University of Wisconsin-Extension

GEOLOGICAL AND NATURAL HISTORY SURVEY
3817 Mineral Point Road
Madison, Wisconsin 53705

M.E. Ostrom, State Geologist and Director

GROUND-WATER CONDITIONS AND THE EFFECTS OF LAKE MANAGEMENT ON GROUND WATER IN THE SNAKE LAKE AREA, WOODRUFF, WISCONSIN

by

P.G. Olcott

Open-File Report 69-1
21 p.

1969

67-1

UNIVERSITY EXTENSION
THE UNIVERSITY OF WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

in cooperation with

THE UPPER GREAT LAKES REGIONAL COMMISSION
INLAND LAKE RENEWAL AND MANAGEMENT DEMONSTRATION PROJECT COMMITTEE

GROUND-WATER CONDITIONS AND THE EFFECTS OF LAKE MANAGEMENT ON GROUND WATER IN THE SNAKE LAKE AREA, WOODRUFF, WISCONSIN

by

Perry G. Olcott

August, 1969

SUMMARY OF FINDINGS AND RECOMMENDATIONS

The water table in the Snake Lake area is very flat and ground water moves under a gradient of about 3 to 6 feet per mile. Under present conditions, with the level of Snake Lake artificially raised 2-3 feet above its natural level, ground water moves into the lake from the east. Water is discharged from the lake through the sand dam to the north and by reentering the ground-water reservoir on the west and south. Ground water movement generally is southwesterly to Lake Minocqua south of a divide that bisects the lake and north and northwesterly to Arrowhead and Brandy Lakes and Johnson Creek north of the divide. Under natural conditions, ie., with the dam between the two lakes removed, level of Snake Lake should be only slightly higher than Arrowhead Lake and ground water will move into the lake around its entire periphery and discharge to Arrowhead Lake. Water levels in the Snake Lake area are presently at nearly record high levels showing the amount of ground water in storage is presently near maximum.

Ground water in the Snake Lake area generally is acidic, very soft and contains only small concentrations of dissolved material. A comparison of average concentrations of selected constituents in ground water east, on the recharge side of the lake, and on the west and south, on the discharge side of the lake, indicate much higher concentrations of dissolved material occur on the discharge side, probably owing to dissolved material in the lake moving into the aquifer with the ground water. Lake water also is more highly mineralized than ground water on the east side of the lake. There is indication of contamination of the aquifer by chloride and sodium on the south side of the lake, possibly owing to road salt applied to Highway 47. Concentrations of all constituents tested for in the ground water were within recommended limits for drinking water with the exceptions of chlorides in several wells and of iron in most wells.

Lowering the level of Snake Lake to that of Arrowhead Lake by pumping will alter ground water conditions from the present flow through the lake to movement toward the lake around most of its periphery. This change will increase ground water inflow to the lake.

An 8000 gpm (gallons per minute) pump is proposed for pumping from Snake Lake under the management plan. Pumping at this rate should be adequate to lower lake level the desired amount. It is estimated that discharge water from the pump will infiltrate into the soil at the rate of about 1000 to 1500 gpm per acre. Rough calculations indicate that ground water would move away from the discharge site rapidly enough to prevent water logging at this discharge rate. A discharge site should be chosen that is of adequate size to allow for alternate placing of the discharge to prevent water logging of the soil and soil clogging. An area where the ground water gradient is away from Snake Lake is preferable for the discharge site to prevent recirculation of water back to the lake.

Monitoring of ground-water levels, quality, and temperature at the pump discharge site and around the lake is recommended in order to determine effects of pumping.

INTRODUCTION

This study is part of the Inland Lake Renewal and Management Demonstration Project conducted by a project committee and supported by the Upper Great Lakes Regional Commission. The study was conducted by the Wisconsin Geological and Natural History Survey with partial financial support from the project committee.

The purpose of this report is to present a general definition of ground-water conditions in the vicinity of Snake Lake to aid in reaching decisions on management of the lake and to form a basis for determining changes in the ground-water regimen that may occur with management procedures. Field study was confined to documenting and monitoring configuration of the water table and lake level, and determining the chemical quality of the ground water.

Acknowledgements

The assistance rendered by Mr. Art Husak and Mr. Leo Schlezewski, both of Woodruff, is greatfully acknowledged. Both men, and especially Mr. Husak, spent many hours in gathering field data and aiding in observation well installation for the project.

Acknowledgement is made to Mr. William J. Drescher of the U. S. Geological Survey, a member of the project technical advisory committee, for technical advice during the project.

