements for individual springs generally were not possible, and most discharge measurements were taken below the confluence of two or more springs. Discharge from springs beneath the surface of Utah Lake was measured at the spring orifice. Discharge ranged from about 0.01 cubic foot per second at spring BIS-3 to 0.84 cubic foot per second from spring BIS-1 (table 2). Using the maximum measured discharge from each spring, total discharge from the Lincoln Point area was 2.36 cubic feet per second. Maximum total discharge from the springs at Bird Island was 1.62 cubic feet per second. Discharge from small springs and seep areas was not measured and is estimated to account for about 25 percent of the total discharge. Maximum discharge from all known springs and seeps in the Lincoln Point - Bird Island area is estimated to be about 5 cubic feet per second.

Measurements of spring discharge during the period of study revealed seasonal fluctuations (table 2 and fig. 14). Measurements at flumes LPF-4, LPF-5, LPF-6, and LPF-7 (springs LPS-9 and 10, LPS-13 and 14, LPS-14, LPS-15, respectively) for May and October 1991, and February 1992, show distinct fluctuations in discharge. The maximum variation in discharge from springs at Lincoln Point was about 0.11 cubic foot per second at flume LPF-2 (table 2).

Extensive travertine and tufa deposits at Lincoln Point and Bird Island and the depression at spring BIS-1 indicate that springs in the Lincoln Point - Bird Island area may have been discharging in generally the same location for thousands of years. Reworking of the unconsolidated nearshore surface materials by wave action at Lincoln Point and the fluctuating level of Utah Lake may cause the location of springs to change over time.

Effects of pumping a nearby well on discharge of springs

Information on the effects of pumping a nearby well on spring discharge in the Lincoln Point area was determined by an interference pumping test done on May 6-7, 1991. This test was designed to evaluate if the consolidated-rock ground-water system in the Lincoln Point area is hydraulically connected to the warm springs. A submersible pump was installed in well LPW-3 (fig. 15), pumped for about 16 hours, and the following data were collected: spring discharge; water levels in the pumped well and an observation well; and relative water-level altitude in a pond that is suspected to be supplied by a submerged spring. Well LPW-3 was drilled to a depth of 77 feet, and a description of materials encountered during drilling is shown in figure 16. The driller's lithologic log for well LPW-3 reported unconsolidated basin fill to a depth of 70 feet, consolidated rock from 70 to 75 feet, and fractured consolidated rock producing water from 75 to 77 feet. The well was finished with 6-inch diameter steel casing to 75 feet, and the last 5 feet of the casing were perforated.

The factors controlling the pumping rate during the interference test were the size of the pump (which was controlled by the casing diameter), the depth at which the pump could be set, and the maximum drawdown allowable without causing damage to the pump. Because of an obstruction in the well, the maximum depth the pump could be set was about 45 feet. The depth to water was about 33 feet before pumping began. To avoid damage to the pump, maximum drawdown was considered to be about 9 feet. The well-discharge water was piped several hundred feet into nearby Utah Lake to avoid any recirculation to the shallow ground-water system. Volumetric measurements, using a calibrated 30-gallon container and a stop watch, were used to monitor the well discharge.

Discharge of water from three spring areas was measured using 3-inch modified Parshall flumes, and discharge from two spring areas was combined and measured with a 6-inch modified Parshall flume. Water levels were measured in the pumping well, one observation well, and in a nearby spring-fed pond using pressure transducers and continuous-recording data loggers. Measurements of water temperature, specific conductance, and pH were taken from the well-discharge water at about 15-minute intervals for the first 3

Table 1. Discharge from springs in the Lincoln Point - Bird Island area of Utah Lake

[from Milligan and others, 1966, pg. 35]

Site name: From Milligan and others, 1966.
Spring location: See text and figure 3 for numbering system for hydrologic-data sites in Utah. Locations are interpreted.
Discharge: Discharge measurements obtained by current meter.

Site name	Spring location	Date of measurement	Discharge (cubic feet per second)
Lincoln Point spring No. 1	(D-8-1)2ccd	01-21-60	2.00
		07-07-60	1.00
		10-19-60	.67
		11-30-60	.95
		02-02-61	.75
		07-14-61	.75
		08-04-61	.75
		11-02-61	.75
		12-06-61	.75
Mixture of springs 2 and 3 on Lincoln Point	(D-8-1)2ccb	10-19-60	.61
		11-30-60	.63
		02-02-61	.50
		07-14-61	1.00
		08-04-61	1.00
		11-02-61	.75
		12-06-61	.75
Lincoln Point Spring No. 4 - 100 yards west of swimming pool	(D-8-1)2ccb	07-07-60	2.00
		10-19-60	.73
		11-30-60	.32
		02-02-61	.75
		04-10-61	.75
		07-14-61	.60
		08-04-61	.75
		11-02-61	.50
		12-06-61	.50
North Bird Island spring	(D-7-1)26c	01-27-60	.02

Average discharge of 10 measurements from Lincoln Point springs from October 1960 to April 1961

[from Milligan and others, 1966, pg. 32]

Spring No. 1	1.0
Springs No. 2 and 3	.5
Spring No. 4	.6
Spring No. 6	.7

Table 2. Discharge from selected springs and flumes in the Lincoln Point - Bird Island area of Utah Lake.
[—, no data available; e, estimated; <, less than stated value]
Site name: See figures 11 and 15 for location of springs and flumes.
Location: See text and figure 3 for numbering system for hydrologic-data sites in Utah.

Site name	Location	Date	Time (24-hour)	Discharge (cubic foot per second)
LPF-1	(D-8-1)2ccd-F1	10-17-91	—	.017
LPF-1	(D-8-1)2ccd-F1	02-24-92	1120	.035
LPF-2	(D-8-1)2ccd-F2	04-18-91	1430	.71
LPF-2	(D-8-1)2ccd-F2	10-17-91	—	.50
LPF-2	(D-8-1)2ccd-F2	02-24-92	1350	.61
LPF-3	(D-8-1)2ccb-F3	05-03-91	1525	.45
LPF-3	(D-8-1)2ccb-F3	05-06-91	1409	[1].48
LPF-3	(D-8-1)2ccb-F3	05-06-91	1415	[1].48
LPF-3	(D-8-1)2ccb-F3	05-06-91	1420	[1].48
LPF-3	(D-8-1)2ccb-F3	05-06-91	1425	[1].48
LPF-3	(D-8-1)2ccb-F3	05-06-91	1430	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1435	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1440	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1445	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1500	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1515	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1545	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1610	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1615	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1623	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1630	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1645	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1720	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1745	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1800	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1815	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1845	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1900	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1915	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	1930	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	2000	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	2015	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	2053	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	2150	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	2246	[1].50
LPF-3	(D-8-1)2ccb-F3	05-06-91	2350	[1].50
LPF-3	(D-8-1)2ccb-F3	05-07-91	0050	[1].50
LPF-3	(D-8-1)2ccb-F3	05-07-91	0155	[1].48

Table 2. Discharge from selected springs and flumes in the Lincoln Point - Bird Island area of Utah Lake—Continued

Site name	Location	Date	Time (24-hour)	Discharge (cubic foot per second)
LPF-3	(D-8-1)2ccb-F3	05-07-91	0312	[1].48
LPF-3	(D-8-1)2ccb-F3	05-07-91	0420	[1].47
LPF-3	(D-8-1)2ccb-F3	05-07-91	0617	[1].47
LPF-3	(D-8-1)2ccb-F3	05-07-91	0700	[1].47
LPF-3	(D-8-1)2ccb-F3	05-07-91	0754	[1].47
LPF-3	(D-8-1)2ccb-F3	05-07-91	0918	[1].48
LPF-3	(D-8-1)2ccb-F3	05-07-91	1113	[1].48
LPF-3	(D-8-1)2ccb-F3	05-07-91	1208	[1].48
LPF-3	(D-8-1)2ccb-F3	05-07-91	1305	[1].50
LPF-3	(D-8-1)2ccb-F3	05-07-91	1420	[1].50
LPF-3	(D-8-1)2ccb-F3	05-07-91	1523	[1].50
LPF-3	(D-8-1)2ccb-F3	05-08-91	1330	.50
LPF-3	(D-8-1)2ccb-F3	10-17-91	—	.41
LPF-3	(D-8-1)2ccb-F3	02-24-92	1343	.35
LPF-4	(D-8-1)2ccb-F4	05-07-91	1000	[1].179
LPF-4	(D-8-1)2ccb-F4	05-07-91	1108	[1].179
LPF-4	(D-8-1)2ccb-F4	05-07-91	1207	[1].179
LPF-4	(D-8-1)2ccb-F4	05-07-91	1302	[1].179
LPF-4	(D-8-1)2ccb-F4	05-07-91	1411	[1].179
LPF-4	(D-8-1)2ccb-F4	05-07-91	1522	[1].179
LPF-4	(D-8-1)2ccb-F4	05-08-91	1350	[1].179
LPF-4	(D-8-1)2ccb-F4	10-18-91	1528	.144
LPF-4	(D-8-1)2ccb-F4	02-24-92	1337	.162
LPF-5	(D-8-1)2ccb-F5	04-18-91	1615	.090
LPF-5	(D-8-1)2ccb-F5	05-03-91	1430	.069
LPF-5	(D-8-1)2ccb-F5	05-06-91	1407	[1].076
LPF-5	(D-8-1)2ccb-F5	05-06-91	1416	[1].069
LPF-5	(D-8-1)2ccb-F5	05-06-91	1425	[1].069
LPF-5	(D-8-1)2ccb-F5	05-06-91	1431	[1].069
LPF-5	(D-8-1)2ccb-F5	05-06-91	1439	[1].069
LPF-5	(D-8-1)2ccb-F5	05-06-91	1447	[1].069
LPF-5	(D-8-1)2ccb-F5	05-06-91	1500	[1].069
LPF-5	(D-8-1)2ccb-F5	05-06-91	1517	[1].069
LPF-5	(D-8-1)2ccb-F5	05-06-91	1550	[1].069
LPF-5	(D-8-1)2ccb-F5	05-06-91	1605	[1].069
LPF-5	(D-8-1)2ccb-F5	05-06-91	1630	[1].069
LPF-5	(D-8-1)2ccb-F5	05-06-91	1656	[1].069
LPF-5	(D-8-1)2ccb-F5	05-06-91	1720	[1].069
LPF-5	(D-8-1)2ccb-F5	05-06-91	1758	[1].069
LPF-5	(D-8-1)2ccb-F5	05-06-91	1835	[1].069

Table 2. Discharge from selected springs and flumes in the Lincoln Point - Bird Island area of Utah Lake—Continued

Site name	Location	Date	Time (24-hour)	Discharge (cubic foot per second)
LPF-5	(D-8-1)2ccb-F5	05-06-91	1913	[1].076
LPF-5	(D-8-1)2ccb-F5	05-06-91	1952	[1].076
LPF-5	(D-8-1)2ccb-F5	05-06-91	2035	[1].076
LPF-5	(D-8-1)2ccb-F5	05-06-91	2141	[1].076
LPF-5	(D-8-1)2ccb-F5	05-06-91	2240	[1].076
LPF-5	(D-8-1)2ccb-F5	05-06-91	2340	[1].080
LPF-5	(D-8-1)2ccb-F5	05-07-91	0045	[1].080
LPF-5	(D-8-1)2ccb-F5	05-07-91	0143	[1].080
LPF-5	(D-8-1)2ccb-F5	05-07-91	0300	[1].080
LPF-5	(D-8-1)2ccb-F5	05-07-91	0415	[1].080
LPF-5	(D-8-1)2ccb-F5	05-07-91	0612	[1].076
LPF-5	(D-8-1)2ccb-F5	05-07-91	0652	[1].083
LPF-5	(D-8-1)2ccb-F5	05-07-91	0750	[1].083
LPF-5	(D-8-1)2ccb-F5	05-07-91	0909	[1].083
LPF-5	(D-8-1)2ccb-F5	05-07-91	1103	[1].083
LPF-5	(D-8-1)2ccb-F5	05-07-91	1203	[1].083
LPF-5	(D-8-1)2ccb-F5	05-07-91	1259	[1].083
LPF-5	(D-8-1)2ccb-F5	05-07-91	1408	[1].083
LPF-5	(D-8-1)2ccb-F5	05-07-91	1519	[1].090
LPF-5	(D-8-1)2ccb-F5	05-08-91	1430	.090
LPF-5	(D-8-1)2ccb-F5	10-18-91	1522	.069
LPF-5	(D-8-1)2ccb-F5	02-24-92	1208	.076
LPF-6	(D-8-1)2ccb-F6	04-18-91	1400	.127
LPF-6	(D-8-1)2ccb-F6	05-03-91	1420	.208
LPF-6	(D-8-1)2ccb-F6	05-06-91	1405	[1].188
LPF-6	(D-8-1)2ccb-F6	05-06-91	1414	[1].188
LPF-6	(D-8-1)2ccb-F6	05-06-91	1423	[1].188
LPF-6	(D-8-1)2ccb-F6	05-06-91	1428	[1].188
LPF-6	(D-8-1)2ccb-F6	05-06-91	1433	[1].188
LPF-6	(D-8-1)2ccb-F6	05-06-91	1446	[1].188
LPF-6	(D-8-1)2ccb-F6	05-06-91	1458	[1].188
LPF-6	(D-8-1)2ccb-F6	05-06-91	1515	[1].188
LPF-6	(D-8-1)2ccb-F6	05-06-91	1548	[1].170
LPF-6	(D-8-1)2ccb-F6	05-06-91	1555	[1].179
LPF-6	(D-8-1)2ccb-F6	05-06-91	1607	[1].179
LPF-6	(D-8-1)2ccb-F6	05-06-91	1626	[1].175
LPF-6	(D-8-1)2ccb-F6	05-06-91	1655	[1].170
LPF-6	(D-8-1)2ccb-F6	05-06-91	1721	[1].166
LPF-6	(D-8-1)2ccb-F6	05-06-91	1755	[1].162
LPF-6	(D-8-1)2ccb-F6	05-06-91	1831	[1].166

Table 2. Discharge from selected springs and flumes in the Lincoln Point - Bird Island area of Utah Lake—Continued

