

Utah Geological and Mineral Survey
Report of Investigation

No. 195

CAUSES OF BASEMENT FLOODING
ALONG 11800 SOUTH NEAR 3800 WEST,
SOUTH JORDAN AND RIVERTON
SALT LAKE COUNTY

by

Gary E. Christenson

March 1985

CONTENTS

Purpose and scope	1
Background	1
Geology and soils	3
Ground water	10
Sources	14
Precipitation	14
Stream flow	14
Unlined canals and flood irrigation	15
Septic tank soil absorption fields	16
Upward leakage from the deep confined aquifer.	18
Kennecott evaporation ponds	18
Conclusions and recommendations	23
Acknowledgements	25
References	26
Appendix	28

ILLUSTRATIONS

Figure 1. Location map	2
2. Location map, Kennecott evaporation pond area	5
3. Geologic cross section AA' along 11800 South Street, ...	6
Riverton-South Jordan	
4. Geologic cross section BB' along 3800 West Street in	7
South Jordan	
5. Geologic cross section CC' along south edge of Kennecott . .	8
pond area	
6. Geologic cross section DD' along east edge of Kennecott . .	9
pond area	
7. Ground-water aquifers and directions of ground-water flow .	11
in the southwestern Salt Lake Valley area	

TABLES

Table 1. Water quality analyses	17
2. Drill-hole and water-level data, Kennecott evaporation . . .	21
pond area	

PURPOSE AND SCOPE

The purpose of this investigation was to determine the source of shallow ground water which is flooding basements in three homes along 11800 South between 3600 and 4000 West in South Jordan and Riverton (fig. 1). These homes were flooded for the first time in summer 1984, and one potential source is leakage from new evaporation ponds constructed by Kennecott's Utah Copper Division about 4000 feet upslope to the west. An evaluation of this and other possibilities, as well as recommendations for remedies and/or further study, are included in this study.

The scope of work included a literature review, air photo interpretation, analysis of well logs from the Utah Division of Water Rights, and study of Kennecott well log and water quality/level data, including review of a report for Kennecott by Intera Technologies, Inc. addressing the basement flooding. Recent water-level and canal seepage loss data from the U.S. Geological Survey (USGS) were also reviewed. Field visits to the area were made on September 12, November 6, and December 4, 1984, to study surface-water conditions. A field inspection of the Kennecott ponds was performed with S. D. Taylor, environmental engineer for Kennecott, on November 6, 1984. Local residents were contacted on December 4, 1984, to obtain information on the flooding problem.

BACKGROUND

The Candalot, Bowles, and Callister residences along 11800 South were all

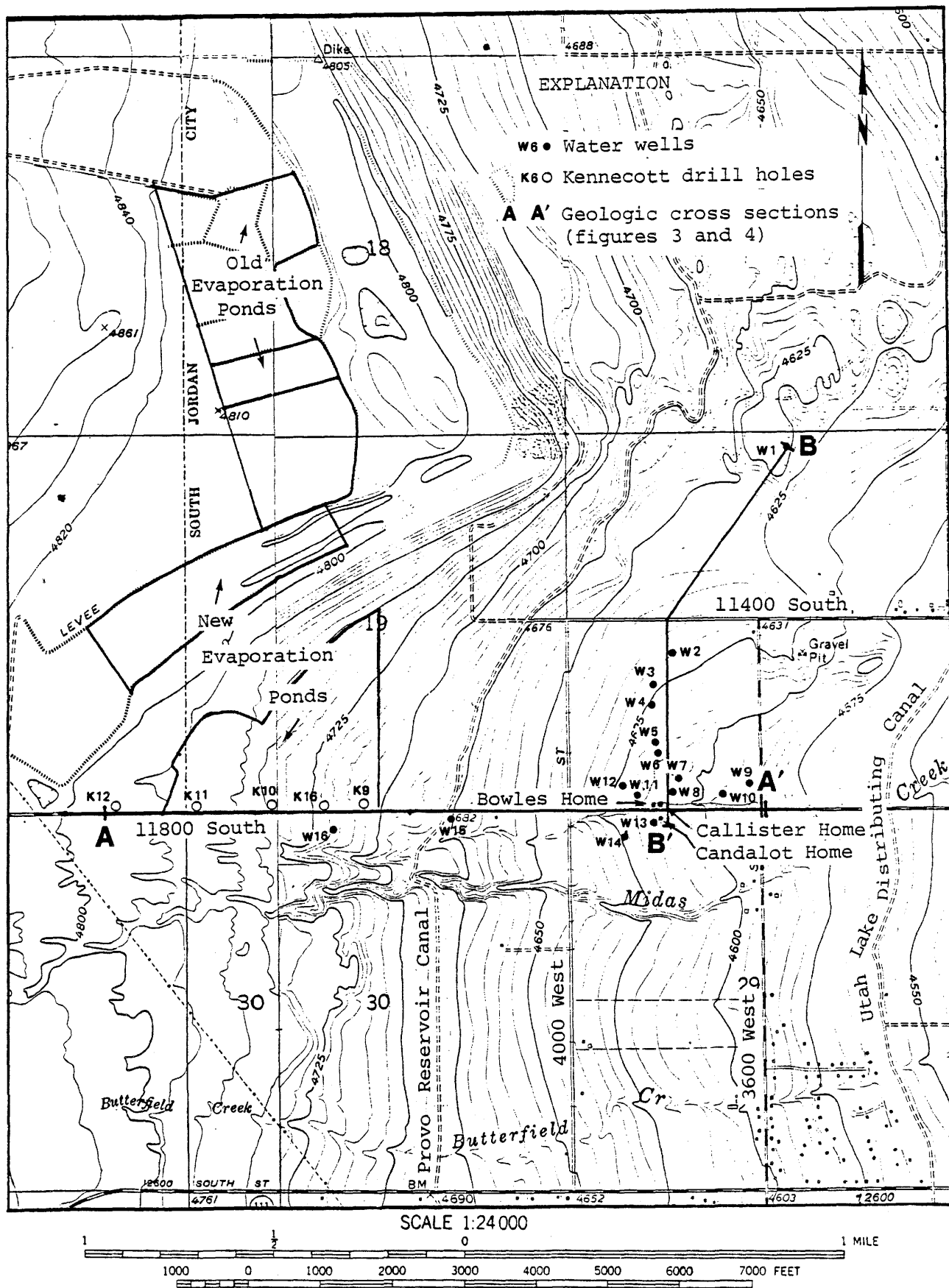


Figure 1. Location map.

affected by basement flooding for the first time in 1984 (fig. 1). Seepage into the basement at the Candalot residence began on June 21 and stopped in mid-November. A drain consisting of a perforated pipe in a gravel-filled trench was installed around the home, but this did not alleviate flooding and pumping from the basement was required. Reports indicate that flooding at the Bowles residence began either June 28 or July 2 and continued until October 2. A drain was placed west of the home and was pumped from a standpipe in the backyard. A vertical culvert was placed in the front yard and pumped. These were insufficient to relieve flooding, and drains and pumps were installed in the basement to keep it dry. Water was pumped from the west-side drain until mid-November, when the water table dropped below the drain. At the Callister residence, flooding began around July 6-7 and stopped October 10. No drains were installed at this home. Trenches were cut into the basement floor to collect water which was then pumped out.

All homes in the area utilize septic tanks and soil absorption fields for domestic wastewater disposal. Flooding of soil absorption fields by ground water caused the systems to function improperly, and residents were forced to greatly reduce their usage. Also, an unprecedented rise in water levels to within several feet of the surface occurred this year at the Candalot and Bowles-Callister wells. A water-logged field east of the Candalot home, presumably caused by shallow ground water, was too wet to be cultivated all summer.