PHYSICAL SETTING

Snake Lake is a 14 acre lake located in the town of Minocqua, Oneida County and town of Arbor Vitae, Vilas County in Secs. 1 and 2, T.39N., R.6E., and Secs. 35 and 36, T.40N., R.6E. The town of Woodruff borders the southern and western side of the lake. The eastern side of the lake is a partially wooded area where only 2 homes are located. Arrowhead Lake lies immediately north of a small marsh occupying the northern end of Snake Lake.

Topography and Drainage

The land surface in the Snake Lake area is a relatively flat to gently rolling plain with many drained and undrained depressions or "kettle holes." Snake Lake occupies such a kettle hole as do the many lakes and marshes in the area. The lake lies about 10-15 feet below the surrounding land surface. The land surface slopes gently westward toward the Tomahawk River and southward toward Minocqua Lake, ranging in elevation from approximately 1590 to 1620 feet above mean sea level.

Snake Lake forms part of the headwaters of Johnson Creek, a westward flowing tributary of the Tomahawk River which, in turn, is tributary to the Wisconsin River. Drainage from the lake flows through Arrowhead, Brandy, and Johnson Lakes, and thence to Johnson Creek.

Storm drainage from a section of Highway 51 is diverted into Snake Lake, and another diversion to the lake to drain a section of Highway 47 is contemplated. It is estimated that drainage from Highway 51 during the 10-year storm (4 inches in 24 hours) is about 19.2 cfs (cubic feet per second). (C. J. Dvorak, District Chief Maintenance Engineer, Wis. Dept. of Transportation, Personal Communications, June, 1969). Drainage from Highway 47 during the 10-year storm is estimated at about 4.8 cfs.

According to a Notice of Investigation and Hearing (2-WP-1672) before the Former Public Service Commission of Wisconsin held on August 20, 1962, Snake Lake originally drained into Arrowhead Lake through about 600 feet of bog and a natural sand ridge separating the two lakes and had no well defined communicating channel. Relative elevations of the two lakes at that time are unknown. A connecting channel, about 5 feet deep, was dredged through the marsh and sand ridge about 50 years ago and allowed free flow of water from Snake into Arrowhead Lake. Under these conditions it is assumed that the elevation of Snake Lake was only slightly above that of Arrowhead Lake. The elevation of Snake Lake on Marsh 25, 1938 from a 1938 water works plan map of the town was 1594.4.

In about 1962, the connecting channel between the lakes was blocked by a dam consisting of silty sand and gravel in an attempt to prevent floating vegetation in Snake Lake, resulting from sewage effluent discharged from the Woodruff sewage plant, from entering Arrowhead Lake. The dam reportedly resulted in a rise of water levels in Snake Lake of an unknown amount. However, a measurement made on April 17, 1969 (a period of high water) showed a difference in elevation of 2.84 feet between the two lakes.

The marsh at the northern end of Snake Lake is presently inundated to the level of the lake and therefore is considered part of the lake. A small stream emerges from the dam and flows into Arrowhead Lake. The discharge of this stream was measured at 17 gpm on April 17, 1969. A small spring located on the extreme northwestern side of the marsh discharges an estimated 5-10 gpm and also flows to Arrowhead Lake.

Geology

Glacial deposits laid down during the Wisconsinan Stage of glaciation cover the Snake Lake area. The deposits are mapped as pitted outwash, as is much of Vilas and Oneida Counties (Thwaites, 1956). The unconsolidated material consists predominantly of stratified sand with some clay, silt, and gravel layers and is characterized by numerous depressions or "kettles", in the land surface formed by the slow melting of ice blocks incorporated in the outwash as the glacier receded. The glacial drift overlies crystalline rock of Precambrian age.

Unconsolidated depoists are about 230 feet thick in the Snake Lake area. Village Well Number 1 at Minocqua, about 2 miles south of the lake encountered basalt at a depth of 213 feet. The log of test well Number 1 drilled at Woodruff is reproduced below and shows the general character of the material.