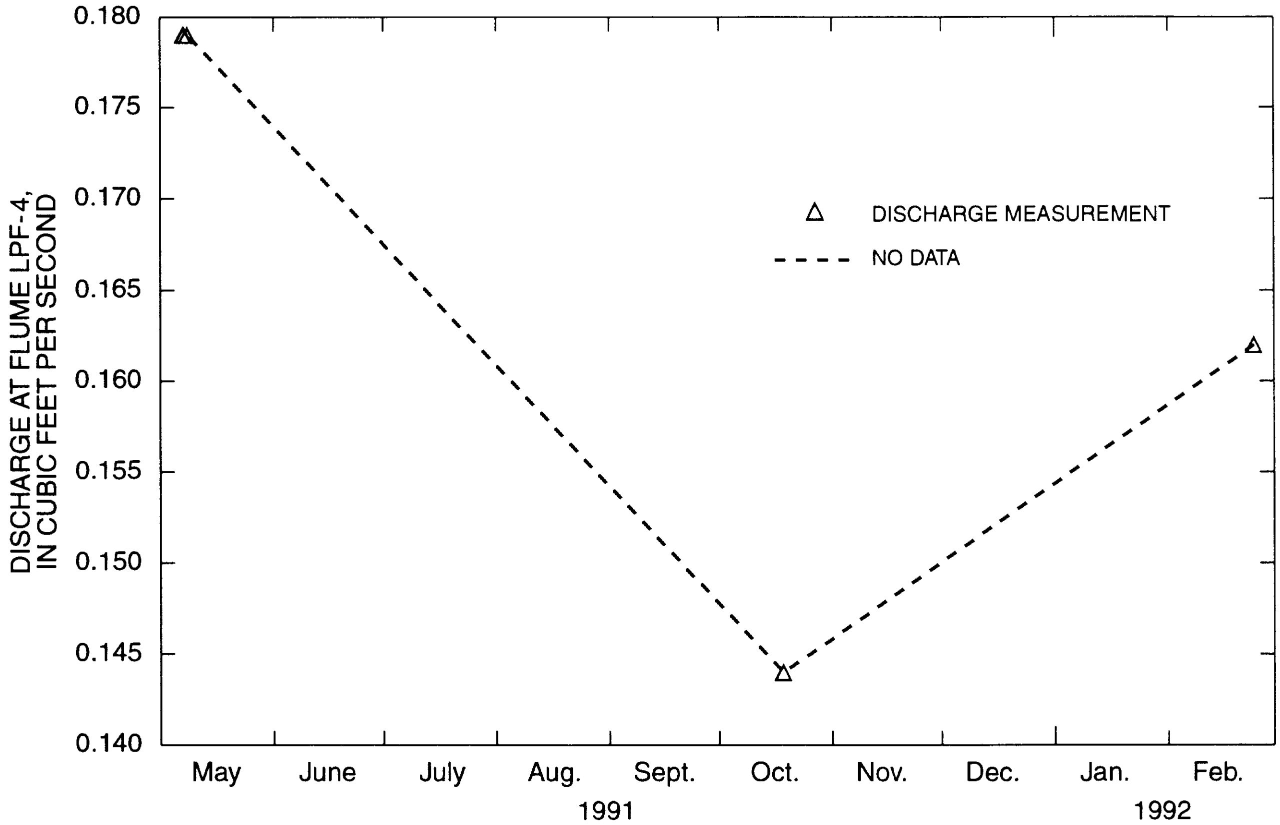
Site name	Location	Date	Time (24-hour)	Discharge (cubic foot per second)
LPF-6	(D-8-1)2ccb-F6	05-06-91	1916	[1,2].158
LPF-6	(D-8-1)2ccb-F6	05-06-91	1949	[1,2].153
LPF-6	(D-8-1)2ccb-F6	05-06-91	2031	[1,2].149
LPF-6	(D-8-1)2ccb-F6	05-06-91	2137	[1,2].149
LPF-6	(D-8-1)2ccb-F6	05-06-91	2252	[1,2].153
LPF-6	(D-8-1)2ccb-F6	05-06-91	2335	[1].166
LPF-6	(D-8-1)2ccb-F6	05-07-91	0041	[1].170
LPF-6	(D-8-1)2ccb-F6	05-07-91	0137	[1].170
LPF-6	(D-8-1)2ccb-F6	05-07-91	0254	[1].170
LPF-6	(D-8-1)2ccb-F6	05-07-91	0410	[1].170
LPF-6	(D-8-1)2ccb-F6	05-07-91	0608	[1].162
LPF-6	(D-8-1)2ccb-F6	05-07-91	0647	[1].162
LPF-6	(D-8-1)2ccb-F6	05-07-91	0748	[1].170
LPF-6	(D-8-1)2ccb-F6	05-07-91	0906	[1].170
LPF-6	(D-8-1)2ccb-F6	05-07-91	1059	[1].179
LPF-6	(D-8-1)2ccb-F6	05-07-91	1200	[1].179
LPF-6	(D-8-1)2ccb-F6	05-07-91	1257	[1].179
LPF-6	(D-8-1)2ccb-F6	05-07-91	1402	[1].179
LPF-6	(D-8-1)2ccb-F6	05-07-91	1517	[1].188
LPF-6	(D-8-1)2ccb-F6	05-08-91	1545	.179
LPF-6	(D-8-1)2ccb-F6	10-18-91	1505	.135
LPF-6	(D-8-1)2ccb-F6	02-24-92	1432	.153
LPF-7	(D-8-1)2ccb-F7	04-18-91	1315	.188
LPF-7	(D-8-1)2ccb-F7	05-03-91	1405	.218
LPF-7	(D-8-1)2ccb-F7	05-06-91	1400	.228
LPF-7	(D-8-1)2ccb-F7	05-06-91	1410	[1].228
LPF-7	(D-8-1)2ccb-F7	05-06-91	1419	[1].228
LPF-7	(D-8-1)2ccb-F7	05-06-91	1421	[1].228
LPF-7	(D-8-1)2ccb-F7	05-06-91	1427	[1].228
LPF-7	(D-8-1)2ccb-F7	05-06-91	1434	[1].228
LPF-7	(D-8-1)2ccb-F7	05-06-91	1445	[1].228
LPF-7	(D-8-1)2ccb-F7	05-06-91	1457	[1].228
LPF-7	(D-8-1)2ccb-F7	05-06-91	1514	[1].228
LPF-7	(D-8-1)2ccb-F7	05-06-91	1545	[1].218
LPF-7	(D-8-1)2ccb-F7	05-06-91	1555	[1].218
LPF-7	(D-8-1)2ccb-F7	05-06-91	1608	[1].218
LPF-7	(D-8-1)2ccb-F7	05-06-91	1625	[1].218
LPF-7	(D-8-1)2ccb-F7	05-06-91	1654	[1].213
LPF-7	(D-8-1)2ccb-F7	05-06-91	1722	[1].213

Table 2. Discharge from selected springs and flumes in the Lincoln Point - Bird Island area of Utah Lake—Continued

Site name	Location	Date	Time (24-hour)	Discharge (cubic foot per second)
LPF-7	(D-8-1)2ccb-F7	05-06-91	1753	[1].213
LPF-7	(D-8-1)2ccb-F7	05-06-91	1830	[1].213
LPF-7	(D-8-1)2ccb-F7	05-06-91	1917	[1].213
LPF-7	(D-8-1)2ccb-F7	05-06-91	1948	[1].213
LPF-7	(D-8-1)2ccb-F7	05-06-91	2030	[1].213
LPF-7	(D-8-1)2ccb-F7	05-06-91	2135	[1].213
LPF-7	(D-8-1)2ccb-F7	05-06-91	2236	[1].213
LPF-7	(D-8-1)2ccb-F7	05-06-91	2333	[1].213
LPF-7	(D-8-1)2ccb-F7	05-07-91	0038	[1].213
LPF-7	(D-8-1)2ccb-F7	05-07-91	0135	[1].213
LPF-7	(D-8-1)2ccb-F7	05-07-91	0252	[1].208
LPF-7	(D-8-1)2ccb-F7	05-07-91	0406	[1].208
LPF-7	(D-8-1)2ccb-F7	05-07-91	0607	[1].208
LPF-7	(D-8-1)2ccb-F7	05-07-91	0645	[1].208
LPF-7	(D-8-1)2ccb-F7	05-07-91	0746	[1].213
LPF-7	(D-8-1)2ccb-F7	05-07-91	0902	[1].208
LPF-7	(D-8-1)2ccb-F7	05-07-91	1100	[1].213
LPF-7	(D-8-1)2ccb-F7	05-07-91	1158	[1].218
LPF-7	(D-8-1)2ccb-F7	05-07-91	1255	[1].218
LPF-7	(D-8-1)2ccb-F7	05-07-91	1400	[1].218
LPF-7	(D-8-1)2ccb-F7	05-07-91	1515	[1].218
LPF-7	(D-8-1)2ccb-F7	05-08-91	1450	.218
LPF-7	(D-8-1)2ccb-F7	10-18-91	1500	.170
LPF-7	(D-8-1)2ccb-F7	02-24-92	1226	.179
LPF-8	(D-8-1)2ccb-F8	04-18-91	1500	.051
LPF-9	(D-8-1)9adc-F9	08-12-91	1530	.300
LPF-9	(D-8-1)9adc-F9	10-18-91	1435	.323
LPF-9	(D-8-1)9adc-F9	02-24-92	—	inundated
BIS-1	(D-7-1)26cbd-S1	09-18-91	1500	.77
BIS-1	(D-7-1)26cbd-S1	10-14-92	1230	.84
BIS-3	(D-7-1)26cac-S2	08-05-92	1100	.02 e
BIS-3	(D-7-1)26cac-S2	10-14-92	1045	<.01 e
BIS-2	(D-7-1)26cac-S1	09-18-91	1630	.74

[1]Measurement taken during interference test

[2] Data in question because of leakage around flume.



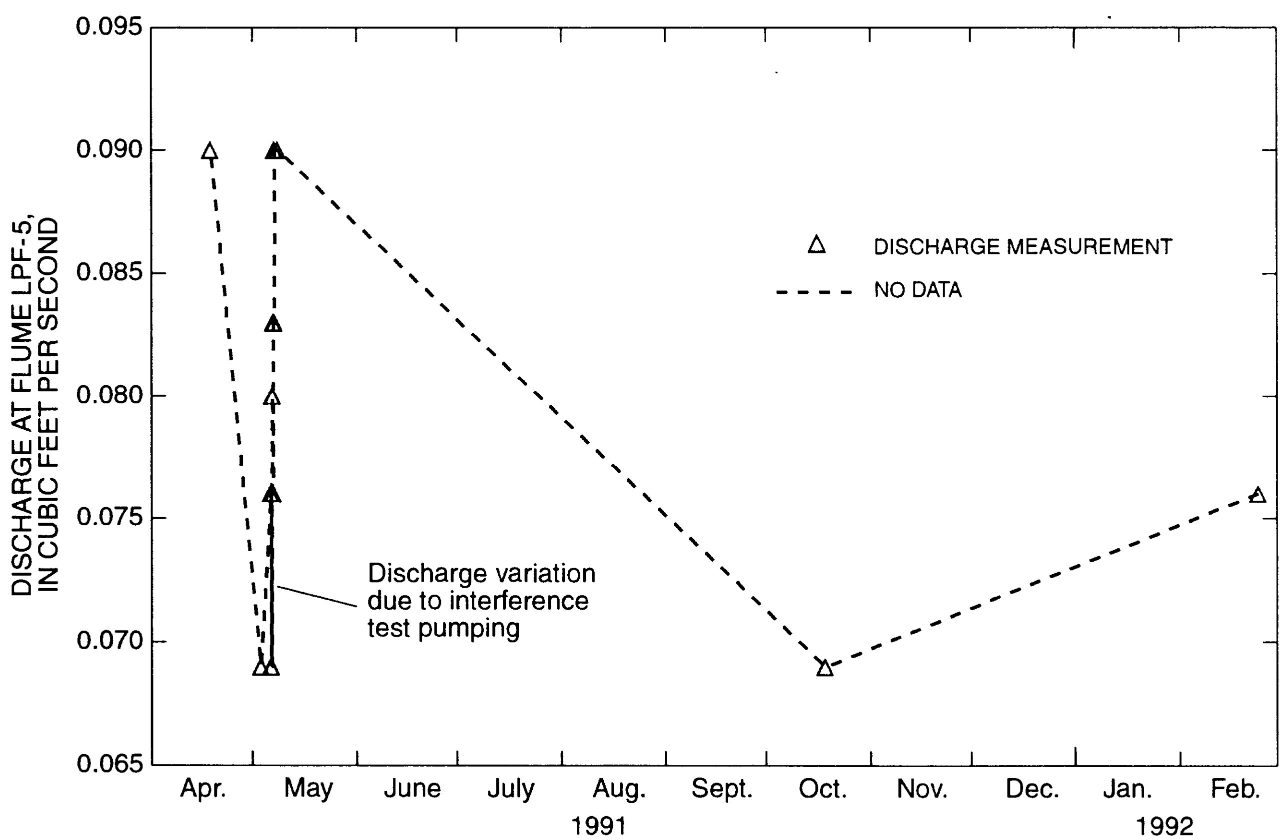


Figure 14. Seasonal fluctuations in discharge for selected measurement sites in the Lincoln Point area, Utah Lake.

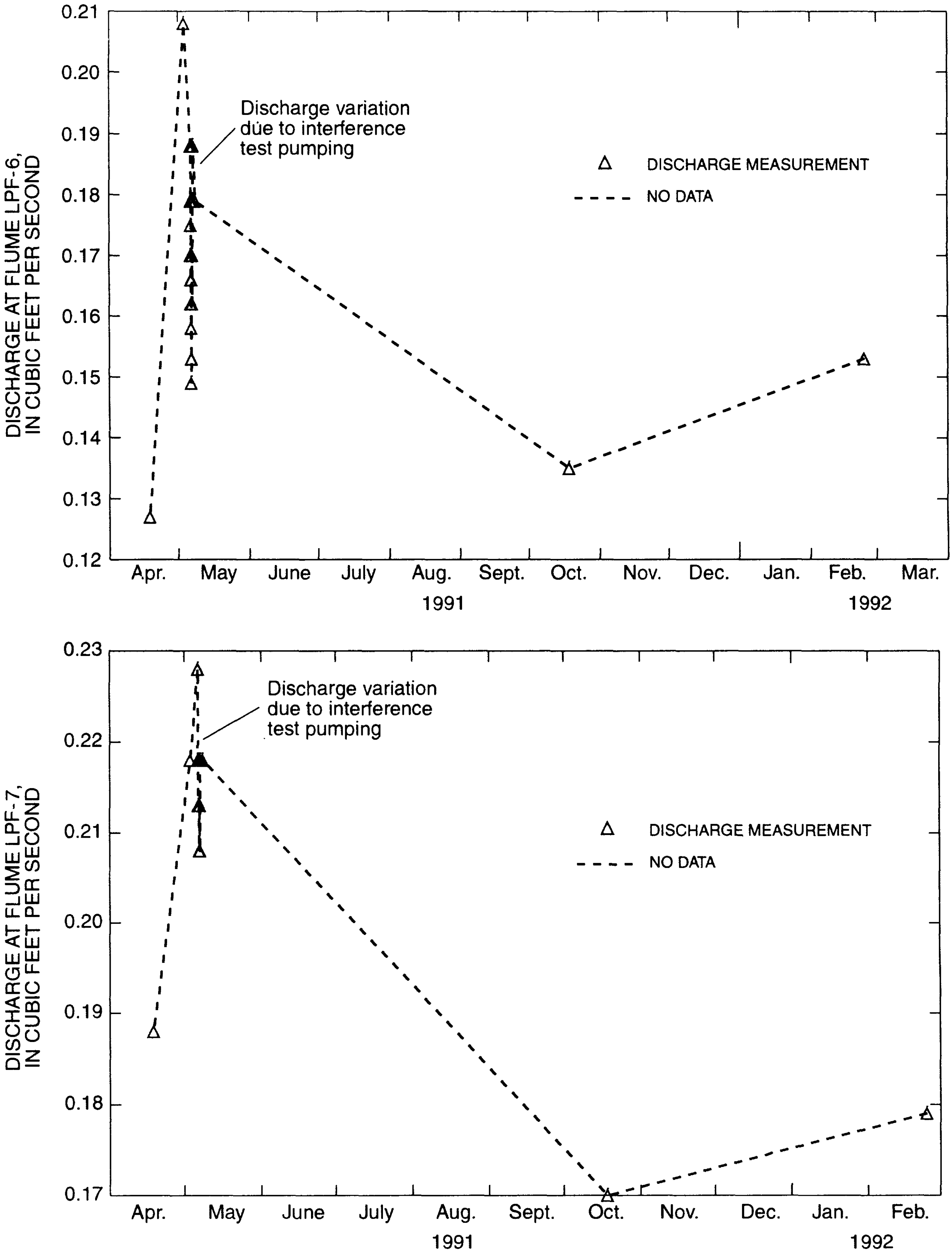
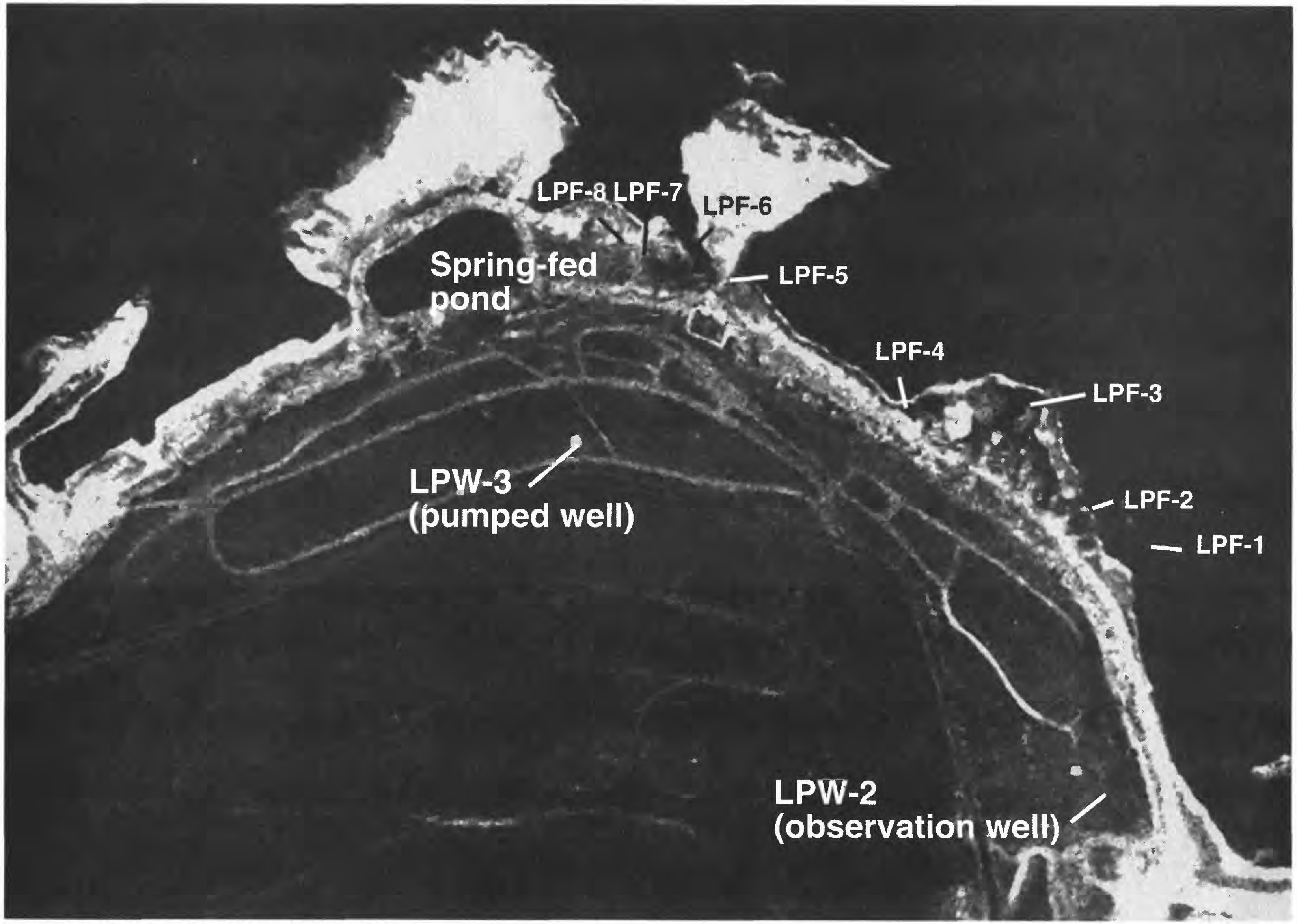