GEOLOGY AND SOILS

The area of evaporation ponds and basement flooding is underlain chiefly

by unconsolidated deposits of Pleistocene Lake Bonneville. Post-lake alluvium and alluvial-fan deposits veneer the lake sediments locally. The evaporation ponds are on beach and nearshore deposits along one of the prominent shorelines of the lake (Provo shoreline, 4813 feet) occupied between 13,000 and 14,000 years ago (Miller, 1980; Currey, 1982; Davis, 1983). Deposits consist of sand and gravel in a V-shaped or cusped beach ridge, which interfingers with nearshore gravel, sand, silt, and clay deposits to the east. A group of old evaporation ponds and one new pond (pond 6, fig. 2) are on the upper sand and gravel beach deposits; the remainder of the new ponds and the area of basement flooding are to the south and east in finer-grained nearshore deposits. Most of the sediment in these deposits was delivered to the lake by Bingham and Midas Creeks and reworked under the influence of converging long-shore currents to form the cusped shoreline (Currey, 1979).

Logs of water wells and Kennecott exploratory drill holes were used to construct geologic cross sections along 11800 South (fig. 3), 3800 West (fig. 4), and in the evaporation pond area (figs. 5 and 6). Locations of wells, drill holes, and cross sections are shown in figures 1 and 2. Logs of water wells shown in figures 3 and 4 were prepared by well drillers and are very generalized. These logs and U. S. Soil Conservation Service soil maps by Woodward and others (1974) indicate that near-surface soils in the pond and basement flooding area generally consist of silt and clay. They are underlain by interbedded gravel, sand, and clay with local thick beds of unknown lateral extent. Correlation of units between water wells was not possible because of the natural variability of soils, generally poor quality of logs, and distance between wells. Kennecott drill-hole logs shown in figures 5 and 6 are more detailed and accurate. The closer drill-hole spacing and 5-foot sample interval give a better indication of soil types. Soils in these drill holes

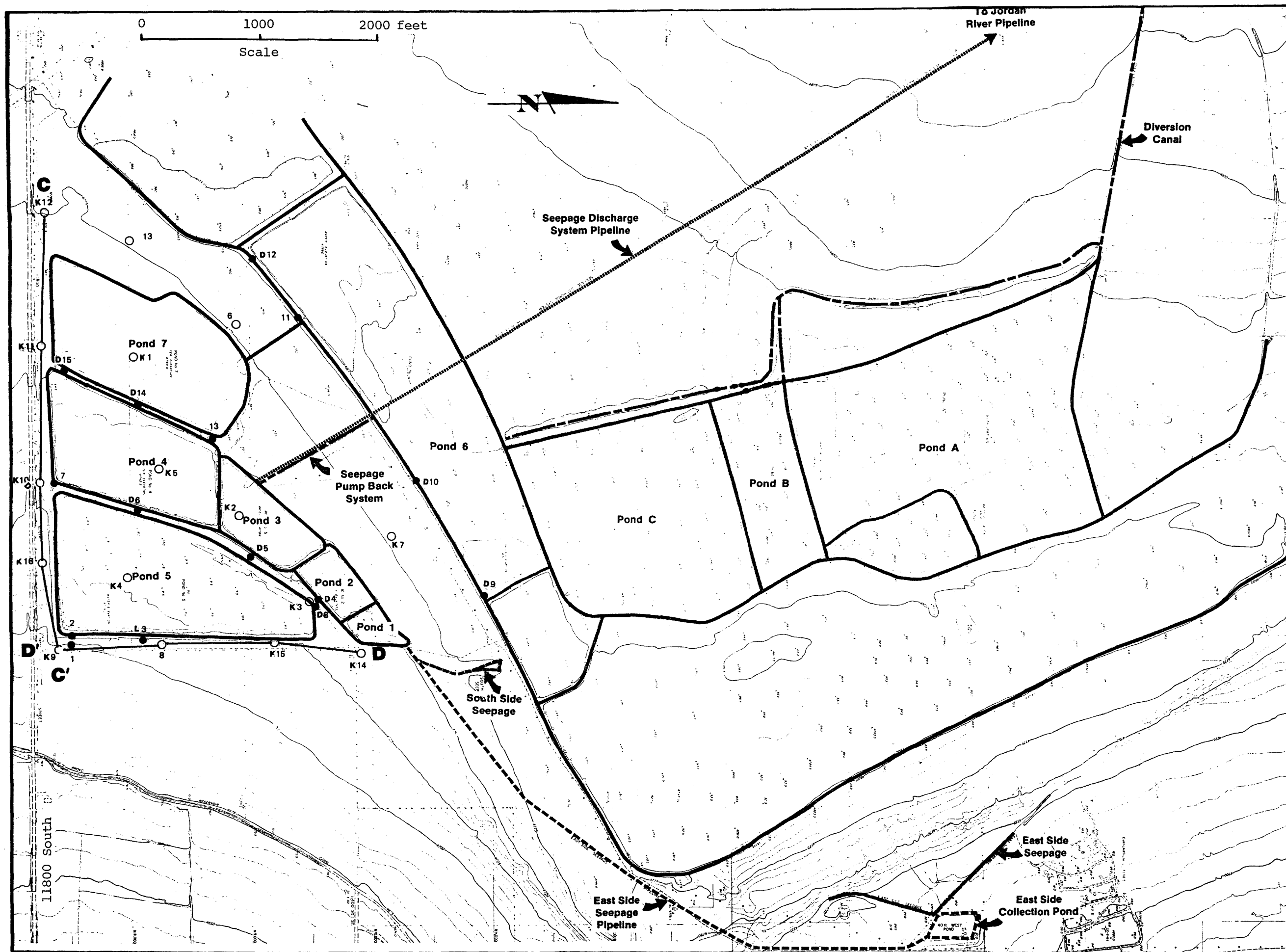


Figure 2.
Location map, Kennecott
evaporation pond area
(from Kennecott, 1984a;
unpub. Kennecott data).

EXPLANATION

- D6 ● Dames and Moore
drill holes and
monitoring wells
- K6 ○ Kennecott drill
holes
- C C' Geologic cross
sections
(figures 5 & 6)