Log of Test Well No. 1
Woodruff, Wisconsin, 1947

Lithology	Depth below land surface (feet)
Sand, medium-grained, red-grey	0- 20
Sand, medium to fine-grained, grey	20- 25
Sand, medium to fine-grained, light grey	25- 40
Sand, medium to coarse-grained, light grey	40- 60
Silt, grey	60-110
Clay, grey and red	110-125
Clay, pink, dolomitic, or calcareous	125-130
Silt, light grey	130-160
Sand, medium to fine-grained, light grey, slightly calcareous	160-165
Sand, medium to coarse-grained, light grey, slightly calcareous	165-175
Sand, medium to fine-grained, slightly calcareous	175-190
Sand, medium to coarse-grained, light grey, slightly calcareous	190-195
Clay, silty, grey	195-208
Samples missing	208-230
Sand, medium to coarse-grained, dark grey	230-233

Glacial outwash is relatively homogeneous in composition but materials may change rapidly in very short distances both vertically and horizontally. The log of test well number 1 indicates that unconsolidated materials in the Snake Lake area consist of medium to fine-grained sand down to about 60 feet in depth. Shallow observation wells drilled for this study indicate a similar material at least down to 30 feet (the limit of drilling). The sand is quite permeable and allows rapid recharge to the water table from the land surface.

A silt and clay layer occurs below the sand from 60 to 160 feet below land surface (Test Well #1). This layer has a much lower permeability than the sand. The silt and clay layer is underlain by a permeable, coarse to fine-grained sand to a depth of 195 feet below land surface. The interval from 195 to 233 is poorly defined but appears to consist of both sand and silt and clay layers and probably is not very permeable. Presumably, bedrock was encountered at 233 feet below land surface.

Soils

Soils in the immediate area of Snake Lake consist of the Pence-Vilas "soils community" and are nearly level to rolling. (Hole and Schmude, 1959). They consist predominantly of sandy loam, loamy fine sand, sand, and loamy sand. Small lake depressions in the area, including Snake Lake, are mapped as having nearly level Peat-Cable soils consisting of about 80 percent peat with loam, silt loam, stoney loam, and stoney silt loam. Much of this peat soil surrounding Snake Lake is now inundated because of the rise in lake level.

HYDROLOGY

The hydrology of the Snake Lake area is a part of the larger hydrologic system of the Tomahawk River basin. That part of the precipitation that falls in the Tomahawk basin that is not lost to evaporation, transpiration by plants, or runoff to streams sinks into the ground and recharges the ground-water reservoir. The ground-water reservoir receives recharge from precipitation throughout the basin, and movement of ground water, under the influence of gravity, generally is toward the Tomahawk River and tributaries where it is discharged.

The Snake Lake area lies adjacent to Arrowhead and Brandy Lakes which are principal ground-water discharge areas and about 2/3 mile north of Minocqua Lake, also a principal discharge area.