Figure 14. Seasonal fluctuations in discharge for selected measurement sites in the Lincoln Point area, Utah Lake—Continued.



Photograph from USDA-ASCS-APO, NAPP 327-97X, Aug. 22, 1988

Figure 15. Location of LPW-2, LPW-3, flumes, and spring-fed pond in the Lincoln Point area of Utah Lake.

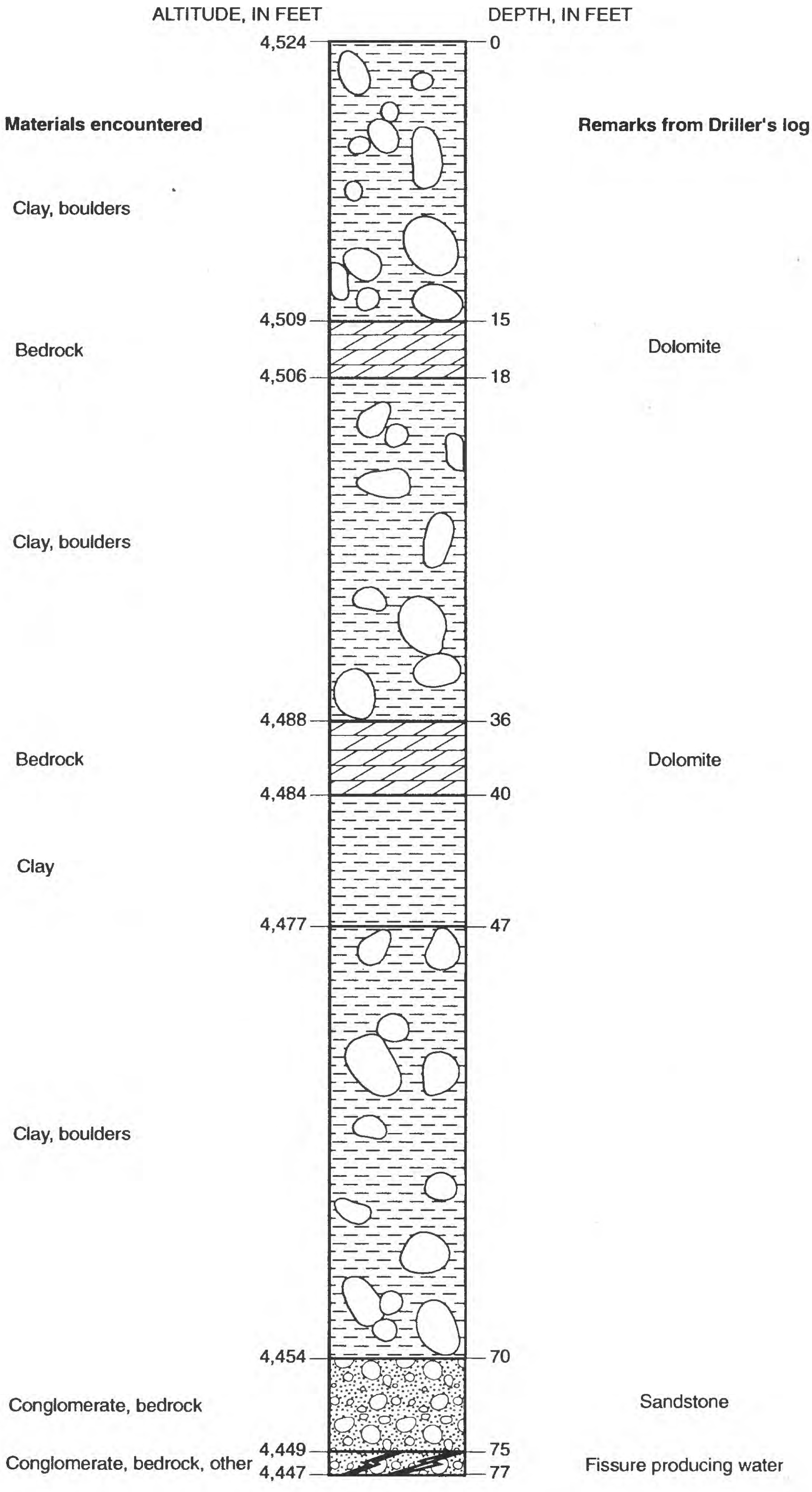


Figure 16. Driller's log for well LPW-3 [(D-8-1)3dda-1], Lincoln Point area, Utah Lake.

hours, 30-minute intervals for the next 3 hours, and 60-minute intervals for the last 10 hours. Location of flumes, springs, wells, and the spring-fed pond are shown in figure 15. Graphs showing fluctuations in water levels in the pumped and observation wells, spring discharge, and water-surface altitude in the pond are shown in figures 17 through 20.

The discharge rate during pumping of the production well, LPW-3, ranged from about 0.69 to 1.0 cubic foot per second and averaged about 0.89 cubic foot per second. The discharge rate of the submersible pump was adjusted using a valve mounted in the discharge line. The discharge rate was adjusted twice during pumping to obtain maximum drawdown without lowering the water level in the well to the depth of the pump. The pump was shut off three times to change fuel filters on the generator that supplied power to the pump. The longest period of time the pump was shut off was about 8 minutes. Changes in the discharge rates and periods when the pump was shut off are reflected in the water-level fluctuations shown in figure 17.

Drawdown in the pumped well (LPW-3) at the end of the pumping period was about 8 feet (fig. 17), and drawdown in well LPW-2 was about 0.5 foot (fig. 18). Water levels in well LPW-2 showed typical drawdown and recovery responses associated with a nearby pumping well. This well was drilled in unconsolidated basin-fill deposits to a depth of 65 feet and was finished as an open hole. These data indicate that the unconsolidated basin-fill deposits are in hydraulic connection with the water-producing formation in which well LPW-3 is completed.

Spring-discharge measurements at three of the four flume installations showed fluctuations in discharge (fig. 19) that could be related to pumping from well LPW-3, indicating that the springs are in hydraulic connection with the fractured consolidated rock aquifer encountered in the pumping well. Measurements at flume LPF-3, which represent discharge from two spring areas, showed a decline in discharge of about 6 percent after 16 hours of pumping; measurements at flume LPF-7 showed a decline in discharge of about 9 percent after 16 hours of pumping; and measurements at flume LPF-6 showed a decline in discharge of about 14 percent after 16 hours of pumping. All three spring-measurement sites showed increases in discharge after pumping stopped, but discharge only at flumes LPF-3 and LPF-6 returned to the pre-pumping discharge rate. Measurements of discharge at flume LPF-5 could not be related to pumping and generally showed small increases in discharge during the test. The reason for the increased discharge in this spring cannot be explained with available data.

The water-surface altitude in the spring-fed pond was slowly declining before pumping began in well LPW-3 (fig. 20). The rate of water-surface decline in the pond elevation increased during pumping and decreased after pumping stopped. These data indicate that the spring in the bottom of the pond is in hydraulic connection with the fractured consolidated rock aquifer encountered in the pumping well.

The temperature of the pump-discharge water was a constant 25 degrees Celsius and did not vary during pumping. The specific conductance values of the pump-discharge water ranged from 7,760 to 8,100 and averaged about 7,900 microsiemens per centimeter. No general trend in values of specific conductance was noted during pumping, and a variation of 340 microsiemens per centimeter is within generally accepted measurement error of plus or minus 5 percent for field measurements of specific conductance. The pH of the pump-discharge water ranged from 6.5 to 6.7 and averaged about 6.6. These values indicate no significant change in pH during pumping.

The results of the interference test indicate that springs in the Lincoln Point area are connected through fractured consolidated rock to well LPW-3. Water-level changes in well LPW-2 indicate that this well may also be hydraulically connected to the springs in the Lincoln Point area since it is hydraulically connected to well LPW-3. Additional research needs to be conducted to determine the degree of connectivity between the ground-water system and the warm springs in the Lincoln Point area.

QUALITY OF WATER FROM SPRINGS AND WELLS

Water-quality data obtained from spring and well waters in the Lincoln Point - Bird Island area were examined to determine if spatial or temporal variations in water quality were evident, to determine if sources of the water could be distinguished on the basis of the data, and to provide a record of the quality of water entering the lake. Samples collected for water-quality analyses from springs at altitudes above and below that of the surface of Utah Lake were collected at the spring orifice. Samples collected for water-quality analyses from springs beneath the surface of Utah Lake were obtained by lowering a hose into the orifice and pumping the sample directly from the spring to the surface of the lake.

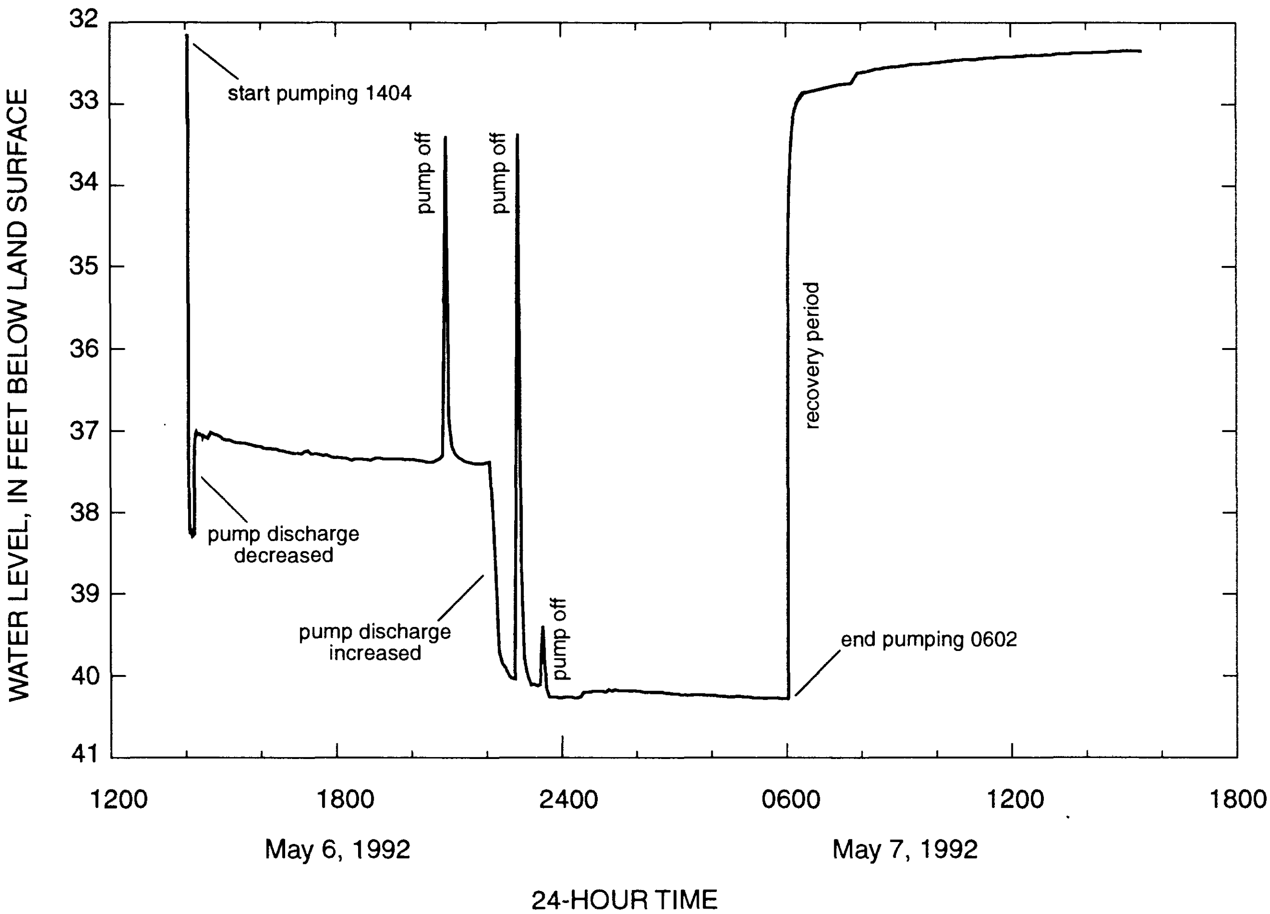


Figure 17. Water level in well LPW-3 (pumped well) in Lincoln Point area during interference test.

Water-quality data were collected during the latter one-half of the 1991 water year, the 1992 water year, and the early 1993 water year. Data were collected from selected springs and wells on Lincoln Point above the lake surface and from springs above and beneath the lake surface offshore at Bird Island. Temperature, specific conductance, and pH were measured during May 1991, October 1991, and February 1992, at selected spring locations along Lincoln Point to define spatial and seasonal variations in water quality.

Water samples were obtained for laboratory water-quality analyses from three distinct springs above the surface of Utah Lake and three wells in the Lincoln Point area. Field measurements of temperature, specific conductance, pH, and alkalinity were obtained at the time of sample collection for each of the water samples. Analyses included major anions and cations, selected trace elements, and hydrogen 2/1 (δ^2H or deuterium) and oxygen 18/16 ($\delta^{18}O$) ratios. One spring (LPS-15) also was sampled for tritium.

Three springs were sampled for water-quality analyses at Bird Island. Two springs beneath the surface of the lake were sampled September 18, 1991, and one spring above the surface of the lake was sampled October 12, 1992. Field measurements of temperature, specific conductance, and pH were obtained at the time of sample collection for each of the water samples. Analyses included major anions and cations, selected trace elements, and δ^2H and $\delta^{18}O$ ratios.

Historical discharge and water-quality data for springs in the Lincoln Point - Bird Island area were included in this report for comparison purposes. The location of springs and measuring sites reported in previous reports generally were not accurate enough to locate specific springs. Direct comparisons of historical data with data gathered for this study generally were not possible.