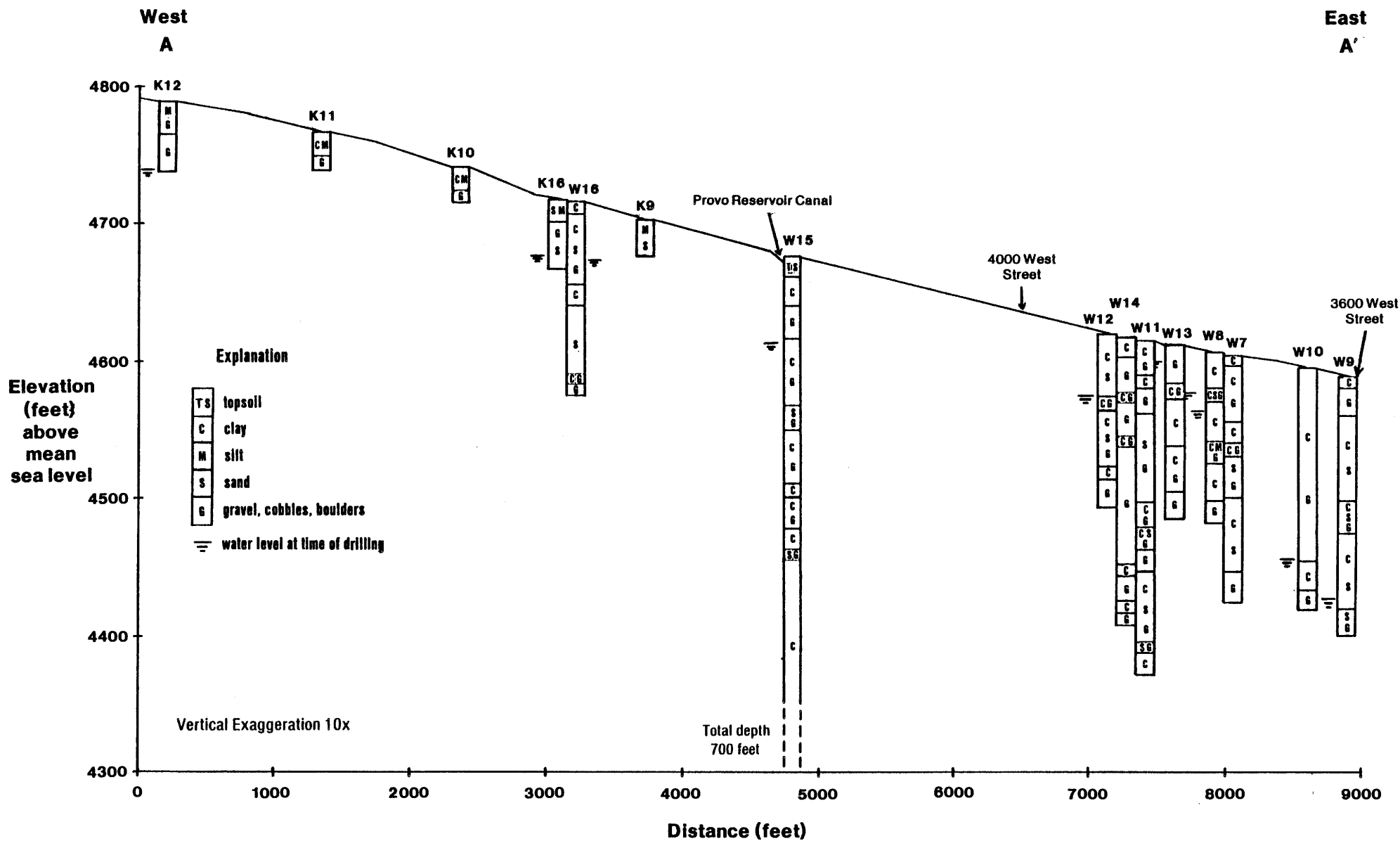


Figure 3. Geologic cross section A A' along 11800 South Street, Riverton-South Jordan (see fig. 1 for location).

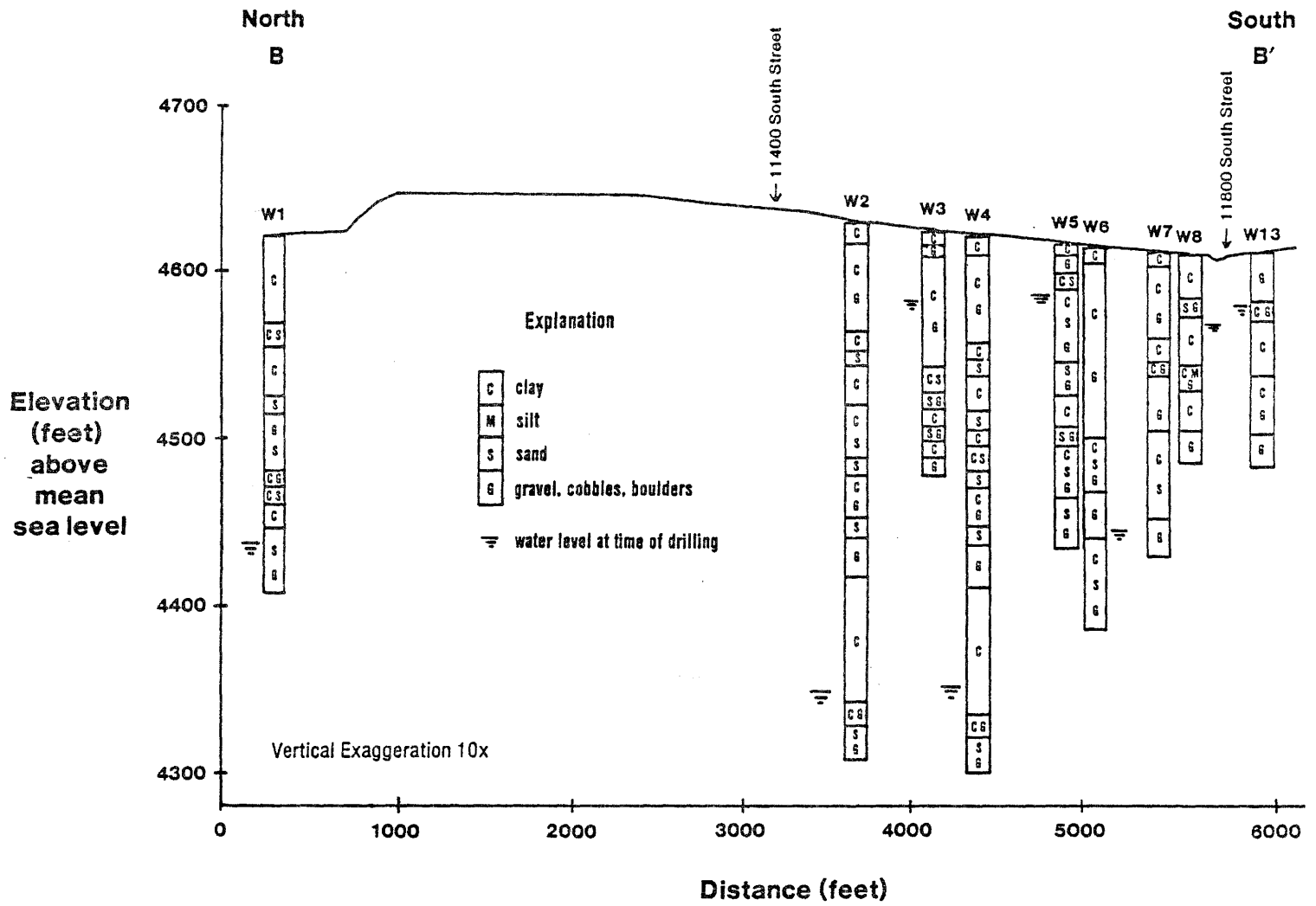


Figure 4. Geologic cross section B B' along 3800 West Street in South Jordan (see fig. 1 for location).