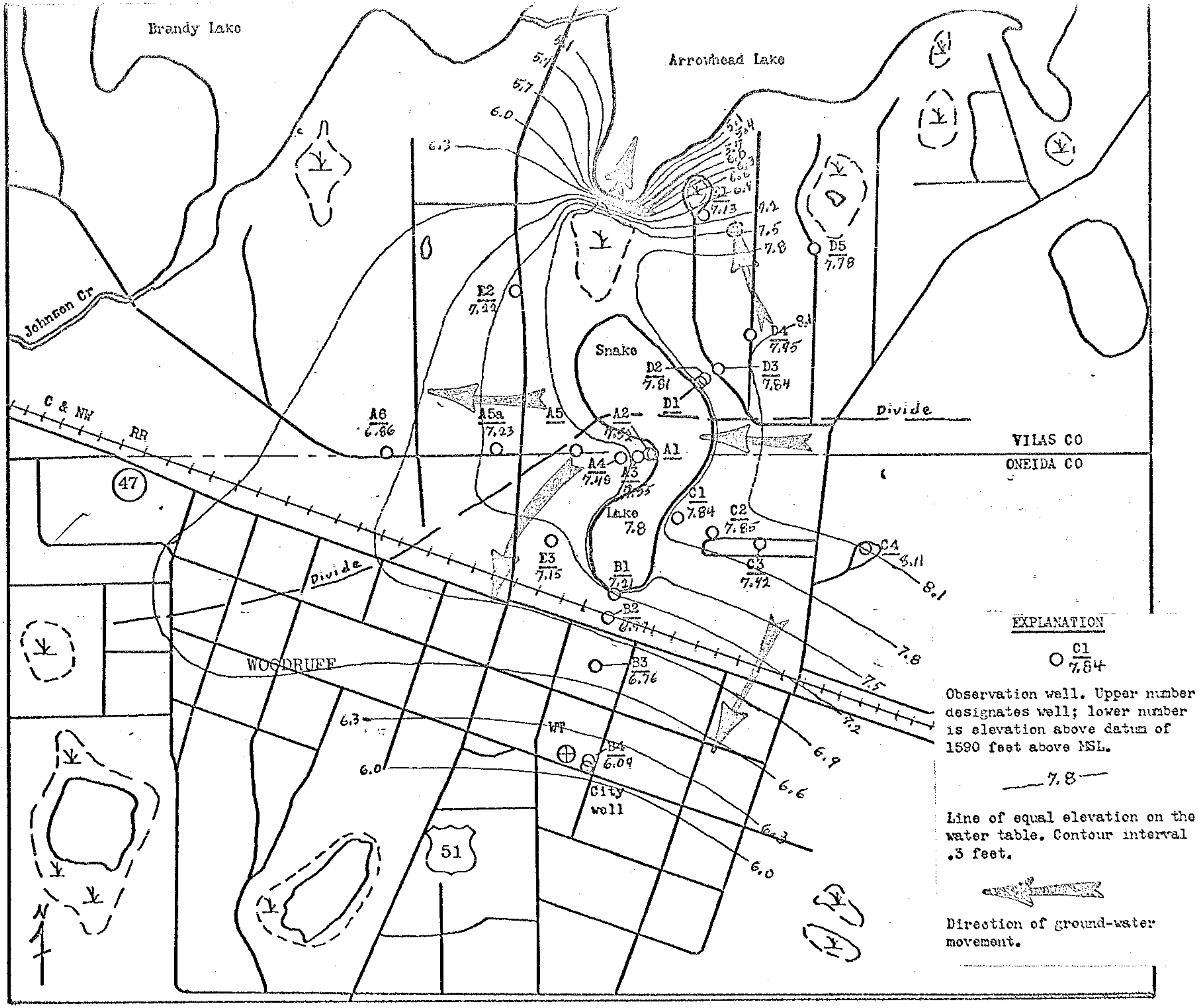
Present Conditions

Under present conditions, the Snake Lake area is bisected by a hydraulic divide that separates ground-water movement to Johnson Creek drainage and Lake Minocqua drainage. Ground-water movement is southwesterly to Lake Minocqua south of the divide and north and northwesterly to Arrowhead Lake, Brandy Lake, and Johnson Creek north of the divide as shown on figure 1. The water table is very flat and water moves under a gradient of about 3 to 6 feet per mile.

Ground water enters Snake Lake on the east side and is discharged to the ground water reservoir on the west and south sides of the lake. Principal discharge from the lake is on the north through the sand dam to Arrowhead Lake where the nearly 3 foot difference in elevation between the 2 lakes creates a gradient of about .03 feet per foot or 150 feet per mile.

Present conditions of ground-water movement into the lake on the east side and lake water movement into the aquifer on the west and south sides of Snake Lake probably resulted from the rise of the lake surface after the dam was emplaced in about 1962. Before the dam was emplaced, the lake was only slightly above that of Arrowhead Lake and below the level of the surrounding water table. The lake should have received inflow from ground-water around its whole perimeter except on the north side. The ground-water divide between Johnson Creek and Lake Minocqua drainage was south of the lake. When the lake level was raised, it had the effect of partial plugging of a ground-water drain or discharge area and the divide shifted northward to its present position. (Fig. 1).

The seepage field located next to the municipal sewerage plant on the west side of Snake Lake discharged effluent from the plant to the ground-water reservoir from about 1940 to about 1963 when operation of the plant was suspended. The water table gradient was toward the lake at that time and the effluent moved into the lake. The rise in lake level when the dam was implaced on the lake outlet reversed the gradient at the seepage field site. Therefore any residual



Base expanded from USGS Topographic map
Minocqua 7½ Min Quadrangle, advance sheet.
Scale approximately 1 inch = 723 feet.

FIGURE 1. -- Configuration of the water table in the Snake Lake area, April 30, 1969.

material in the vicinity of the seepage field will presently move southwestward away from the lake with ground-water movement.

Ground-water levels fluctuate in response to changes in recharge and indicate the amount of water in storage in the ground-water reservoir. Present ground-water levels in the Snake Lake area are at a near record high as indicated by the long term record of well On-22 (figure 2) which is located about 8 miles to the east of Snake Lake. Therefore, ground water in storage in the Snake Lake area is presently near maximum.

Ground-water levels in the Snake Lake area show a very rapid response to recharge because of the permeable nature of the sediments and the shallow depth to water table. Wells were installed and monitoring began in October 1968. Representative hydrographs are shown in figure 3. The water levels declined during the winter months when water from precipitation was stored on the land surface in the form of snow and ice. In late March, a short thaw caused a minor rise in levels, but the weather turned cold again and water levels continued to decline. The spring thaw started in early April, and water levels rose from 1 to 2 feet. Recharge from snow melt diminished and ceased in about the middle of April and water levels again started to decline. This decline will continue throughout the year until next spring except for rises that may follow heavy rains. For example, the high water level in July followed a rainfall of nearly 5 inches on July 15.