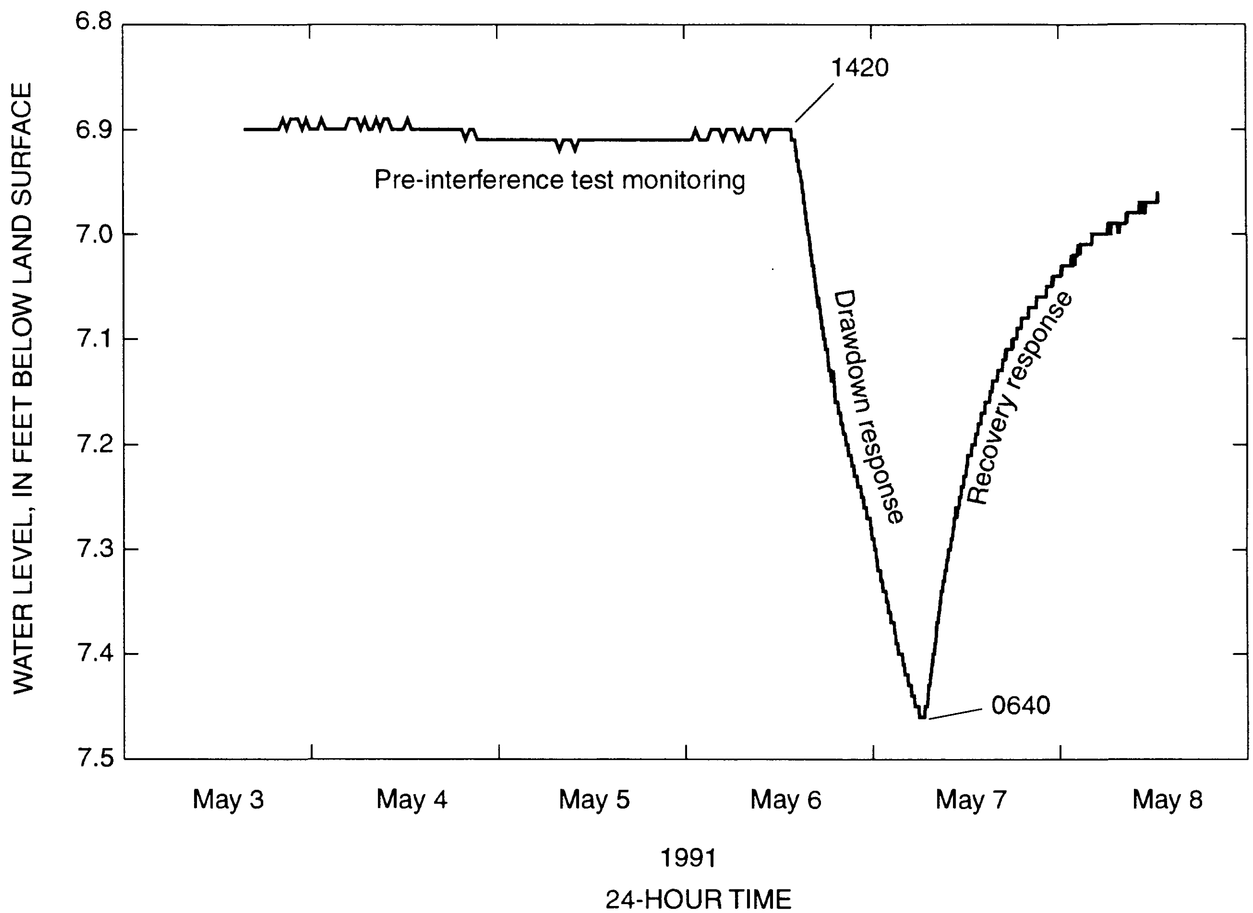


Figure 18. Water level in well LPW-2 (observation well) in Lincoln Point area during interference test.

Physical Characteristics

Physical characteristics of spring and well water include temperature, specific conductance, and pH. These constituents were measured in the field because of changes that take place in water samples during shipping to and storage at the laboratory.

Temperature

The temperature of water from springs in the Lincoln Point area ranged from 21.0 degrees Celsius to 36.5 degrees Celsius, generally increasing from east to west (tables 3 and 4). Field measurements of spring water discharging from the eastern part of Lincoln Point (fig. 8, springs LPS-1 to LPS-12) during 1991-92 indicated an average temperature range of 24.0 to 24.5 degrees Celsius (table 3.). Average temperature of spring water discharging from the northern part of Lincoln Point (fig. 8, springs LPS-13 to LPS-16) during this same period was about 29.5 degrees Celsius (table 3.). The apparent increase of 5 degrees between springs from the eastern and northern parts of Lincoln Point occurs abruptly over a short distance (about 100 feet).

The temperature of water from springs in the Lincoln Point area increases to the west. A temperature of 31.5 degrees Celsius was measured at spring LPS-17, and a temperature of 36.5 degrees Celsius was measured at spring LPS-18, about 1.1 miles southwest of spring LPS-17. Temperature of water pumped from well LPW-4, south of spring LPS-18, was 36.0 degrees Celsius (table 4), indicating a possible interconnection of ground water between this well and spring LPS-18. The driller's log for well LPW-4 shows bedrock from 200 to 275 feet below land surface. The well is cased to 240 feet and is not perforated.

Seasonally (1991-92), water temperatures at most of the springs around Lincoln Point varied only

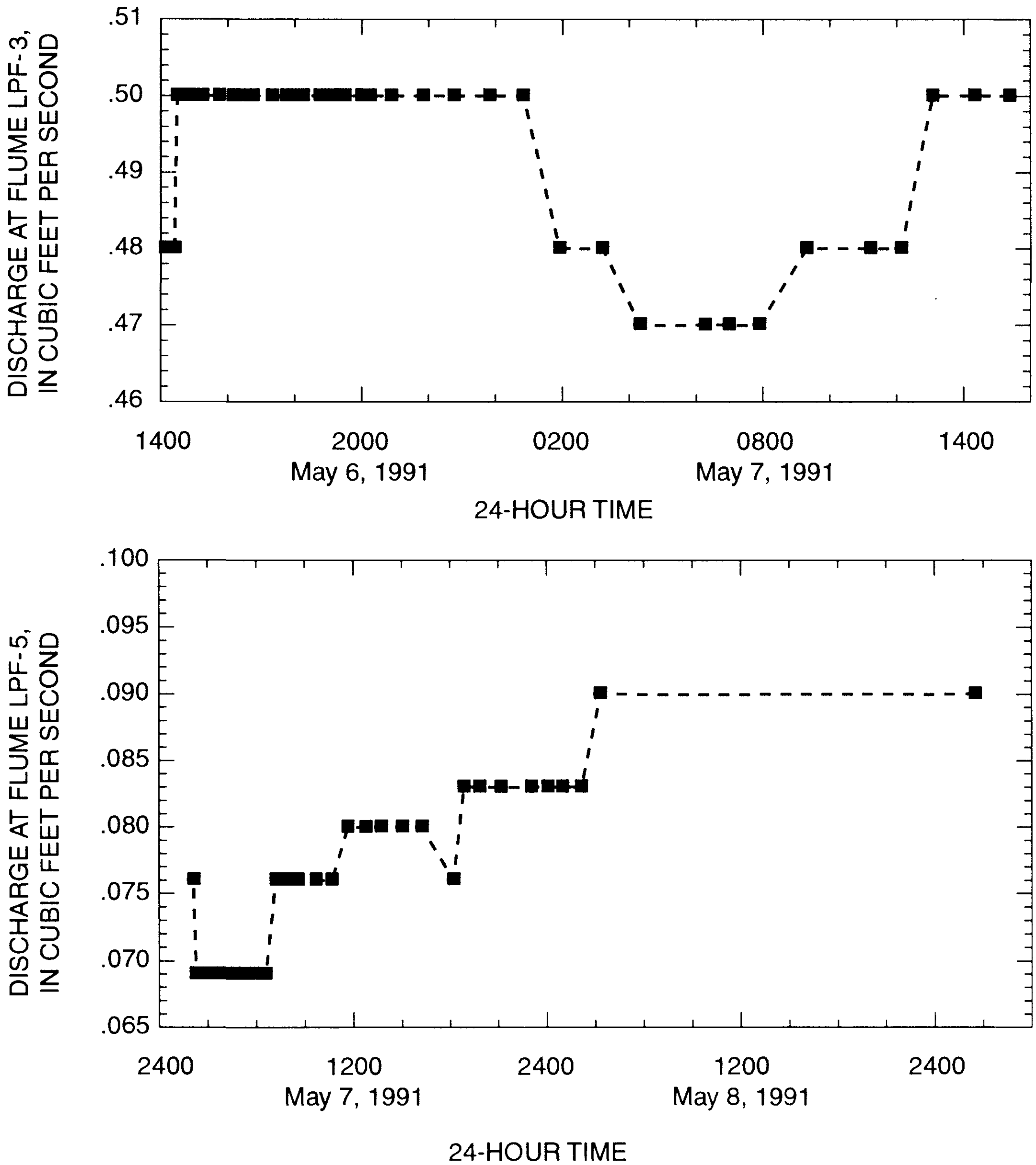


Figure 19. Fluctuations in discharge from selected springs in the Lincoln Point area during interference test.

about one-half degree (table 3). The greatest seasonal changes in temperature were noted in water from springs LPS-11 and LPS-12 where differences as large as 4 degrees Celsius were measured. The lowest temperature of water from these springs was 21.0 degrees Celsius and was measured during February 1992. Reasons for the larger variance in temperature of these springs are unknown. These springs discharge from an area where an abrupt change in water temperature takes place between the eastern and northern parts of Lincoln Point.

Water sampled from well LPW-1 (fig. 4), about 0.5 mile south-southeast of LPW-2, had a temperature of 16.0 degrees Celsius. This water is substantially

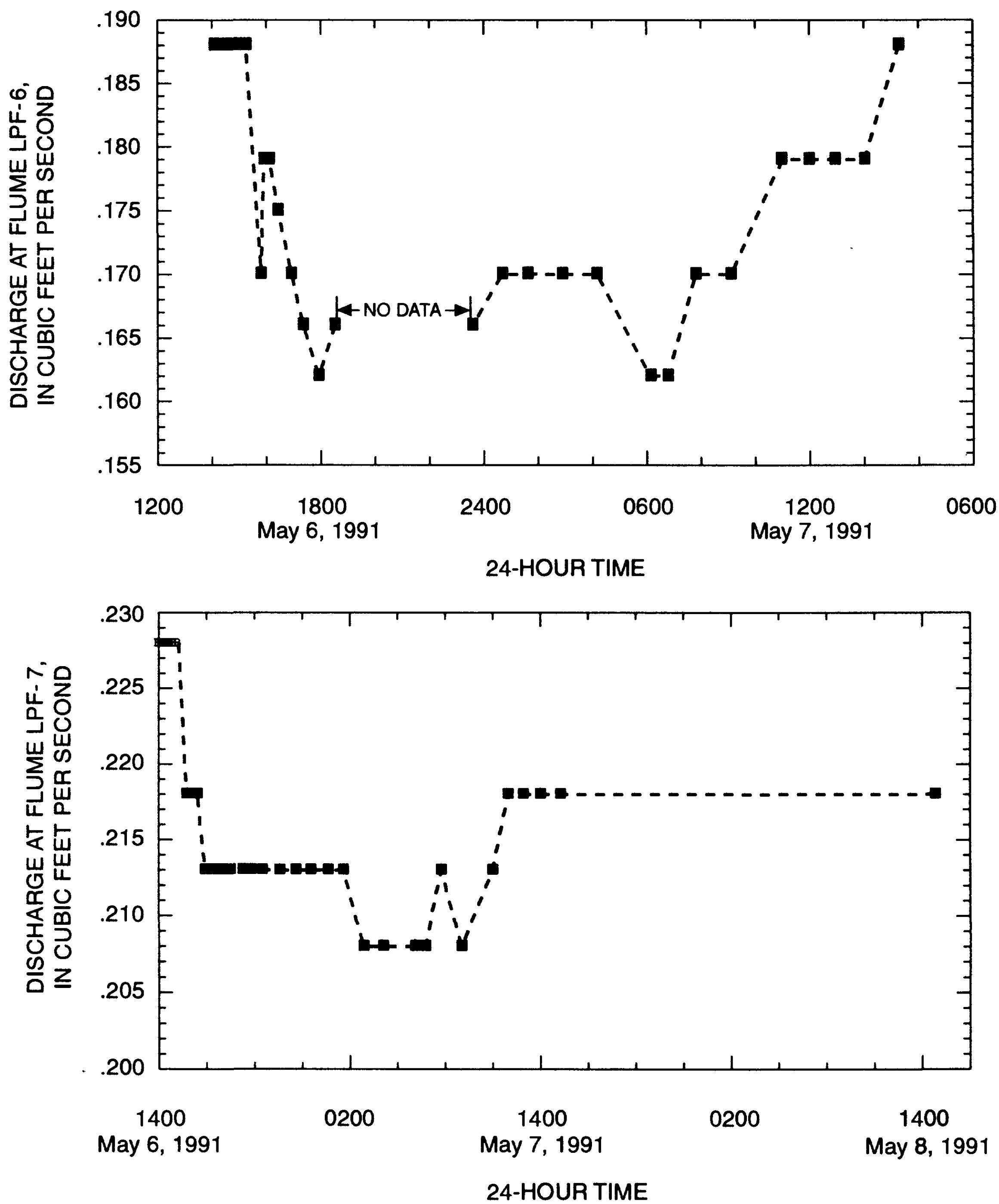


Figure 19. Fluctuations in discharge from selected springs in the Lincoln Point area during interference test—Continued.

lower in temperature than water from the warm springs and well LPW-3, immediately to the northwest (fig. 8 and table 3), indicating a different source or shallower flow path, or both, for water from the well than from the springs. Well LPW-1 is finished in unconsolidated sand and gravel and is perforated from 200 to 251 feet below land surface. Water temperatures from wells to the southeast in Utah Valley are similar to that of water from well LPW-1 (Cordova, 1969, p. 22-26).

Water from springs BIS-1 and BIS-2 at Bird Island had a temperature of 32.0 degrees Celsius. The temperature of water from these springs is more similar to temperatures measured in springs on the northern and western parts of Lincoln Point than to temperatures

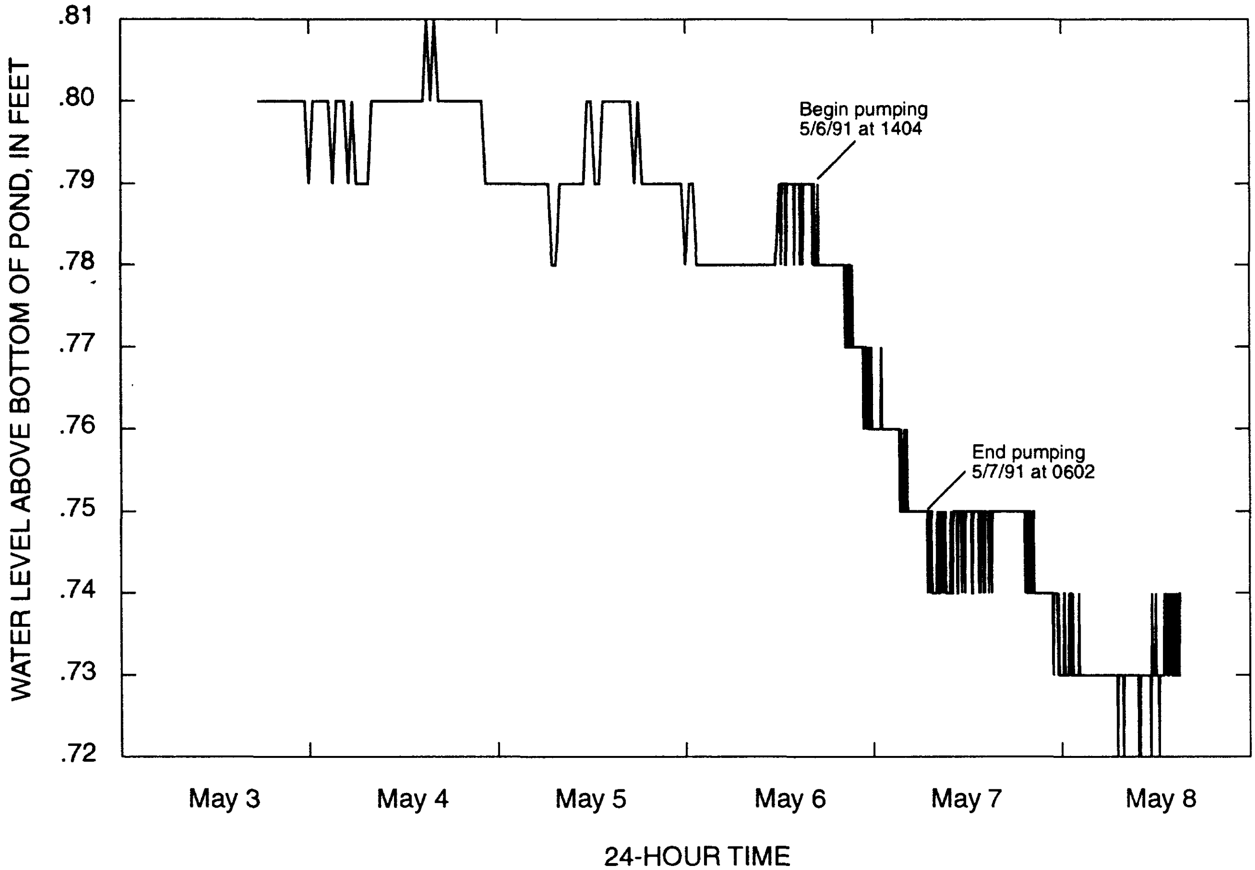


Figure 20. Fluctuations of water level in spring-fed pond at Lincoln Point during interference test.

measured in springs on the eastern part of Lincoln Point (fig. 8). Water from spring BIS-3, on the south side of Bird Island, however, had a temperature of 24 degrees Celsius, anomalously low when compared with water temperatures of the other springs on Bird Island. Water temperature in this spring is most similar to water temperatures in springs LPS-1 to LPS-12, on the eastern part of Lincoln Point (fig.8).