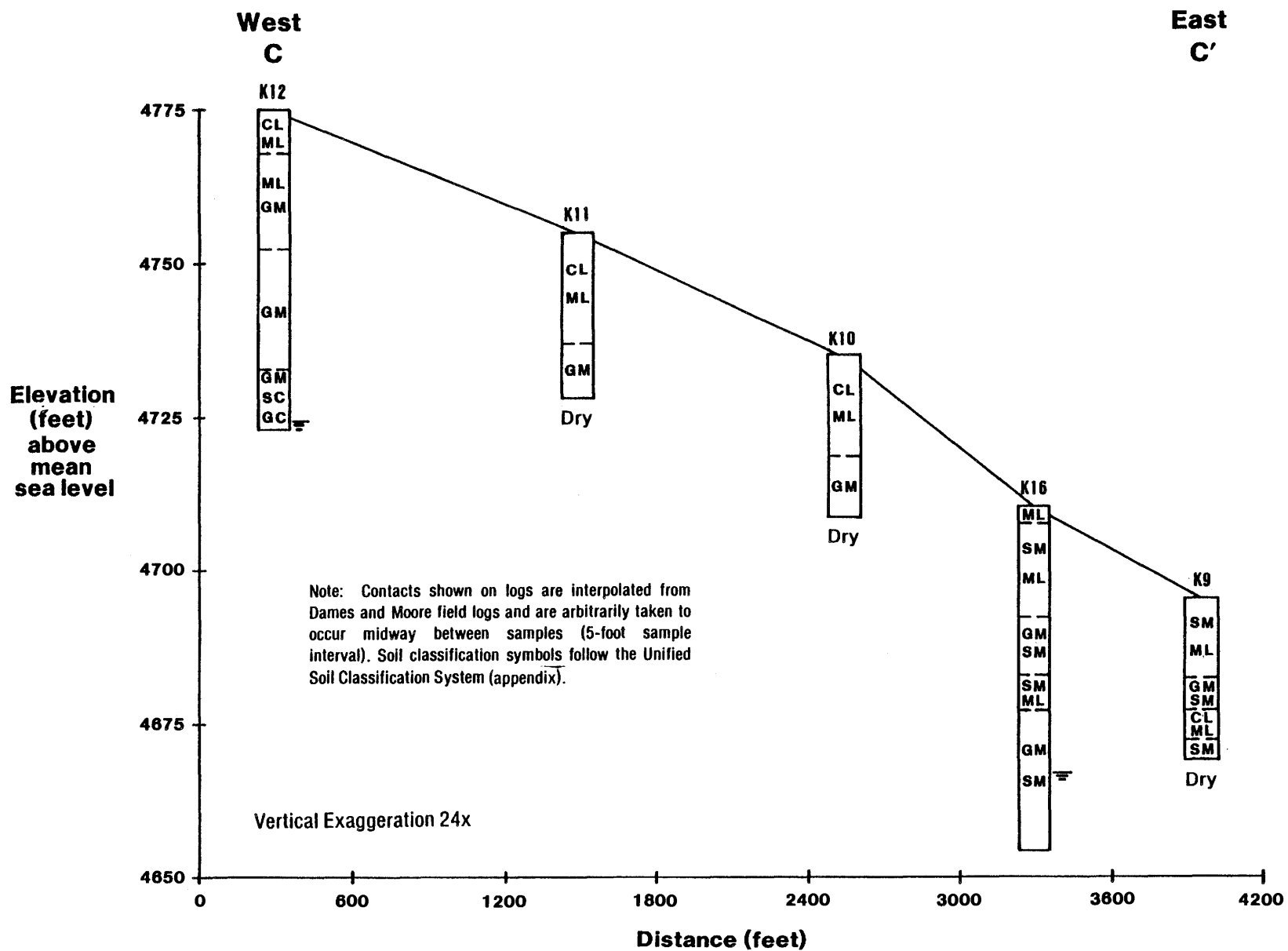


Figure 5. Geologic cross section C C' along south edge of Kennecott pond area (see fig. 2 for location).

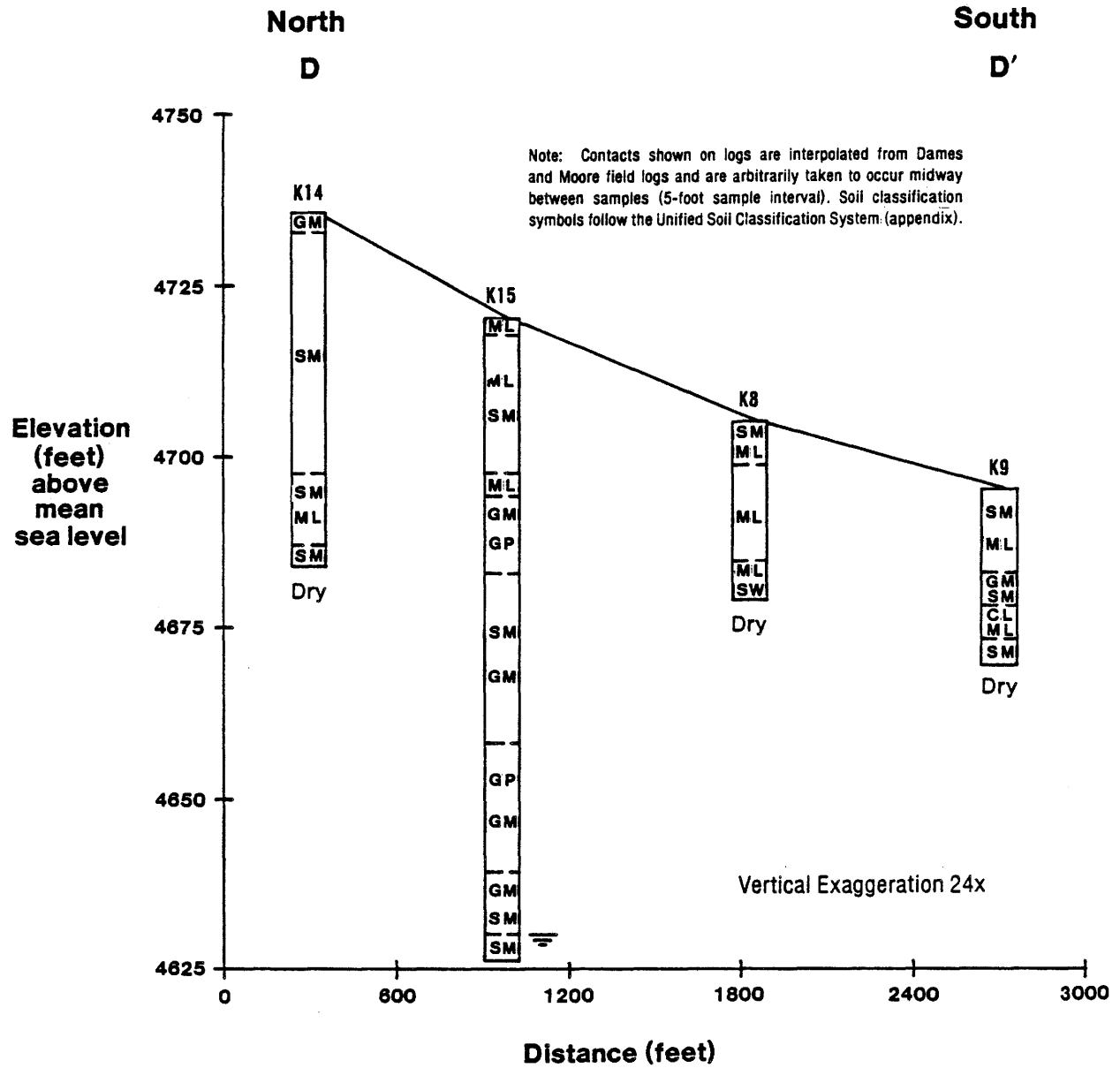


Figure 6. Geologic cross section D D' along east edge of Kennecott pond area (see fig. 2 for location).

were also logged by trained soil technicians and classified according to the Unified Soil Classification System (appendix). Surficial soils are primarily clayey silt, sandy silt, and silty sand. At depths below 20 feet, sand and gravel predominate.