Temperature data from springs and wells in the Lincoln Point - Bird Island area indicate that water in wells and discharging from springs probably has undergone deep circulation. Decreasing temperatures to the east around Lincoln Point indicate a probable flow direction from the west side of Lincoln Point toward the east where mixing with cooler water may occur. Similar temperatures between Lincoln Point springs and wells and Bird Island springs indicate deep circulation of water but do not provide sufficient information to determine probable flow direction.

Specific Conductance

The specific conductance values of water from springs in the Lincoln Point area ranged from 4,290 microsiemens per centimeter to 9,960 microsiemens per centimeter, generally increasing from east to west (tables 3 and 4). Specific conductance values of water from springs LPS-1 to LPS-10, along the eastern part of Lincoln Point (fig. 8) during 1991-92 ranged from about 4,290 to 4,990 microsiemens per centimeter (table 3). Specific conductance values of water from springs LPS-11 to LPS-16, along the northern part of Lincoln Point (fig. 8), ranged from about 5,520 to 9,450 microsiemens per centimeter (table 3). Water from spring LPS-18 had a specific conductance value of about 9,430 microsiemens per centimeter in October 1991.

The greatest increase in specific conductance from east to west around Lincoln Point during 1991-92 occurred between springs LPS-10 and LPS-13 (table 3). An increase in specific conductance of as much as

Table 3. Measurements of temperature, specific conductance, and pH of water from selected springs in the Lincoln Point area of Utah Lake

Site name: See figures 4 and 8 for location of springs.
Spring location: See text and figure 3 for numbering system for hydrologic-data sites in Utah.
Temperature: °Celsius, degrees Celsius
Specific conductance: μS/cm, microsiemens per centimeter at 25 degrees Celsius.

Site name	Date	Spring location	Temperature (in °Celsius)	Specific conductance (μS/cm)	pH (standard unit)
LPS-1	05-01-91	(D-8-1)2ccd-S2	24.5	4,510	6.7
LPS-2	05-01-91	(D-8-1)2ccd-S1	24.5	4,590	6.7
LPS-4	05-01-91	(D-8-1)2ccd-S4	24.5	4,760	6.7
LPS-5	05-01-91	(D-8-1)2cca-S1	24.5	4,980	6.7
LPS-7	05-01-91	(D-8-1)2cca-S3	24.5	4,800	6.7
LPS-10	05-01-91	(D-8-1)2ccb-S3	25.0	4,930	6.7
LPS-11	05-01-91	(D-8-1)2ccb-S4	24.5	5,520	6.6
LPS-12	05-01-91	(D-8-1)2ccb-S5	23.0	8,500	6.5
LPS-13	05-01-91	(D-8-1)2ccb-S6	30.5	9,400	6.4
LPS-14	05-01-91	(D-8-1)2ccb-S7	31.0	9,450	6.4
LPS-15	05-01-91	(D-8-1)2ccb-S1	29.0	9,120	6.4
LPS-16	05-01-91	(D-8-1)3dda-S1	27.0	9,320	6.4
LPS-1	10-17-91	(D-8-1)2ccd-S2	24.5	4,430	6.7
LPS-2	10-17-91	(D-8-1)2ccd-S1	24.5	4,380	6.7
LPS-3	10-17-91	(D-8-1)2ccd-S3	24.0	4,470	6.8
LPS-4	10-17-91	(D-8-1)2ccd-S4	24.5	4,590	6.8
LPS-5	10-17-91	(D-8-1)2cca-S1	24.5	4,680	6.8
LPS-6	10-17-91	(D-8-1)2cca-S2	24.0	4,450	6.7
LPS-7	10-17-91	(D-8-1)2cca-S3	24.0	4,630	6.7
LPS-9	10-17-91	(D-8-1)2ccb-S2	24.0	4,590	6.9
LPS-10	10-17-91	(D-8-1)2ccb-S3	24.5	4,900	6.6
LPS-11	10-17-91	(D-8-1)2ccb-S4	24.0	5,740	6.6
LPS-12	10-17-91	(D-8-1)2ccb-S5	25.0	7,800	6.4
LPS-13	10-17-91	(D-8-1)2ccb-S6	30.0	8,680	6.4
LPS-14	10-17-91	(D-8-1)2ccb-S7	31.0	8,820	6.3
LPS-15	10-17-91	(D-8-1)2ccb-S1	29.5	8,590	6.3
LPS-16	10-17-91	(D-8-1)3dda-S1	27.5	8,710	6.3
LPS-17	10-17-91	(D-8-1)3ddb-S1	31.5	8,950	6.4
LPS-18	10-17-91	(D-8-1)9adc-S1	36.5	9,430	6.3
LPS-1	02-24-92	(D-8-1)2ccd-S2	24.2	4,310	6.7
LPS-2	02-24-92	(D-8-1)2ccd-S1	24.5	4,290	6.7
LPS-3	02-24-92	(D-8-1)2ccd-S3	24.0	4,340	6.8
LPS-4	02-24-92	(D-8-1)2ccd-S4	24.3	4,520	6.7
LPS-5	02-24-92	(D-8-1)2cca-S1	24.4	4,580	6.7
LPS-6	02-24-92	(D-8-1)2cca-S2	24.0	4,630	6.7
LPS-7	02-24-92	(D-8-1)2cca-S3	24.0	4,500	6.7
LPS-8	02-24-92	(D-8-1)2cca-S4	24.2	4,600	6.7
LPS-9	02-24-92	(D-8-1)2ccb-S2	24.0	4,840	6.6
LPS-10	02-24-92	(D-8-1)2ccb-S3	24.0	4,990	6.6
LPS-11	02-24-92	(D-8-1)2ccb-S4	21.0	6,960	6.5
LPS-12	02-24-92	(D-8-1)2ccb-S5	21.0	7,740	6.4
LPS-13	02-24-92	(D-8-1)2ccb-S6	30.0	8,500	6.4
LPS-14	02-24-92	(D-8-1)2ccb-S7	31.0	8,500	6.4
LPS-15	02-24-92	(D-8-1)2ccb-S1	29.0	8,260	6.4
LPS-16	02-24-92	(D-8-1)3dda-S1	26.5	8,320	6.4

4,470 microsiemens per centimeter between these springs was measured in May 1991. Measurements of specific conductance of water from these same springs in October 1991 and February 1992, however, showed differences that were not as large. These springs represent a transition between the less-saline ground water to the east and the more-saline ground water to the west. Changes in specific conductance measured in water from spring LPS-10 were within an accepted measurement error of plus or minus 5 percent.

Specific conductance values of water from most springs decreased between May 1991 and February 1992 (table 3). Specific conductance values of water from springs LPS-1 to LPS-7, along the eastern part of Lincoln Point (fig. 8), decreased between 200 and 400 microsiemens per centimeter during this period. Specific conductance values of water from springs LPS-12 to LPS-16, along the northern part of Lincoln Point (fig. 8), decreased between 760 and 1,000 microsiemens per centimeter during this same period. Increases in specific conductance during this period occurred only in water from spring LPS-11, where values increased from 5,520 microsiemens per centimeter in May 1991 to 6,960 microsiemens per centimeter in February 1992.

The specific conductance value of water from well LPW-3 was about 7,960 microsiemens per centimeter and is most similar to the specific conductance value of water from spring LPS-12, about 7,800 microsiemens per centimeter during October 1991. The specific conductance value of water from well LPW-4 is about 9,400 microsiemens per centimeter and is most similar to the specific conductance value of water from spring LPS-18 (fig. 8), about 9,430 microsiemens per centimeter during October 1991. Differences in specific conductance values between these springs and wells are within generally accepted measurement error of plus or minus 5 percent for field measurements of specific conductance. The close proximity of the springs and wells and the similarity in specific conductance values indicate a common source of water for the springs and adjacent wells.

The specific conductance value of water from well LPW-1 (fig. 4), was 740 microsiemens per centimeter in June 1991, considerably less than the specific conductance values of water from springs immediately to the northwest (fig. 8 and table 3). The smaller specific conductance value of water from well LPW-1 implies a source of water or a flow path different from that which supplies the springs and other wells on Lincoln Point.

Table 4. Selected properties and constituents in water from springs and wells in the Lincoln Point - Bird Island area of Utah

[°C, degrees Celsius; mg/L, milligrams per liter; per mil, per thousand; dashes indicate no data; <, less than stated value; ?, value difficult to transcribe from

Site name: See figures 4, 8, and 11 for location of springs and wells.
Spring/well location: See text and figure 3 for numbering system for hydrologic-data sites in Utah; data-site locations for sources 1, 2, 4, 5, 6,
Specific conductance: µS/cm, microsiemens per centimeter at 25 degrees Celsius.
pH: Values above 7.0 assumed to be determined in laboratory.
Alkalinity: Method of determination unknown except where indicated; L, determined in laboratory; F, determined in field.
Dissolved-solids concentration: Method of determination unknown except where indicated; S, sum of constituents; R, residue
Bicarbonate: F, calculated from field titration.

Site name	Spring/well location	Date of sample	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Hardness, (mg/L as $CaCO_3$)	Alkalinity, total, (mg/L as $CaCO_3$)	Dissolved solids concentration (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
Lincoln Point[1]	(D-8-1)2cc	04-27-33	—	6.4	29	1,783	—	5,089.47 S	516.96	135.6
Lincoln Point[2]	(D-8-1)2cc	10-31-34	—	—	—	1,530	—	5,710 R	410	124
Lincoln Point[3]	(D-8-1)3dda-S1	05-27-64	9,490	7.0	30	1,610	—	6,550	457	114
Lincoln Point[3]	(D-8-1)3dda-S1	06-16-66	9,340	7.6	32	1,680	—	6,140	451	136
Lincoln Point[4]	(D-8-1)2cc	08-05-64	9,300	7.4	33	1,688	—	6,230 D	330	210
Lincoln Point East[5]	(D-8-1)2cc		5,592	—	—	—	—	3,505	218	80
Lincoln Point West[5]	(D-8-1)2cc,3dd		9,684	—	—	—	—	6,393	406	136
Bird Island[5]	(D-7-1)26c		11,417	—	—	—	—	7,224	340	128
Lincoln Point East Side, north of spit, confluence of numerous springs[6]	(D-8-1)2ccd	09-27-77	5,230 ?	7.5	—	857 ?	482	3,110 G	223	70
Lincoln Point spring No.2[6]	(D-8-1)2ccb	10-14-77	—	7.95	—	848 ?	480	4,270 G	191	90
Lincoln Point, spring pool 10 yards north of northeast corner of storage pond[6]	(D-8-1)3dda	09-27-77	9,370 ?	7.9	—	1,630	554	6,210 G	440	129
Lincoln Point, northwest end of old swimming pool[6]	(D-8-1)2ccb	09-27-77	9,940	7.4	—	1,640	625	6,120 G	455	122
Lincoln Point spring No. 4 100 yards west of swimming pool[7]	(D-8-1)2ccb	07-07-60	9,960	7.1	32	—	—	6,500	450	124
		10-19-60	9,847	7.4	—	—	—	6,514	436	122
		11-30-60	9,522	7.7	—	—	—	6,200	—	—
		01-17-61	9,847	7.6	—	—	—	6,488	397	143
		02-02-61	9,735	7.3	—	—	—	6,354	410	123
		04-10-61	9,522	7.6	—	—	—	6,282	368	120
		07-14-61	9,522	7.4	—	—	—	6,554	461	125
		08-04-61	9,623	7.5	—	—	—	6,528	456	125
		11-02-61	9,630	7.6	—	—	—	6,220	298	178
		12-06-61	9,630	7.5	—	—	—	6,292	385	128
Lincoln Point, mixture of springs No. 2 and 3[7]	(D-8-1)2ccb	10-19-60	7,601	7.6	—	—	—	4,906	301	104
		11-30-60	7,343	7.7	—	—	—	4,698	244	99
		01-17-61	7,535	7.5	—	—	—	4,802	—	—
		02-02-61	7,161	8.1	—	—	—	4,478	196	96
		07-14-61	7,282	7.8	—	—	—	4,772	271	98
		08-04-61	7,282	7.6	—	—	—	4,524	255	103
		11-02-61	7,223	7.6	—	—	—	4,536	243	96
		12-06-61	6,879	7.6	—	—	—	4,434	242	94

Lake

original source]

and 7 are interpreted; data-site locations for source 3 reported as published.

on evaporation; D, dissolved solids at 105 °C; G, dissolved solids at 180 °C.

Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Bicarbonate, dissolved (mg/L as HCO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Boron, dissolved (mg/L as B)	Silica, dissolved (mg/L as SiO_2)	Nitrate, dissolved (mg/L as NO_3)	Phosphate, total, dissolved (mg/L as PO_4)	Hydrogen 2/1 stable isotope ratio (per mil)	Oxygen 18/16 stable isotope ratio (per mil)
932.1	—	622.8	1,582.86	1,273.15	—	—	16	—	—	—	—
1,080	457	661	790	2,210	—	—	26	—	—	—	—
1,820	—	756	953	2,800	—	—	22	12	—	—	—
1,510	159	751	940	2,530	2.8	1.7	21	2.4	—	—	—
940	185	159	879	2,429	—	1.9	—	—	—	—	—
881	98	479	574	1,248	—	—	—	—	—	—	—
1,598	183	616	1,086	2,556	—	—	—	—	—	—	—
2,035	175	687	711	3,330	—	—	—	—	—	—	—
725	82	593	462	1,200	2.2	1.13	—	0.64	.010	—	—
769 ?	63	586 ?	521	1,370	2.2	1.25	—	0.27	.008	—	—
1,140 ?	160 ?	676	860	2,659 ?	2.3	2.24	—	0.11	.015	—	—
1,385	140	762	920	2,689 ?	2.4	2.14	—	<0.05	.011	—	
1,581	178	732	1,085	2,531	—	2.22	—	—	—	—	—
1,575	180	721	1,021	2,547	—	—	—	—	—	—	—
—	—	425	—	2,537	—	—	—	—	—	—	—
1,586	184	675	1,087	2,536	—	—	—	—	—	—	—
1,632	184	599	1,187	2,545	—	2.40	—	—	—	—	—
1,621	180	576	1,080	2,526	—	—	—	—	—	—	—
1,598	192	755	1,095	2,570	—	—	—	—	—	—	—
1,586	180	698	1,064	2,588	—	—	—	—	—	—	—
1,598	178	434	1,113	2,589	—	—	—	—	—	—	—
1,598	177	548	1,042	2,589	—	—	—	—	—	—	—
1,207	137	527	790	1,930	—	—	—	—	—	—	—
1,201	136	295	831	1,893	—	—	—	—	—	—	—
—	—	484	—	1,926	—	—	—	—	—	—	—
1,213	137	120	884	1,899	—	—	—	—	—	—	—
1,207	137	450	742	1,940	—	—	—	—	—	—	—
1,161	125	412	732	1,874	—	1.60	—	—	—	—	—
1,172	128	345	741	1,883	—	—	—	—	—	—	—
1,126	122	473	679	1,776	—	—	—	—	—	—	—

Table 4. Selected properties and constituents in water from springs and wells in the Lincoln Point - Bird Island area of Utah

Site name	Spring/well location	Date of sample	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Hardness, (mg/L as $CaCO_3$)	Alkalinity, total, (mg/L as $CaCO_3$)	Dissolved solids concentration (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
Lincoln Point spring No.1[7]	(D-8-1)2ccd	01-21-60	5,633	7.9	21	—	—	3,464	196	75
		07-07-60	5,777	7.4	31	—	—	3,622	237	76
		10-19-60	5,855	7.7	—	—	—	3,664	233	84
		11-30-60	5,554	7.9	23	—	—	3,478	193	94
		02-02-61	5,519	8.0	22	—	—	3,434	169	77
		04-10-61	5,554	7.8	24	—	—	3,484	213	78
		07-14-61	5,554	7.5	24	—	—	3,588	278	58
		08-04-61	5,701	7.4	—	—	—	3,544	248	77
		11-02-61	5,350	8.0	—	—	—	3,328	181	75
		12-06-61	5,383	7.5	—	—	—	3,446	234	80
South Bird Island spring[7]	(D-7-1)26c	01-27-60	10,452	7.8	—	—	—	6,644	276	114
		09-06-61	10,442	7.7	21	—	—	6,552	278	120
North Bird Island spring[7]	(D-7-1)26cac	01-27-60	12,393	7.4	—	—	—	7,768	393	134
		09-06-61	12,381	7.2	30	—	—	7,932	417	131
LPW-3[8]	(D-8-1)3dda-1	05-06-91	7,960	6.6	25	1,300	567 L	5,200 G	360	97
LPS-2[8]	(D-8-1)2ccd-S1	04-30-91	4,580	6.7	24.5	720	447 F	2,700 G	190	59
LPS-15[8]	(D-8-1)2ccb-S1	04-30-91	9,060	6.4	29	1,500	610 F	5,990 G	420	110
LPW-1[8]	(D-8-1)11bac-1	06-14-91	740	7.7	16	210	125 F	444 G	50	20
LPS-18[8]	(D-8-1)9adc-S1	08-21-91	9,500	6.3	36.5	1,600	558 F	6,390 G	450	110
LPW-4[8]	(D-8-1)10bcb-1	07-03-91	9,400	6.3	36.0	1,600	588 F	6,680 G	440	110
BIS-2[8]	(D-7-1)26cac-S1	09-18-91	12,100	6.4	32.0	1,600	681 L	7,420 G	400	140
BIS-3[8]	(D-7-1)26cac-S2	10-14-92	10,100	6.5	24.0	1,200	615 L	6,240 G	310	110
BIS-1[8]	(D-7-1)26cbd-S1	09-18-91	11,900	6.5	32.0	1,500	689 L	6,200 G	390	130

[1]Decker and Maw, 1933, p. 36-37; analyses by Brigham Young University laboratory.
[2]Subitzky, 1962, p. 14; analyses by Salt Lake City chemist.
[3]Cordova, 1969, p. 31, and Mundorff, 1970, p. 18.
[4]Milligan and others, 1966, Table 1; analyses by Utah State University laboratory.
[5]Dustin and Merritt, 1980, p. 10; mean values for several springs from each site, taken at different times from 1970-78.
[6]Dustin, 1978, p. 159-160; analyses by Brigham Young University laboratory.
[7]Milligan and others, 1966, p. 35; analyses by U.S. Bureau of Reclamation laboratory.
[8]Analyses by U.S. Geological Survey laboratory.

The specific conductance value of water from springs BIS-1, BIS-2, and BIS-3 at Bird Island ranged from 10,100 to 12,100 microsiemens per centimeter during the study, averaging about 1,100 microsiemens per centimeter larger than the largest specific conductance value of water reported from springs on Lincoln Point (table 4). The larger values of specific conductance probably indicate a longer and/or deeper flow path for water from these springs than for water from springs on Lincoln Point.

pH

The pH of water from springs in the Lincoln Point area has been measured or reported to range from 6.3 to 8.1 (tables 3 and 4). Reported values of pH greater than 7.0 are believed to be the result of measurements taken in the laboratory, which are less accurate than measurements taken in the field.

During 1991-92, water from springs LPS-1 to LPS-10 in the eastern part of Lincoln Point (fig. 8) had an average pH of 6.7. Water from springs LPS-11 to LPS-17 in the northern and western parts of Lincoln Point (fig. 8) had an average pH of 6.4. Values for pH

Lake—Continued

Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Bicarbonate, dissolved (mg/L as HCO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Boron, dissolved (mg/L as B)	Silica, dissolved (mg/L as SiO_2)	Nitrate, dissolved (mg/L as NO_3)	Phosphate, total, dissolved (mg/L as PO_4)	Hydrogen 2/1 stable isotope ratio (per mil)	Oxygen 18/16 stable isotope ratio (per mil)
868	97	447	511	1,334	—	1.20	—	—	—	—	—
910	97	535	619	1,358	—	1.49	—	—	—	—	—
906	98	582	573	1,382	—	—	—	—	—	—	—
915	102	335	726	1,369	—	—	—	—	—	—	—
906	98	309	614	1,358	—	—	—	—	—	—	—
906	98	451	628	1,360	—	1.30	—	—	—	—	—
892	103	583	579	1,365	—	—	—	—	—	—	—
852	90	581	520	1,338	—	—	—	—	—	—	—
828	94	401	462	1,309	—	—	—	—	—	—	—
828	93	562	509	1,305	—	—	—	—	—	—	—
1,839	159	610	701	2,911	—	2.30	—	—	—	—	—
1,897	164	557	832	2,978	—	2.25	—	—	—	—	—
2,207	178	757	940	3,500	—	2.47	—	—	—	—	—
2,195	192	822	371	383	—	2.55	—	—	—	—	—
1,200	140	—	820	2,200	2.9	2.0	20	—	—	-123.0	-16.10
690	73	546 F	460	1,100	2.5	1.1	20	—	—	-120.0	-15.75
1,500	140	744 F	800	2,500	1.2	2.2	22	—	—	-124.0	-16.15
50	14	153 F	20	140	0.9	0.09	52	—	—	-132.0	-17.65
1,500	160	681 F	980	2,600	3.0	2.4	23	—	—	-124.0	-16.20
1,500	190	718 F	1,000	2,700	3.0	2.4	24	—	—	-122.0	-16.15
2,100	180	—	790	3,400	3.8	2.6	18	—	—	-124.0	-16.00
1,700	130	—	670	2,700	3.6	20.0	16	—	—	-125.0	-16.50
2,100	190	—	800	3,100	4.1	2.6	19	—	—	-123.0	-16.10

generally decrease from east to west around Lincoln Point with the greatest decrease of 0.2 unit occurring between springs LPS-10 and LPS-12 (table 3). Values for pH in the Lincoln Point area did not show distinct seasonal trends and did not vary more than 0.1 unit at individual springs from May 1991 to February 1992 (table 3).

The pH of water from wells LPW-3 and LPW-4 was 6.6 and 6.3, respectively. The pH of water from well LPW-3 is most similar to the pH of water from springs along the eastern part of Lincoln Point. The pH of water from well LPW-4 is most similar to the pH of water from springs along the northern and western parts of Lincoln Point. The pH of water from well LPW-1 was 7.7, substantially greater than the pH of water from springs and other wells in the Lincoln Point area, indicating a different source of water for the well.

Water from springs BIS-1, BIS-2, and BIS-3 at Bird Island had pH values of 6.5, 6.4, and 6.5, respectively, during 1991-92 (table 4), although values as great as 7.8 previously were reported. Values of pH in water from the Bird Island springs during this study are most similar to pH values in water from springs LPS-12 to LPS-18, along the northern part and to the west of Lincoln Point (table 3).

Chemical Characteristics

Water samples were obtained for laboratory analyses from three springs and three wells in the Lincoln Point area and from three springs at Bird Island. Major constituents, selected trace elements, and stable isotopes of hydrogen and oxygen were analyzed for all eight sampling locations. Tritium was analyzed in water from spring LPS-15. Collection of water samples from all springs was at the point of discharge. Water-quality data were compiled from previous investigations and are included in table 4.

Major constituents

The dissolved-solids concentration in water from springs in the Lincoln Point area ranged from 2,700 milligrams per liter to 6,554 milligrams per liter (table 4). The dissolved-solids concentration in water from springs generally increases from east to west around Lincoln Point. Specific conductance/dissolved-solids ratios in the Lincoln Point area indicate that dissolved-solids concentrations less than 5,000 milligrams per liter generally are from springs on the east side of Lincoln Point (spring LPS-2). Dissolved-solids concentrations larger than 5,000 milligrams per liter generally are from springs on the north and west sides of Lincoln Point (springs LPS-15 and LPS-18).

Dissolved-solids concentrations in water from wells LPW-3 and LPW-4 were 5,200 and 6,680 milligrams per liter, respectively, in 1991. The similarity of dissolved-solids concentrations in water from these wells, and springs LPS-15 and LPS-18 north of the wells, indicates that water from the springs and wells probably is from a similar source or traveled along a similar flow path. The dissolved-solids concentration in water from well LPW-1 was 444 milligrams per liter, indicating a different source or flow path from that for water in wells LPW-3 and LPW-4.

The dissolved-solids concentration in water from Bird Island springs ranged from 6,200 milligrams per liter to 7,932 milligrams per liter (table 4). The dissolved-solids concentrations in water from these springs are most similar to the dissolved-solids concentrations in water from springs LPS-15 and LPS-18, on the north side and to the west side of Lincoln Point.

The U.S. Geological Survey classification of dissolved-solids concentration in water (Heath, 1989, p. 65) indicates that most of the water from springs and wells in the Lincoln Point - Bird Island area is moderately saline (3,000 to 10,000 milligrams per liter). Water from well LPW-1 is classified as fresh (less than 1,000 milligrams per liter).

Hardness, as an expression of the sum of calcium plus magnesium, in milligrams per liter of calcium carbonate ($CaCO_3$), ranged from 720 to 1,783 milligrams per liter in water from springs in the Lincoln Point area (table 4). The largest value was reported by Decker and Maw (1933, p. 36-37) for a sample collected from an unidentified spring on Lincoln Point in 1933. Concentrations of calcium and magnesium generally increase with increasing dissolved-solids concentration. Hardness of water increases from east to west around Lincoln Point similar to the increase in dissolved-solids concentration. Hardness of water from springs at Bird Island ranged from 1,200 to 1,600 milligrams per liter, similar to the hardness of water on the north side of Lincoln Point (table 4). On the basis of the U.S. Geological Survey classification of hardness (Heath, 1989, p. 65), water from springs in the Lincoln Point - Bird Island area would be considered very hard. Water from wells LPW-3 and LPW-4 had similar hardness to water from springs LPS-15 and LPS-18 (table 4). Water from well LPW-1 had a hardness of 210 milligrams per liter, which also would be classified as very hard.

The major cations in water from springs and wells in the Lincoln Point - Bird Island area, in order of decreasing abundance, are sodium, calcium, magnesium, and potassium. The major anions in water from springs and wells in order of decreasing abundance are chloride, sulfate, and bicarbonate (table 4).

Stiff diagrams (fig. 21) showing the concentrations of major cations and anions (Stiff, 1951, p. 60-62) indicate that increases in dissolved-solids concentration in water from springs and wells at Lincoln Point and at Bird Island result from proportional increases of individual ions in solution and are not the result of dramatic increases or decreases in the concentration of one or two ions. Changes in the concentration of individual ions in relation to increases in the dissolved-solids concentration generally are less than 2 percent.

Overall, the Stiff diagrams for water from springs at Lincoln Point and Bird Island and from most wells on Lincoln Point indicate that water in this region has a similar origin and flow path. The lower water temperature, smaller specific conductance values, and greater pH of water from springs on the eastern part of Lincoln Point, however, are likely a result of mixing with water from a different source or local recharge area. Water

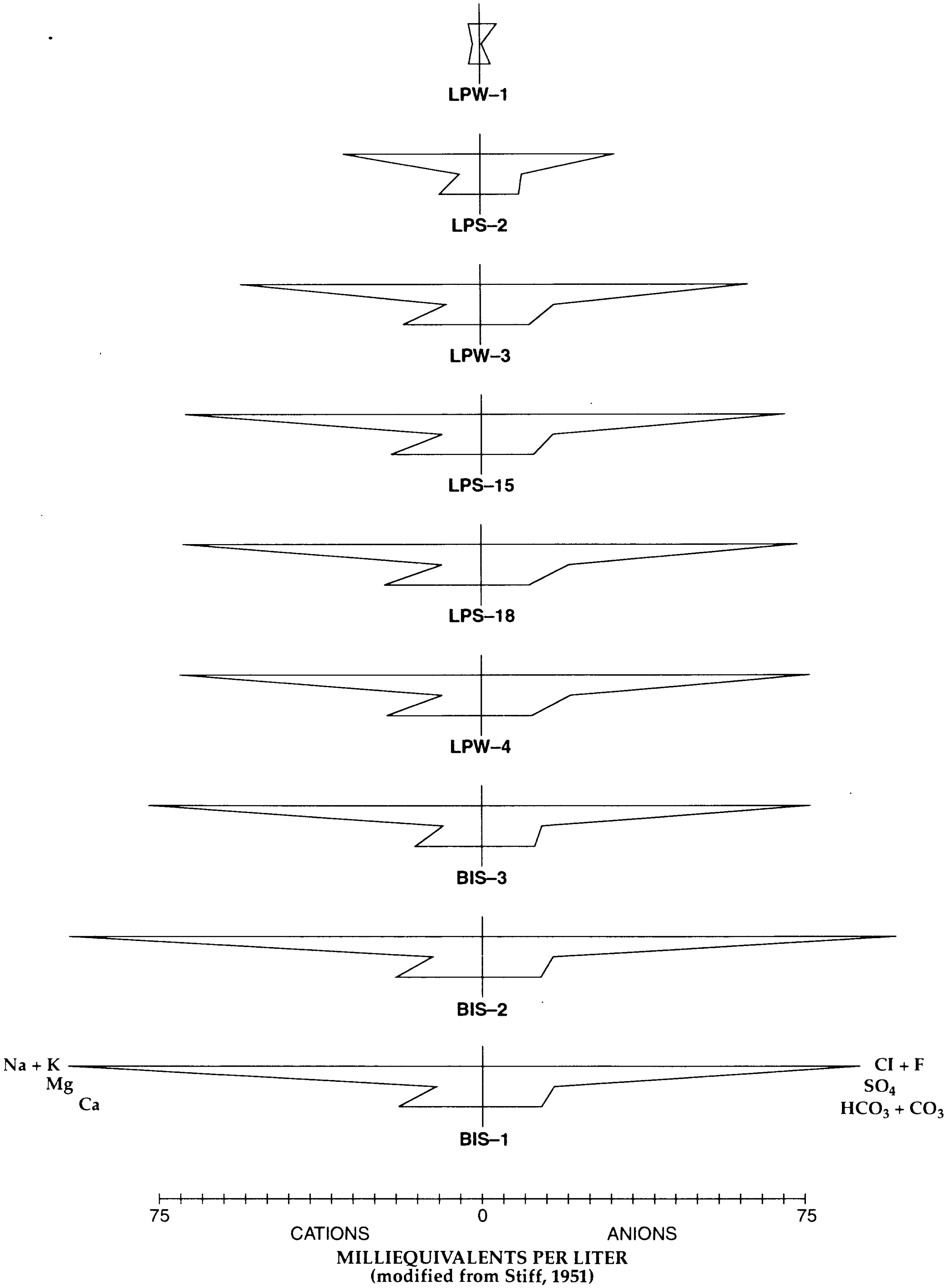


Figure 21. Composition of water in selected springs and wells in the Lincoln Point-Bird Island area, Utah Lake.

from well LPW-1 is considerably lower in temperature and specific conductance and greater in pH than water from springs on Lincoln Point. Water from the aquifer supplying this well may be mixing with water discharging from springs LPS-1 to LPS-10, on the eastern part of Lincoln Point (fig. 8).