The stratigraphy in the area is typical of shoreline and nearshore deposits of Lake Bonneville where an abundant source of sand and gravel was available. Laterally continuous fine-grained beds that may exist in the area would be the lake-bottom deposits laid down during the highest (Bonneville-level) stillstand of the lake. However, no thick clay beds representing such a deposit were encountered in the pond area. Such beds may either be present below the depth of exploration or absent in the area. Thick clay beds which may represent such deep-lake deposits are recorded at various depths in water wells east of the pond area.

The homes being flooded along 11800 South are along a stream channel incised between lake deposits to the north and post-lake alluvial-fan deposits of Midas Creek to the south (Woodward and others, 1974). The channel is about 5 feet deep and is in the area of lowest topography between Bingham and Midas Creeks. To construct the Bowles and Callister homes, this channel was filled and drainage was diverted along 11800 South. Deposits more permeable than the surrounding silts and clays were probably present in the channel and were buried during lot leveling for home construction.

GROUND WATER

As shown in figure 7, ground water in the southwestern Salt Lake Valley

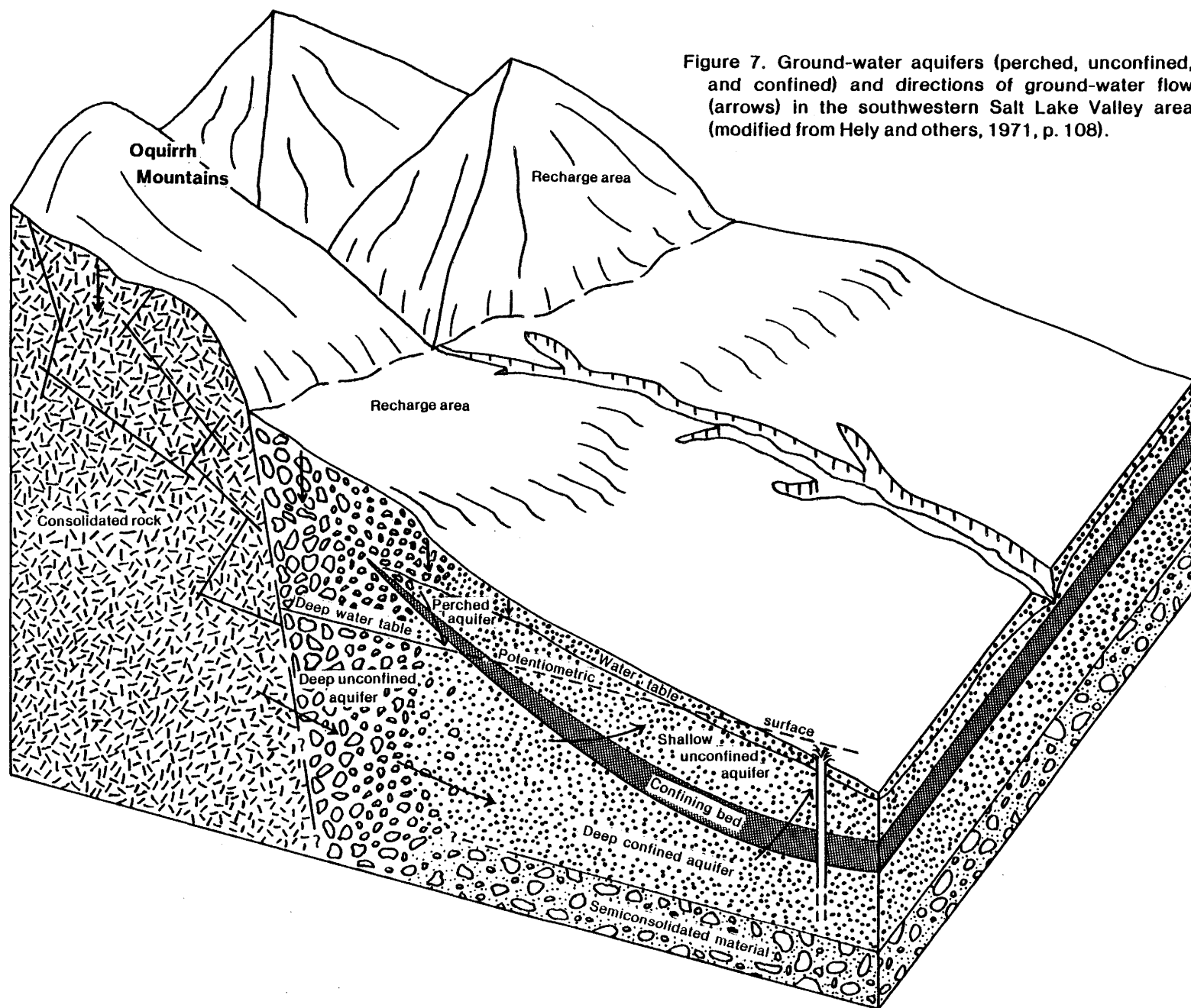


Figure 7. Ground-water aquifers (perched, unconfined, and confined) and directions of ground-water flow (arrows) in the southwestern Salt Lake Valley area (modified from Hely and others, 1971, p. 108).

occurs in: 1) a deep unconfined aquifer in gravelly deposits along the front of the Oquirrh Mountains, 2) a deep confined aquifer in the central valley in gravel deposits beneath clayey confining beds, 3) a shallow unconfined aquifer in the central valley above confining beds and coextensive with the deep confined aquifer, and 4) local perched aquifers (Hely and others, 1971). Flow occurs between the various aquifers as shown in figure 7. The deep unconfined aquifer is recharged from direct infiltration of water along the mountain front and flow from bedrock aquifers at depth. Eastward flow from the deep unconfined aquifer recharges the deep confined aquifer, and the elevation of the potentiometric surface of the confined aquifer is dependent on the amount of recharge. Both the shallow unconfined and perched aquifers are recharged from infiltration from surface sources (irrigation, stream flow, direct precipitation). As defined by Hely and others (1971), the distinction between these two aquifers is that the shallow unconfined aquifer also receives recharge from upward flow through leaky confining beds from the deep confined aquifer. The perched aquifer is above the potentiometric surface of the deep confined aquifer, and any movement of water from the perched aquifer is downward into the unsaturated zone above the deep aquifer or laterally into the adjacent shallow unconfined aquifer.

Both the deep confined and shallow unconfined aquifers are present in the area of basement flooding. Water well logs indicate substantial thicknesses of clayey material in the upper 100 feet act as confining beds to separate the two aquifers. All wells in the area tap the deep confined aquifer, and the potentiometric surface varies from 17 to 200 feet below ground surface (figs. 3 and 4). The wide range in water levels results from many factors, including: 1) depth of the well and perforated interval, 2) date and accuracy of measurement, and 3) location. Unpublished USGS monitoring-well data

indicate the potentiometric surface in the deep confined aquifer in February, 1983, to be 70 feet below the ground surface near the intersection of the Provo Reservoir Canal and 11800 South Street. By September 1984, the level had risen to 53 feet. At the Candalot home, the water level rose from 32 feet when the well was drilled in 1973 to near the ground surface in summer 1984. Water levels in other private wells along 11800 South Street also rose significantly in 1984, indicating an increase in recharge to the deep confined aquifer with an accompanying rise of the potentiometric surface.

Basement flooding is occurring as the water table in the shallow unconfined aquifer rises. No wells tap this aquifer in the area of basement flooding, and it is only known that the water table is above the basement floors. Shallow monitoring wells are present in the evaporation pond area to the west, and these indicate an absence of a shallow water table in either perched or shallow unconfined aquifers beneath the ponds. Hely and others (1971) show the approximate westward extent of confining beds to be along the western edge of the ponds, and Kennecott (1984b, p. 29) indicates that the confining beds may extend much further west. However, a drill hole to 95 feet (K15, fig. 6) in the evaporation pond area did not encounter any clayey confining beds, and most other holes to depths of 50 feet likewise encountered no clay. From these data, it appears that confining beds are absent in the upper 95 feet in this part of the pond area and that the water level (89.5 feet) recorded in the deepest drill hole (K15, total depth - 95 feet) may represent the water table in the deep unconfined aquifer.

Sources

Potential sources for shallow ground water in the area include: 1) precipitation, 2) stream flow, 3) unlined canals and flood irrigation, 4) septic tank soil absorption fields, 5) upward leakage from the deep aquifer, and 6) leakage from Kennecott evaporation ponds.

Precipitation

Much of northern Utah has received record amounts of precipitation over the past three years. At the Bingham Canyon mine, total precipitation in 1983 was 37 inches and in 1984 it was 39 inches. The average annual precipitation for the previous ten years was 20 inches with a maximum of 24 inches in 1982 (Intera Technologies Inc., 1984; Kennecott, 1984a). Thus, precipitation during 1983 and 1984 was nearly double the ten-year average. This has resulted in increased stream flow, both in terms of quantity and duration, and an increase in water levels in lakes, ponds, and water-retention structures. Infiltration of this excess surface water has caused a rise in the water table in the shallow unconfined aquifer. Reports of basement flooding and septic tank failures from high ground water have increased throughout northern Utah during the current wet cycle, and unprecedented high ground-water levels have been reported elsewhere in South Jordan and Riverton.

Stream flow

The flooded homes are in a topographically low area where surface runoff can collect and infiltrate. As the water table rises, it is in this area

where depths to water are least and basement flooding occurs first. Coarser-grained, more permeable materials buried in the channel which was filled prior to construction of the Bowles and Callister homes may also transmit ground water more freely than in surrounding areas. Stream flow still occurs along the old drainage course, as was evident in August, 1983, when flash flooding from storms to the west resulted in water several feet deep along 11800 South (Mrs. Callister, oral commun., December, 1984). On September 9, 1984, water was observed flowing along the south side of 11800 South. The source of the water was probably irrigation runoff.

In 1984, stream flow in the area was greater than normal due to the diversion of water into Midas Creek by Salt Lake County to control flooding on Butterfield Creek. The diversion was made through irrigation canals east of Herriman about 2 miles west of the area of basement flooding (Terry Way, oral commun., March 6, 1985). The additional flow would result in increased infiltration which could have contributed to the rise of the water table along 11800 South Street.

Unlined canals and flood irrigation

The Provo Reservoir Canal is situated between the evaporation ponds and the area of basement flooding (fig. 1) and is the source of water for local flood irrigation. The canal is not lined and loses water through leakage into the subsurface. In 1982, the USGS collected seepage loss data on the three upper west-side canals for a report being prepared at present. They documented seepage losses of 2.8 cubic feet per second per mile of canal between 12600 to 11200 South. This is the greatest recorded seepage loss for any segment of the Provo Reservoir, Utah Lake Distributing, or Utah and Salt

Lake Canals investigated by the USGS. Seepage losses from the Provo Reservoir Canal from 11200 South to 7800 South averaged 1.0 cubic feet per second per mile in 1982. In November, 1984, after flow had been turned out of the canal, water was observed seeping into the canal just north of 11200 South near the old Kennecott evaporation ponds. The seepage indicates a local high water table.

Residents with flooded basements (Mrs. Callister, Mrs. Candalot, Mr. Bowles, oral commun., December 4, 1984) report that water-table fluctuations, detected from periodic changes in rates of pumping needed to keep basements dry, followed a 12- to 14-day cycle coincident with flood irrigation of fields to the west. Probable overflow from irrigated fields was noted on September 9 along the south side of 11800 South and crossing 11400 South at 3800 West.

Septic tank soil absorption fields

Homes in the flooded area all utilize septic tanks with buried soil absorption fields for the disposal of domestic wastes. No change in total volume of effluent produced is known to have occurred prior to basement flooding in 1984, and the contribution to the ground water from this source has probably remained constant or been reduced as failures occurred and usage was curtailed. However, coliform bacteria were found in water in the Callister and Bowles basements (table 1). Weekly monitoring at the Bowles home from July 13 to October 30 by Kennecott showed consistently high fecal and total coliform counts with maxima of greater than 2400 per 100 ml. Coliform bacteria (reflected in total coliform counts) have not been found in the deep aquifer in this area or in the Kennecott evaporation ponds. However, they are a common constituent of septic tank effluent and, to a lesser extent,

Table 1. - Water quality analyses

Sample	Date	pH	Coliforms/ 100 ml		TDS	mg/l			Sulfate	Silver	Arsenic	Lead
			Total	Fecal		Zinc	Copper	Manganese				
<u>Shallow aquifer</u>												
Callister bsmt.	7/31/84	7.2	1100	<3	1324	0.25	0.03	0.02	177			
Callister sump	7/31/84	7.3			1500				300			
Candalot sump	7/31/84	7.2			1300	0.027		<0.05	350	<0.01	0.08	<0.005
Bowles bsmt.	7/31/84	7.2	2400	240	1427	0.23	0.02	0.45	329			
Bowles sump	7/31/84	6.8			1300	0.016		0.07	375	<0.01	<0.01	<0.005
<u>Deep aquifer</u>												
Callister-Bowles well	7/31/84	6.6			1500	0.85		<0.05	600	<0.01	<0.01	<0.005
Candalot well	7/31/84	6.6			1550	0.105		<0.05	600	<0.01	<0.01	<0.005
<u>Evaporation pond area</u>												
Ponds	8/01/84	4.4			14000	21.8		<50	10000	0.06	<0.02	0.010
South side seepage	8/01/84	4.7				31.9	11.07	91.7			0.04	0.54

irrigation water. Fecal coliforms in the quantities found are probably derived from septic tank effluent, and it is likely that ground water contaminated by local septic tanks was drawn into basements by pumping.

Upward leakage from the deep confined aquifer

The rise of the potentiometric surface as measured in wells along 11800 South and elsewhere indicates an increase in hydrostatic pressure in the deep confined aquifer. This is due to additional recharge, and the increased hydrostatic pressure has resulted in an increase in upward flow through leaky confining beds into the shallow unconfined aquifer. A component of upward flow of ground water in the area of basement flooding is indicated by: 1) failure of drain systems designed to intercept lateral flow into basements (assuming proper drain design and construction and no recharge between the home and drain lines), and 2) the similarity in water quality between water in wells from the deep confined aquifer and that in basements from the shallow unconfined aquifer (table 1). Upward flow through confining layers may thus be contributing significantly to the rise in the water table in the unconfined aquifer.