Relative percentages of the major cations and anions in water from springs and wells in the Lincoln Point - Bird Island area are shown by trilinear diagram (Piper, 1944, p. 50-59) in figure 22. This diagram shows that differences between waters are not the result of any dramatic increases or decreases in the concentration of one or two ions and also indicates that water from all springs and most wells is similar in chemistry and likely originated from a common source. Relative percentages of ionic concentrations in water from well LPW-1, however, indicate a distinct difference in water chemistry and therefore a difference in source compared with water from other springs and wells in this area.

On the basis of the Stiff and trilinear diagrams, water from all springs and wells in the Lincoln Point - Bird Island area, except well LPW-1, is classified as sodium chloride type water (Davis and DeWiest, 1966, p. 119). Water from well LPW-1 is classified as a sodium calcium bicarbonate chloride type water.

Trace elements

Results of water-quality analyses for selected trace elements in water from springs and wells in the Lincoln Point - Bird Island area are shown in table 5. Generally, concentrations of trace elements in water increase with increasing pH and dissolved-solids concentrations but do not increase proportionally as do major cations and anions.

Arsenic concentrations ranged from 1.8 to 150 micrograms per liter, with the largest concentrations in water from springs at Bird Island. Arsenic concentrations in water from springs at Bird Island and well LPW-4 exceed the U.S. Environmental Protection Agency limit of 50 micrograms per liter in drinking water (U.S. Environmental Protection Agency, 1976). Concentrations of barium in water from springs at Lincoln Point also were close to or exceeded the drinking water limit of 1,000 micrograms per liter (table 5). Bromide concentrations at Lincoln Point ranged from 80 micrograms per liter in water from well LPW-1 to 1,700 micrograms per liter in water from well LPW-4. The largest concentrations of bromide (2,200-2,300 micrograms per liter) were in water from springs BIS-1 and BIS-2 at Bird Island.

Iron concentrations in water from springs and wells ranged from 10 to 4,500 micrograms per liter, with the largest concentration in water reported from an unidentified spring at Lincoln Point in 1934 (table 5). Lead concentrations in water from springs on Lincoln Point in 1977 ranged from 161 to 328 micrograms per liter (table 5), exceeding the drinking water limit of 50 micrograms per liter (U.S. Environmental Protection Agency, 1976). In 1977, nickel concentrations in water from these springs were as large as 145 micrograms per liter. Lithium concentrations in water ranged from 89 micrograms per liter in well LPW-1 to 3,900 micrograms per liter from an unidentified sampling location on Lincoln Point in 1964 (table 5). Concentrations of lithium in water as small as 60 to 100 micrograms per liter have been known to cause damage to citrus trees, although other instances of lithium toxicity to plants are not known (Gough, Shacklette, and Case, 1979, p. 31).

Manganese concentrations in water ranged from about 10 to 150 micrograms per liter, with the largest concentrations in water from well LPW-3. Selenium concentrations were 2 micrograms per liter or less for all springs and wells sampled in the Lincoln Point - Bird Island area. Strontium concentrations in water ranged from 1,700 micrograms per liter at wells LPW-1 and LPW-3 to 11,000 micrograms per liter at well LPW-4 and from an unidentified sampling site on Lincoln Point in 1966 (table 5). Large concentrations of strontium often are present in water that has moved through carbonate rocks.

Stable isotopes

The isotopic content of precipitation can be used to investigate ground-water recharge and fractionation processes. Isotopic content of precipitation is influenced primarily by altitude, latitude, distance inland from the ocean, and season (Dansgaard, 1964, p. 436-468). Relative to standard mean ocean water (SMOW), the deuterium (δ^2H) and oxygen-18 ($\delta^{18}O$) content of precipitation decreases with increasing altitude and latitude, decreases inland from the coast, and decreases in winter precipitation. Isotopically, precipitation becomes enriched in lighter isotopes with a reduction in the deuterium and oxygen-18 content.

Evaporation and condensation are the primary processes that affect isotopic ratios. The relation between deuterium and oxygen-18 in meteoric water that has not been evaporated is given by the equation in

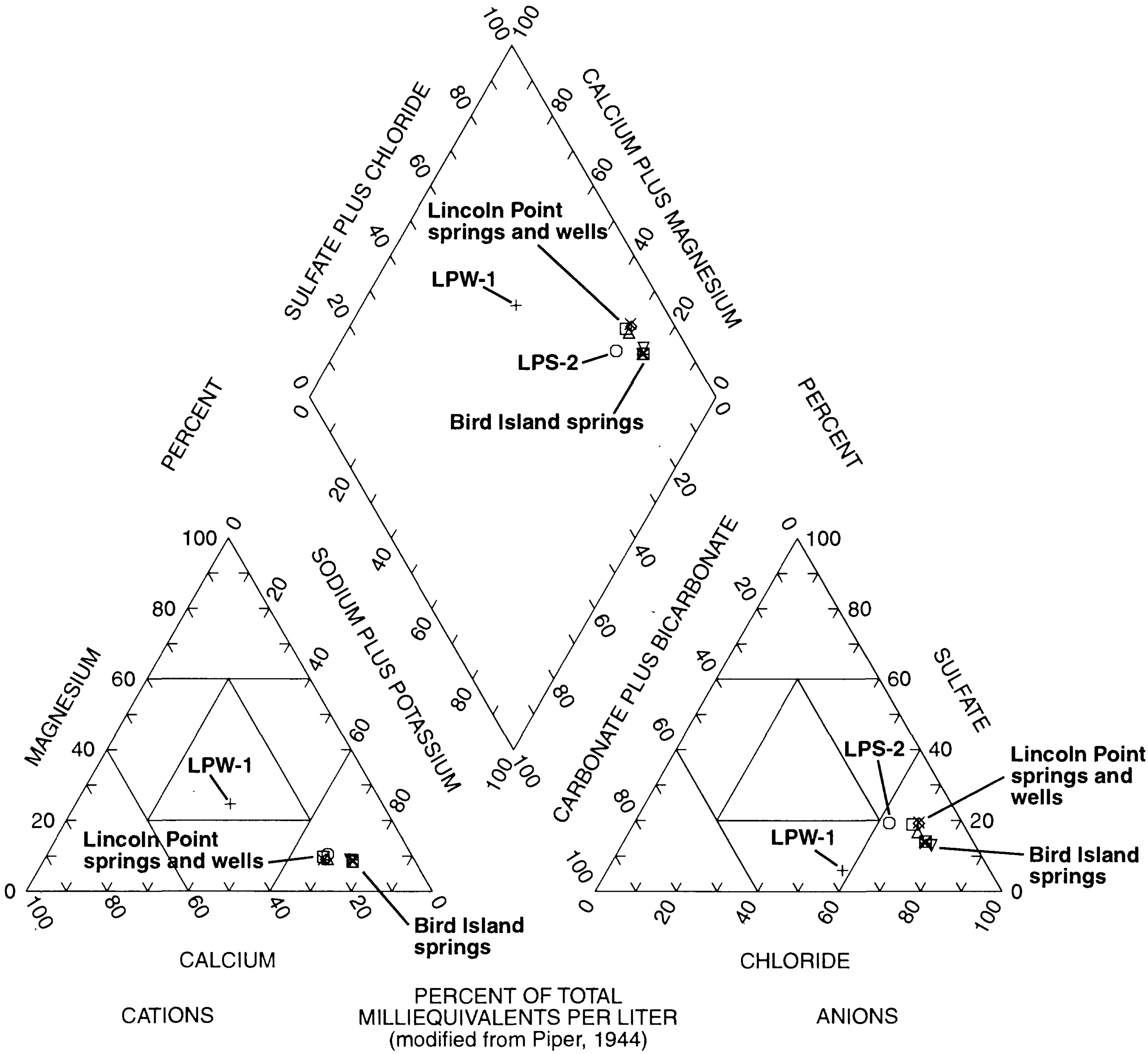


Figure 22. Composition of water in selected springs and wells in the Lincoln Point-Bird Island area, Utah Lake.

Table 5. Selected trace elements in water from springs and wells in the Lincoln Point - Bird Island area of Utah Lake

[µg/L,micrograms per liter; dashes indicate no data; <, less than stated value; ?, value difficult to transcribe from original source]

Site name: See figures 4, 8, 11, and 15 for location of springs and wells.
Spring/well location: See text and figure 3 for numbering system for hydrologic-data sites in Utah; data-site locations for sources

Site Name	Spring/well Location	Date of sample	Aluminum, dissolved (µg/L as Al)	Arsenic, dissolved (µg/L as Ar)	Barium, dissolved (µg/L as Ba)	Bromide, dissolved (µg/L as Br)	Cadmium, dissolved (µg/L as Cd)	Cesium, dissolved (µg/L as Cs)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)
Lincoln Point[1]	(D-8-1)2cc	04-27-33	—	—	—	—	—	—	—	—
Lincoln Point[2]	(D-8-1)2cc	10-31-34	—	—	—	—	—	—	—	—
Lincoln Point[3]	(D-8-1)3dda-S1	05-27-64	—	—	—	—	—	—	—	—
Lincoln Point[3]	(D-8-1)3dda-S1	06-16-66	—	—	—	—	—	—	—	—
Lincoln Point[4]	(D-8-1)2cc	08-05-64	—	—	—	—	—	700	—	—
Lincoln Point east side, north of spit, confluence of numerous springs[5]	(D-8-1)2ccd	09-27-77	<100	1.8	900	—	<0.30	—	11	<5
Lincoln Point spring No. 2[5]	(D-8-1)2ccb	10-14-77	<100	6.7	900	—	—	—	24	<5
Lincoln Point, spring pool 10 yards north of northeast corner of storage pond[5]	(D-8-1)3dda	09-27-77	<100	2.8	1,550	—	<0.30	—	23	9
Lincoln Point, northwest end of old swimming pool[5]	(D-8-1)2ccb	09-27-77	<100	5.5	1,460	—	<0.30	—	20	14
LPW-3[6]	(D-8-1)3dda-1	05-06-91	—	6	—	1,200	—	—	—	—
LPS-2[6]	(D-8-1)2ccd-S1	04-30-91	—	3	—	590	—	—	—	—
LPS-15[6]	(D-8-1)2ccb-S1	04-30-91	—	28	—	1,600	—	—	—	—
LPW-1[6]	(D-8-1)11bac-1	06-14-91	—	4	—	80	—	—	—	—
LPS-18[6]	(D-8-1)9adc-S1	08-21-91	—	10	—	1,400	—	—	—	—
LPW-4[6]	(D-8-1)10bcb-1	07-03-91	—	58	—	1,700	—	—	—	—
BIS-2[6]	(D-7-1)26cac-S1	09-18-91	—	89	—	2,200	—	—	—	—
BIS-3[6]	(D-7-1)26cac-S2	10-14-92	—	150	—	1,600	—	—	—	—
BIS-1[6]	(D-7-1)26cbd-S1	09-18-91	—	86	—	2,300	—	—	—	—

[1] Decker and Maw, 1933, p. 36-37; analysis by Brigham Young University laboratory.
[2] Subitzky, 1962, p. 14; analysis by Salt Lake City chemist.
[3] Cordova, 1969, p. 31, and Mundorff, 1970, p.18.
[4] Milligan and others, 1966, Table 1; analysis by Utah State University laboratory
[5] Dustin, 1978, p. 159-160; analysis by Brigham Young University laboratory.
[6] Analysis by U.S. Geological Survey laboratory

figure 23. This equation defines a line of data points that represent mean global values of the isotopic (δ^2H and $\delta^{18}O$) composition of meteoric waters (Craig, 1961). Plots of δ^2H and $\delta^{18}O$ values relative to this line indicate processes that have occurred prior to infiltration of recharge into the ground-water system. Water from springs or wells that has originally undergone evaporation is enriched in heavier isotopes (^{18}O is enriched relative to ^2H) and shifts away from the meteoric water line. Water from springs or wells that has undergone exchanges of oxygen between water and rock in geothermal systems also may increase in oxygen-18 (more positive). Results of analyses of the stable isotope ratios for deuterium and oxygen-18 determined for water from the eight springs and wells sampled during 1991-92 are shown in table 4 and in figure 23.

Deuterium ratios for water from springs and wells at Lincoln Point and Bird Island ranged from -120.0 to -132.0 per mil. Oxygen-18 ratios for water from the same sites ranged from -15.75 to -17.65 per mil. The small variation in δ^2H and $\delta^{18}O$ values of most springs and wells indicates that water from most of these sites has undergone similar processes (degree of evaporation) and may have originated from a common source.

Water from spring LPS-2 is more enriched in oxygen-18 than water from the other springs and wells, implying greater evaporation prior to recharge or possi-

1, 2, 4, and 5 are interpreted; data-site locations for source 3 reported as published.

Iron, dis- solved (µg/L as Fe)	Lead, dis- solved (µg/L as Pb)	Lith- ium, dis- solved (µg/L as Li)	Manga- nese, dis- solved (µg/L as Mn)	Mer- cury, dis- solved (µg/L as Hg)	Molyb- denum, dis- solved (µg/L as Mo)	Nickel, dis- solved (µg/L as Ni)	Selen- ium, dis- solved (µg/L as Se)	Silver, dis- solved (µg/L as Ag)	Stron- tium, dis- solved (µg/L as Sr)	Zinc, dis- solved (µg/L as Zn)
—	—	—	—	—	—	—	—	—	—	—
4,500	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	20	1,700	80	—	—	—	—	10	11,000	30
260	—	3,900	—	—	—	—	—	—	4,700	—
28	161	—	<10	3.8	<0.05	74	2	4.3	—	<5
40	—	—	<10	<0.05	<50 ?	<20	1.2	—	—	<5
90	328	—	25	0.23	<0.05	100	1.3	18.5	—	7
220	309 ?	—	55	<25	<0.05	145	1.1	15.4	—	7
300	—	1,800	150	—	—	—	1	—	1,700	—
10	—	890	10	—	—	—	2	—	4,400	—
180	—	2,000	70	—	—	—	1	—	10,000	—
120	—	89	32	—	—	—	1	—	1,700	—
280	—	3,300	20	.	—	—	1	—	9,800	—
1,200	—	2,300	40	—	—	—	1	—	11,000	—
990	—	3,100	30	—	—	—	1	—	9,800	—
920	—	130	30	—	—	—	1	—	9,400	—
990	—	3,100	40	—	—	—	1	—	9,400	—

ble effects from thermal heating. Water from spring LPS-2 also may have been mixed with water having a heavier isotopic composition than water from the other springs and wells at Lincoln Point. Water from springs LPS-15 and LPS-18, and wells LPW-3 and LPW-4, along the northern part and to the west of Lincoln Point, had δ^2H and $\delta^{18}O$ ratios that were almost identical to those in water from Bird Island springs BIS-1 and BIS-2, indicating a common origin. Results of isotopic analyses are consistent with other chemical data for water from springs and wells in the Lincoln Point - Bird Island area, which also indicate a similar origin or flow path.

Water from well LPW-1 is more enriched in the lighter isotopes (δ^2H, -132.0 and $\delta^{18}O$, -17.65 per mil) than water from the other springs and wells at Lincoln Point and, when combined with water chemistry, indicates a source of water considerably different from that discharging from the other sites. This isotopic ratio plots on the meteoric water line (fig. 23) and indicates that little or no evaporation occurred prior to recharge. Water from this well may have originated locally as high altitude snowmelt or may be older than water from other sites.