Kennecott evaporation ponds

A series of evaporation ponds operated by Kennecott are located about a mile west of the area of basement flooding. The nearest pond is about 4,000 feet west of the Bowles home. The ponds are used to store runoff from the Bingham Canyon mine before being discharged to the Jordan River. Ponds A, B, and C (fig. 2) were constructed in the 1930's and have been used periodically since that time, including 1982 and 1983. These ponds are located in

permeable sands and gravels and are unlined. Two trenches and a new collection pond were excavated east of Ponds A, B, and C in 1984 to collect and contain seepage from these ponds (east side seepage area, attachment 2). New evaporation ponds were constructed in 1983 (ponds 1 through 7; figs. 1 and 2). Ponds 1 and 2 were constructed under emergency conditions in August, 1983, to provide additional storage for both south and east side seepage from Ponds A, B, and C. The remaining new ponds were constructed later in 1983 to contain runoff expected from the 1984 snowmelt. Ponds 3, 4, 5, and 7 were excavated in fine-grained materials which were compacted in the pond bottoms to form a liner. Pond 6 is on permeable sand and gravel and was lined with material excavated from ponds 3, 4, 5, and 7. Ponds 1, 2, and 3 were full (7 feet of water) during part of 1983 and throughout 1984. Ponds 4, 6, and 7 were full or nearly full from June 1 into August but have been allowed to dry up except for pond 6 which has been periodically refilled. Pond 5 has been held in reserve for emergency storage and receives water only from direct precipitation and leakage from ponds 1, 2, and 3. The water level has remained at less than one foot.

Prior to construction of the ponds, soil testing and exploratory drilling were undertaken to determine subsurface conditions. Laboratory permeability tests performed by Dames and Moore for Kennecott on undisturbed soils in the pond area in the upper 15.5 feet ranged from 0.7 feet/day (6.7×10^{-7} cm/sec) to 100 feet/day (9.6×10^{-5} cm/sec). For comparison, generally accepted permeabilities for impermeable liners are on the order of 10^{-6} to 10^{-7} cm/sec. The tests performed at the ponds were all on uncompacted silty soils. A test on a compacted silty soil, probably typical of the liners in ponds 3 through 7, yielded a value of 0.7 feet/day. These data indicate that natural soil permeabilities are low, and compacted soil permeabilities are

within the range for impermeable clay liners. Kennecott reports that sand lenses found during construction were removed prior to compaction of liners (Steve Taylor, oral commun., November 6, 1984).

Sixteen exploratory holes were drilled, ranging in depth from 25 to 95 feet. Logs of these holes indicated that the sand and gravel content of soils increases with depth. Permeabilities of these deeper soils are probably significantly higher than those of surficial materials. Six of the drill holes were completed with piezometers to measure the water level in the bottom 20 feet (fig. 2). Given the range in depth of the holes (table 2), piezometers record water levels in the intervals from 5-25 feet, 30-50 feet and 75-95 feet. All sixteen of the holes were dry when drilled in September 1983. When the six piezometers were measured in July 1984, four of the six reported water (table 2). In July and August of 1984, fifteen additional holes were drilled by Dames and Moore through pond embankments and 5-25 feet into underlying soils to evaluate embankment stability. Perforated pipe was placed in all of these to monitor water levels. Water was encountered in only three of the drill holes (D4, D5, and D8; table 2) near the unlined ponds. Measurements on November 1, 1984, indicated that conditions had not changed, except that levels in the three had dropped 5-10 feet (table 2), even though the ponds had been kept full.

The ponds may potentially contribute to a rise in the water table along 11800 South Steet through: 1) direct flow of ground water eastward along shallow permeable beds, and/or 2) recharge to the deep unconfined and confined aquifers causing an increase in artesian pressure and additional upward flow into the shallow unconfined aquifer.

Table 2. - Drill-hole and water-level data, Kennecott evaporation pond area

Drill hole/ piezometer*	Depth of drill hole (ft)	Depth to ** subgrade (ft)	Date drilled	Depth to water (feet)		
				When drilled	7/84	11/84
Kennecott (preconstruction)						
K1	25.0	--	9/83	Dry		
K2	50.0	--	9/83	Dry		
K3	25.0	--	9/83	Dry		
K4	52.5	--	9/83	Dry		
K5	25.0	--	9/83	Dry		
K6*	26.0	--	9/83	Dry	1.27	
K7	26.5	--	9/83	Dry		
K8*	26.5	--	9/83	Dry	Dry	
K9	26.5	--	9/83	Dry		
K10*	26.5	--	9/83	Dry	Dry	
K11	26.5	--	9/83	Dry		
K12*	51.5	--	9/83	~50	51.25	
K13	26.5	--	9/83	Dry		
K14	51.0	--	9/83	Dry		
K15*	94.5	--	9/83	Dry	89.5	
K16*	55.0	--	9/83	Dry	42.75	
Dames & Moore* (post-construction)						
D1	21.5	--	7/31/84	Dry		Dry
D2	46.5	40.0	7/31/84	Dry		Dry
D3	36.5	31.0	8/01/84	Dry		Dry
D4	34.0	30.0	8/01/84	14.5***		19.10
D5	41.5	19.0	8/02/84	21.9***		28.83
D6	31.5	25.0	8/02/84	Dry		Dry
D7	31.5	26.5	8/02/84	Dry		Dry
D8	16.5	5.0	8/02/84	5.5***		10.91
D9	31.5	20.0	8/02/84	Dry		Dry
D10	26.0	12.0	8/02/84	Dry		Dry
D11	21.5	14.0	8/03/84	Dry		Dry
D12	21.5	15.0	8/03/84	Dry		Dry
D13	26.5	19.0	8/06/84	Dry		Dry
D14	26.5	20.0	8/06/84	Dry		Dry
D15	26.5	24.0	8/06/84	Dry		Dry

*Kennecott drill holes completed as piezometers to measure water level in bottom 20 feet (perforated and gravel packed in bottom 20 feet and sealed with bentonite and cuttings to the surface). All Dames and Moore drill holes completed as observation wells with perforated pipe to measure shallow water table.

**Depth indicates base of fill in pond embankments; dash indicates drill hole placed in natural material.

***Measurements taken 8/31/84.

Water-level measurements in the pond area indicate that it was dry prior to construction, i.e., no natural ground water or seepage from ponds A, B, and C had entered the area. The irregular water levels (table 2) and presence of water in only a few monitoring wells and piezometers following construction and filling of the ponds indicate that a continuous shallow saturated zone (shallow unconfined or perched aquifer) does not exist beneath the ponds. Water appears to occur only locally in isolated permeable beds which may be recharged either by pond leakage or by subsurface flow from the west. In either case, eastward flow along these permeable beds would be necessary to contribute to the water table to the east. It is probable that any significant contribution of water directly from the ponds would result in a reduction in water quality down-gradient to the east. Water in basements shows none of the contamination typical of the pond water (table 1), although some treatment by natural soils could occur in transit. Ground-water flow rates are not known, but measured permeabilities of undisturbed and compacted soils are generally too low to allow water from lined ponds to migrate the necessary distance in the time elapsed between filling of the ponds and the onset of basement flooding. However, the unlined ponds were first filled in August 1983, perhaps allowing sufficient time for water from these ponds to migrate the distance.

The absence of confining beds and a shallow water table beneath the ponds indicates that any leakage, if occurring, would be recharging the deep unconfined aquifer, which in turn recharges the deep confined aquifer causing a rise in the potentiometric surface. Such a rise is evident in wells in the area, although it is not known to what extent this is caused by pond leakage or by increased natural recharge during recent wet years. Because hydrostatic pressure in a confined aquifer system reacts very quickly to changes in

recharge, a comparison of detailed concurrent records of potentiometric surface fluctuations and of pond levels should show the effect of the ponds on the confined aquifer system. At present, the data for such comparisons are not available. Ideally, placement and monitoring of piezometers throughout the area, including both upgradient (west) and downgradient (east, near flooded homes) from the ponds, would be required to define ground-water flow directions and differentiate pond leakage from natural recharge. In addition, testing of soil moisture content at various levels beneath the ponds could be used to evaluate whether downward flow through the unsaturated zone is occurring (K. Waddell, oral commun., January, 1985).

CONCLUSIONS AND RECOMMENDATIONS

Many sources of recharge to the shallow aquifer may be contributing to a rise in water levels in the area of basement flooding. Direct precipitation, stream flow, unlined canals, flood irrigation, septic tank absorption fields, and upward leakage from the deep confined aquifer all probably supply water to the shallow unconfined aquifer. It is possible that leakage from Kennecott evaporation ponds is also contributing, either through leakage along permeable zones in the shallow subsurface or through recharge to the deep aquifers causing increased upward flow into the shallow unconfined aquifer. No direct evidence of leakage in the shallow subsurface has been found and, based on available information, it is unlikely that leakage plays a major role in recharging the shallow unconfined aquifer. To evaluate possible effects on deep aquifers, periodic monitoring and comparison of water levels in ponds, in wells in the area of basement flooding and west of the ponds, and in drill

hole (piezometer) K15 in the pond area would be necessary. Kennecott and various government agencies have recently begun a cooperative study to define the effects of mine operations, including evaporation ponds, on ground water in the western Salt Lake Valley. The data necessary to evaluate this possibility should be included as a part of that study.

Determining the relative contribution of recharge to the shallow unconfined aquifer from each source is very difficult. An extensive program of water-level and water-quality monitoring with drilling of shallow monitoring wells would be required. In addition, detailed canal flow and irrigation timetables, stream-flow records, well (water level) records, and water budgets for evaporation ponds would be needed. Tracer dye tests may also provide useful information but, even with all these data, it cannot be assured that conclusive results showing the contribution from each source would be obtained.

Because of these uncertainties, it is believed that further study would be of little immediate benefit. The investigation underway by Kennecott may help define the impact of the evaporation ponds on the ground-water system, but will not address the other possible sources. Measures which would reduce recharge to the shallow unconfined aquifer and/or the deep aquifers and thus lower the water table in the area of basement flooding include: 1) diverting surface flow in Midas Creek and along 11800 South Street out of the area, 2) lining the Provo Reservoir Canal, 3) reducing flood irrigation, and possibly 4) lining of Kennecott evaporation ponds 1 and 2. Also, pumping of the deep confined aquifer would reduce the upward pressure gradient and thus lower the shallow water table by reducing upward flow. Pumping the deep aquifer will be most effective if the confining beds in the area of basement flooding are

thin, relatively permeable, and/or laterally discontinuous. Pumping directly from the shallow unconfined aquifer may also help lower the water table. However, if permeabilities in this aquifer are low and rates of upward flow are high, a large number of wells may be required. Insufficient data are available to determine the rate and duration of pumping and number of wells requiring pumping in order to significantly lower the shallow water table.

It is possible that high water levels will return next summer, particularly if precipitation continues to be above normal, and effective methods of providing drainage for ground water from the area of basement flooding should be sought. Improvements to drain systems around flooded homes and extension of the systems to keep water levels below septic tank soil absorption fields are needed. Because drain systems placed in 1984 did not function effectively, improved designs should be considered. Such systems must be designed to intercept water rising up from below as well as moving laterally eastward. They may utilize more closely spaced lines with placement of gravel around and, if possible, beneath foundations. Pumping as discussed above may be necessary in conjunction with drain systems to adequately lower the water table.

ACKNOWLEDGEMENTS

The author would like to acknowledge the cooperation and assistance of Steve Taylor and Terry Vandell, Kennecott Utah Copper Division, for supplying drill-hole, water-level, and water-quality data in the evaporation pond area. Discussion and manuscript review by Kidd Waddell and Ralph Seiler, U.S. Geological Survey Water Resources Division, are also greatly appreciated.

REFERENCES

Currey, D.R., 1979, Coastal geomorphology of Great Salt Lake and vicinity, in Gwynn, J.W., ed., Great Salt Lake, a scientific, historical, and economic overview: Utah Geological and Mineral Survey Bulletin 116, p. 69-82.

-----1982, Lake Bonneville-selected features of relevance to neo-tectonic analysis: U.S. Geological Survey Open-File Report 82-1070, 30 p.

Davis, F.D., compiler, 1983, Geologic map of the central Wasatch Front, Utah: Utah Geological and Mineral Survey Map 54-A, scale 1:100,000.

Hely, A.G., Mower, R.W., and Harr, A.C., 1971, Water resources of Salt Lake County: Utah Department of Natural Resources Technical Publication 31, 244 p.

Intera Technologies, Inc., 1984, Technical evaluation of basement flooding problem near Kennecott's evaporation ponds: Houston, consultant's report for Kennecott, 7 p.

Kennecott, 1984a, Bingham Canyon storm water management-treatments, control, and impoundment of excess storm water during the July 1, 1983-June 30, 1984 record precipitation year: Utah Copper Division, Environmental Engineering Department, 9 p.

-----1984b, Geologic, ground, and surface water data background and progress report of Kennecott's Utah Copper Division (UCD) mine hydrogeologic study: Report 1, 45 p.

Marine, I.W., and Price, Don, 1964, Geology and ground-water resources of the Jordan Valley, Utah: Utah Geological and Mineral Survey Water-Resources Bulletin 7, 68 p.

Miller, R.D., compiler, 1980, Surficial geologic map along part of the Wasatch Front, Salt Lake Valley, Utah: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1198, scale 1:100,000.

Seiler, R.L., and Waddell, K.M., 1984, Reconnaissance of the shallow-unconfined aquifer in Salt Lake Valley, Utah: U.S. Geological Survey Water-Resources Investigations Report 83-4272, 34 p.

Woodward, J.L., and others, 1974, Soil survey of Salt Lake area, Utah: U.S. Soil Conservation Service in cooperation with Utah Agricultural Experiment Station, 132 p.

APPENDIX

UNIFIED SOIL CLASSIFICATION SYSTEM

Major divisions		Group symbols	Typical names		Laboratory classification criteria	
Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
		GP	Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW	
		GM*	d	Silty gravels, gravel-sand-silt mixtures	Atterburg limits below "A" line or P.I. less than 4	
			u		Atterburg limits above "A" line with P.I. greater than 7	
		GC	Clayey gravels, gravel-sand-clay mixtures		$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	SW	Well-graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW	
		SP	Poorly graded sands, gravelly sands, little or no fines		Atterburg limits below "A" line or P.I. less than 4	
		SM*	d	Silty sands, sand-silt mixtures	Atterburg limits above "A" line with P.I. greater than 7	
			u		Limits plotting in hatched zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols.	
		SC	Clayey sands, sand-clay mixtures			
Fine-grained soils (More than half of material is smaller than No. 200 sieve)	Silts and clays (liquid limit less than 50)	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity			
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
		OL	Organic silts and organic silty clays of low plasticity			
	Silts and clays (liquid limit greater than 50)	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
		CH	Inorganic clays of high plasticity, fat clays			
		OH	Organic clays of medium to high plasticity, organic silts			
	Highly organic soils	Pt	Peat and other highly organic soils			

Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:

Less than 5 per cent..... GW, GP, SW, SP
More than 5 per cent..... GM, GC, SM, SC
5 to 12 per cent..... Borderline cases requiring dual symbols**

Plasticity index

Liquid limit

Plasticity Chart

*Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is based on Atterburg limits; suffix d used when LL is 28 or less and the P.I. is 6 or less; the suffix u used when LL is greater than 28.
 **Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example: GW-GC, well-graded gravel-sand mixture with clay binder.