Deuterium and oxygen-18 ratios relative to the global meteoric water line indicate that water from springs and wells in the Lincoln Point - Bird Island area

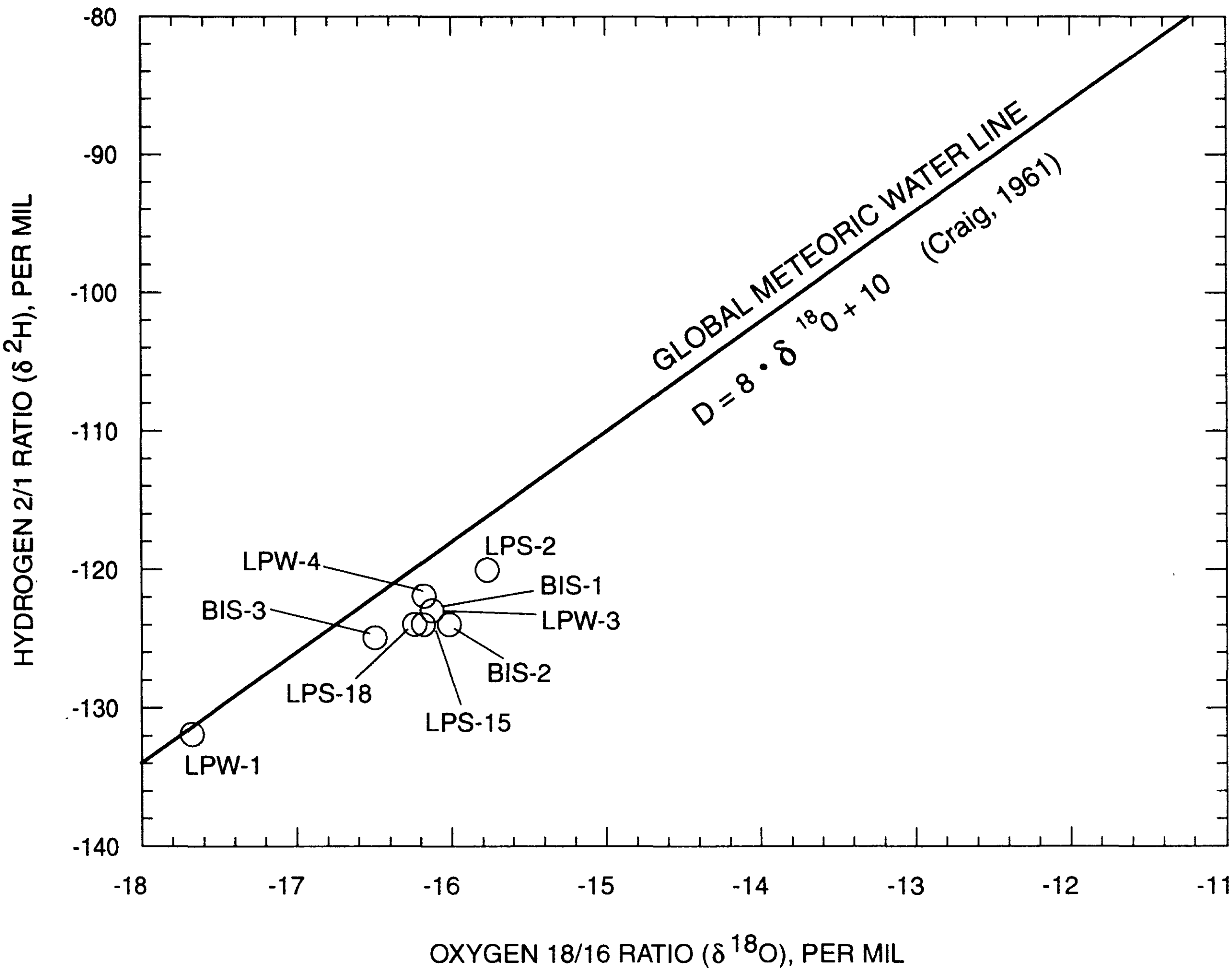


Figure 23. Relation between hydrogen 2/1 ratio and oxygen 18/16 ratio for water from selected springs and wells in the Lincoln Point-Bird Island area, Utah Lake.

has undergone some evaporation prior to recharge. Thermal effects resulting in increases in oxygen-18 also may, in part, explain the data shift from the meteoric water line.

Tritium

Tritium is produced naturally in the atmosphere by cosmic ray activation of nitrogen. During the early to mid-1950's, additional tritium was produced by atmospheric thermonuclear testing (Davis and DeWeist, 1966, p.138). Because the half-life of tritium is about 12.3 years, it can be used to date the entry of surface water into the ground-water system.

A water-quality sample was collected for tritium analysis from spring LPS-15 on April 30, 1991. This spring was chosen because of its distinct orifice and its location in the north area of Lincoln Point. Tritium in water that entered the ground-water system prior to about 1952 has decayed radioactively to less than current (1992) tritium concentrations in ground water. Surface water that has entered the ground-water system during the last 40 years may have measurable concentrations of tritium, assuming that no mixing with modern water has occurred. Tritium analysis of water from spring LPS-15 at Lincoln Point had a concentration of 0.32 picocurie per liter (0.96 tritium unit). This concentration is near the detection limit for tritium and indicates that water discharging from the spring probably entered the aquifer before 1952.

Saturation indices

Broad platforms of travertine and tufa at Lincoln Point and Bird Island indicate that precipitation of calcite has taken place in recent geologic history, although

Table 6. Saturation indices for water from selected springs in the Lincoln Point - Bird Island area of Utah Lake

[Units for each mineral are log AP/KT, where AP is activity product of cations and anions and KT is the equilibrium solubility product of ions at the water's temperature]

Site name: See figures 4, 8, and 11 for location of springs.
Location: See text and figure 3 for numbering system for hydrologic-data sites in Utah.

Site Name	Location	Aragonite	Calcite	Dolomite	Gypsum	Halite	Quartz
LPS-2	(D-8-1) 2ccd-S1	-0.183	-0.039	-0.788	-0.950	-4.796	0.510
LPS-15	(D-8-1) 2ccb-S1	-0.072	0.069	-0.583	-0.603	-4.162	0.502
LPS-18	(D-8-1) 9adc-S1	-0.097	0.038	-0.593	-0.517	-4.167	0.417
BIS-2	(D-7-1)26cac-S1	-0.036	0.103	-0.347	-0.695	-3.906	0.377
BIS-3	(D-7-1)26cac-S2	-0.259	-0.115	-0.890	-0.783	-4.061	0.437
BIS-1	(D-7-1)26cbd-S1	0.062	0.201	-0.174	-0.691	-3.943	0.399

some springs responsible for precipitating travertine and tufa may no longer discharge or may have shifted to other locations. Precipitation of calcite may result from changes in temperature, pH, partial pressures of carbon dioxide, or possibly by the influence of vegetation. The relative saturation state of water from five springs in the Lincoln Point - Bird Island area was computed to determine if deposition of minerals was still occurring.

Concentrations of major cations and anions and determinations of alkalinity (for bicarbonate), field pH, and temperature can be used to determine the relative saturation states of water from springs with respect to certain minerals. Using the computer program WATEQ4F (Ball and Nordstrom, 1991), the relative states of saturation for aragonite, calcite, dolomite, gypsum, halite, and quartz were determined for water from springs LPS-2, LPS-15, and LPS-18 on Lincoln Point and the springs at Bird Island (table 6).

To determine if water is saturated or undersaturated with respect to one of these minerals, the activity products of the individual ions are compared with the equilibrium solubility products of the same ions at the temperature of the water (Freeze and Cherry, 1979, p. 112-113). At equilibrium, or saturation, the logarithm of the activity products divided by the solubility product will be zero. Saturation indices that are negative indicate undersaturation, and positive saturation indices indicate supersaturation. Typically, saturation indices for water at equilibrium range from -0.1 to +0.1, allowing for instrumental and analytical error.

Water from spring LPS-2 is more undersaturated with respect to all minerals except quartz than water sampled from other springs at Lincoln Point and Bird Island. This may be because of mixing of lesser dissolved-solids water from another source with the ground water before it discharges from the spring or through precipitation of minerals before the water discharges from the spring, or both. Water from all of the springs used in determination of saturation indices is undersaturated with respect to dolomite, gypsum, and halite, indicating that deposition of these minerals probably is not occurring. All sampled spring water is supersaturated with respect to quartz. Precipitation of quartz probably is occurring at or near the springs. Aragonite and calcite are very close to saturation or are supersaturated in water from springs LPS-2, LPS-15, and LPS-18 on Lincoln Point and springs BIS-1 and BIS-2 at Bird Island. Deposition of aragonite and calcite may be occurring at or near the springs or may be occurring before the ground water discharges at the springs.

Chemical Geothermometers

Chemical geothermometer temperatures were calculated for water from three wells and five springs in the Lincoln Point - Bird Island area (table 7). The sodium-potassium-calcium (Na-K-Ca) chemical geothermometer (Fournier and Truesdell, 1973) was calculated for each of the water samples to determine equilibrium temperatures at depth and provide information pertaining to the similarities or differences

Table 7. Calculated sodium-potassium-calcium chemical geothermometer temperatures for water from selected springs and wells in the Lincoln Point - Bird Island area of Utah Lake
Site name: See figures 4, 8, 11, and 15 for location of springs and wells.
Location: See text and figure 3 for numbering system for hydrologic-data sites in Utah.

Site name	Location	Calculated reservoir temperature (degrees Celsius)
LPS-2	(D-8-1) 2ccd-S1	189
LPS-15	(D-8-1) 2ccb-S1	189
LPS-18	(D-8-1) 9adc-S1	196
LPW-1	(D-8-1)11bac-1	82
LPW-3	(D-8-1) 3dda-1	199
LPW-4	(D-8-1)10bcb-1	206
BIS-2	(D-7-1)26cac-S1	191
BIS-3	(D-7-1)26cac-S2	183
BIS-1	(D-7-1)26cbd-S1	194

between waters in the Lincoln Point - Bird Island area. Silica geothermometers were not examined as a result of supersaturation of silica in the water samples and possible quartz deposition between the time of sample collection and analysis.

The Na-K-Ca chemical geothermometer was specifically developed to address calcium-rich waters that give anomalously high calculated temperatures by use of the Na-K geothermometer (Fournier, 1981). Application of the Na-K-Ca chemical geothermometer depends on a number of assumptions (Fournier, White, and Truesdell, 1974):

1. Temperature-dependent reactions do occur at depth.
2. Sufficient quantities of the requisite minerals are present in the rocks so that their supply is not a limiting factor for the reactions.
3. Chemical equilibrium is reached at the reservoir temperature.
4. No mixing of hot water with cooler, shallow ground water occurs.
5. Hot water is rapidly transferred from the reservoir to the surface so that re-equilibration does not occur at temperatures cooler than the reservoir temperature.

Fournier, White, and Truesdell (1974) suggest a minimum flow rate of approximately 0.118 cubic foot per second as an arbitrary cut-off for discharge from a single spring. All of the sampled springs in the Lincoln Point - Bird Island area have flow greater than this cut-off limit.

Calculated reservoir temperatures for the Na-K-Ca chemical geothermometer for all springs and wells in the Lincoln Point area except well LPW-1, ranged from about 189 degrees Celsius to 206 degrees Celsius (table 7). Well LPW-1 had an estimated reservoir temperature of about 82 degrees Celsius. Corrections for magnesium (Fournier and Potter, 1979) were calculated, and because they were negative, were not applied.

Na-K-Ca chemical geothermometers indicate that the reservoir supplying water for the springs and wells on Lincoln Point and Bird Island differs from the reservoir supplying water to well LPW-1. Calculated reservoir temperatures for the springs and wells at Lincoln Point generally increase from east to west, similar to spring- and well-water temperatures. Calculated reservoir temperatures between the Lincoln Point springs and Bird Island springs are similar, implying a similar equilibrium temperature for the water. The highest reservoir temperature was calculated from water from well LPW-4.

SUMMARY

From February 1991 to October 1992, the U.S. Geological Survey, in cooperation with the Central Utah Water Conservancy District, studied the hydrology of the Lincoln Point - Bird Island area. The investigation was designed to describe the physical characteristics and quality of water from selected springs and wells in the Lincoln Point - Bird Island area; to obtain the locations of measured springs and wells; to measure the discharge of known warm, saline springs; and to determine, if possible, the geologic source and path of the warm, saline water discharging from the springs.

Twenty-one distinct springs were found during this study, including two springs beneath the surface of Utah Lake at Bird Island. Springs are present at altitudes above the Utah Lake shoreline (about 4,483 feet) in the study area at Lincoln Point and at Bird Island. Springs discharge from sand, gravel, and rounded cobbles in the Lincoln Point area and from travertine deposits at altitudes above and below the lake surface at Bird Island. Many of the springs at Lincoln Point discharge at discrete locations; however, diffuse seepage through the unconsolidated surface materials is widespread.

Measured discharge of springs in the Lincoln Point - Bird Island area ranged from less than 0.01 cubic foot per second to 0.84 cubic foot per second during the study. Discharge in the area, including all known springs and seeps, is estimated to be about 5 cubic feet per second.

Naturally occurring structural features associated with spring locations in the Lincoln Point - Bird Island area include inferred faults and joints, embayments, and depressions in lake-bottom sediment. All of the springs in the Lincoln Point - Bird Island study area occur near inferred faults or in areas adjacent to faults. The effects of pumping from well LPW-3 indicate that springs in the Lincoln Point area are hydraulically connected to fractured consolidated rock in the well, implying discharge from a fracture-flow system.

The results of water-quality analyses for water from the Lincoln Point area show spatial and temporal variations in temperature, specific conductance, pH, and chemical concentrations. Variations in water quality occur from east to west along Lincoln Point with increasing temperature, specific conductance, and dissolved solids. Values for pH generally decrease from east to west along Lincoln Point. Water-quality analyses of water from pumped wells in the Lincoln Point area also show increases in temperature, specific conductance, and dissolved solids to the west. Values for pH also decrease from east to west along Lincoln Point.

Generally, all chemical constituents of water in the Lincoln Point area increase from east to west along Lincoln Point. These data, combined with the variations in the physical characteristics of water in the Lincoln Point area, indicate a probable path for the spring and well water from the west side of Lincoln Point through fractured consolidated rocks to the springs. A gradual decrease in specific conductance and dissolved solids concentrations to the east may indicate mixing of warm, saline water from the west side of Lincoln Point with water containing lesser dissolved-solids concentrations to the east.

Water from well LPW-1 has significantly lesser temperature, specific conductance, and dissolved solids than the other wells and springs along Lincoln Point, and the value for pH is significantly greater. The chemical analysis of water from well LPW-1 shows significant differences in major ions and trace elements compared with water from other springs and wells in the Lincoln Point area. Physically and chemically, the water from well LPW-1 is significantly different from water from other wells and springs in the Lincoln Point area, inferring a different source, age, or flow path for water from LPW-1.

Seasonally (1991-92), physical characteristics at most of the springs around Lincoln Point varied only marginally. The greatest seasonal changes in temperature, specific conductance, and pH generally occurred in springs LPS-11 and LPS-12. The area between spring LPS-10 and LPS-12 is a transition zone where an abrupt increase in temperature, specific conductance, and dissolved solids occurs. Values for pH also decrease in this transition area. This area may be where mixing of two or more waters occurs.

Broad platforms of travertine and tufa at Lincoln Point and Bird Island indicate that precipitation of calcite has taken place in recent geologic history, although some springs responsible for precipitating travertine and tufa may no longer discharge or may have shifted to other locations. Water from all of the springs used in determination of saturation indices is undersaturated with respect to dolomite, gypsum, and halite, indicating that deposition of these minerals probably is not occurring. All sampled spring water is supersaturated with respect to quartz, and precipitation of quartz probably is occurring at or near the springs. Deposition of aragonite and calcite may be occurring at or near some of the springs or may be occurring before the ground water discharges at the springs.

Water from springs and wells along the northern part and to the west of Lincoln Point had δ^2H and $\delta^{18}O$ ratios almost identical to those in water from Bird Island springs BIS-1 and BIS-2, indicating a common origin. The small variation in δ^2H and $\delta^{18}O$ values of most springs and wells in this area indicates that water from these sites has undergone similar processes (degree of evaporation) and may have originated from a common source. Results of isotopic analyses are consistent with other physical and chemical data for water from springs and wells in the Lincoln Point - Bird Island area, which also indicate a similar origin or flow path.

Tritium analysis of water from spring LPS-15 at Lincoln Point had a concentration of 0.32 picocurie per liter (0.96 tritium unit). This concentration is near the detection limit for tritium and indicates that water discharging from the spring probably entered the aquifer before 1952.

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