The stage of the water table in its natural cycle of fluctuation when measurements were made for construction of the configuration of the water table map (figure 1) can be seen in the hydrographs (figure 3). The water level measurements were obtained on April 30, 1969. The configuration of the water table should remain relatively unchanged with natural fluctuations in ground water level.

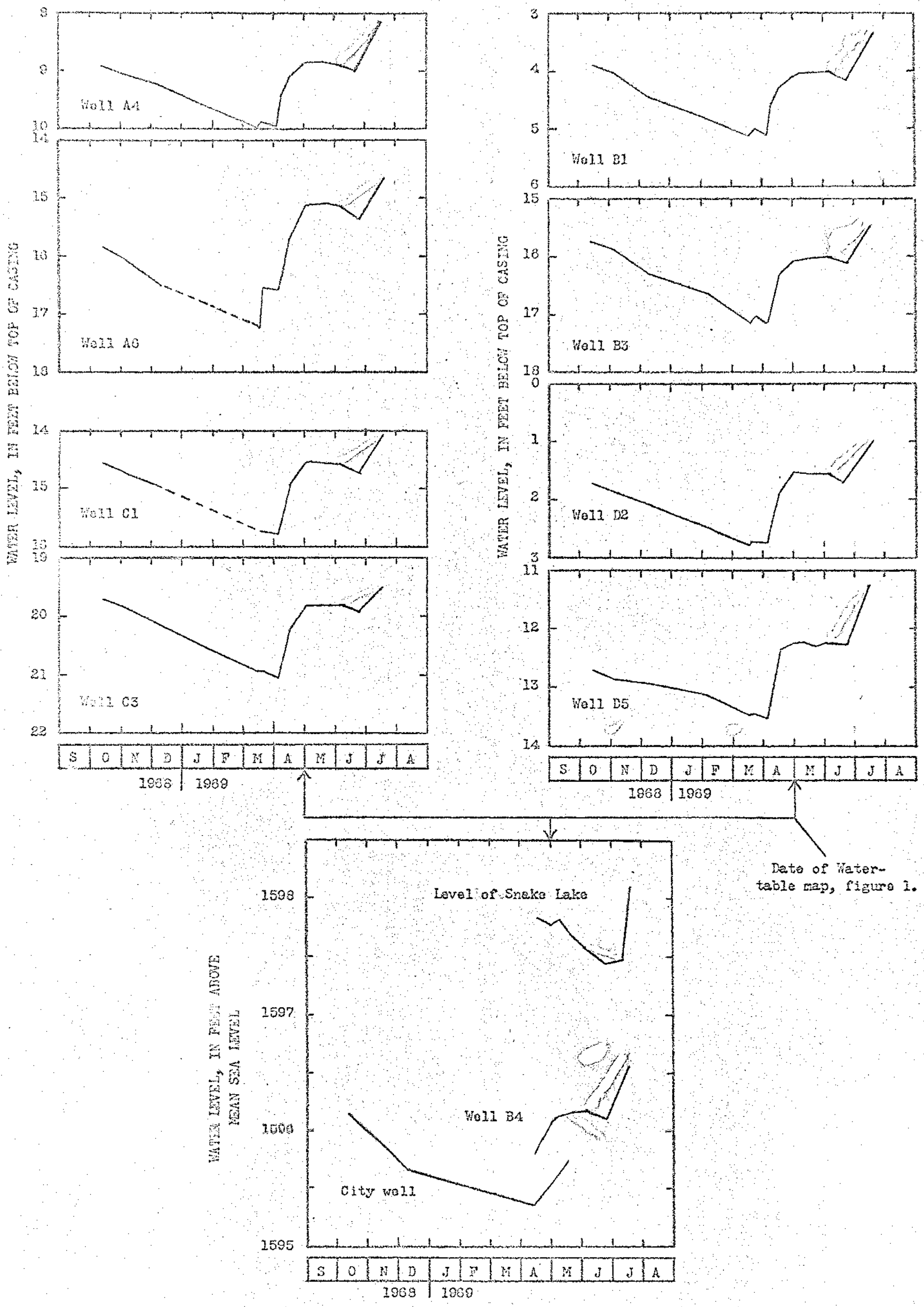


FIGURE 3.-- Hydrographs of selected wells and lake level in the Snake Lake area.

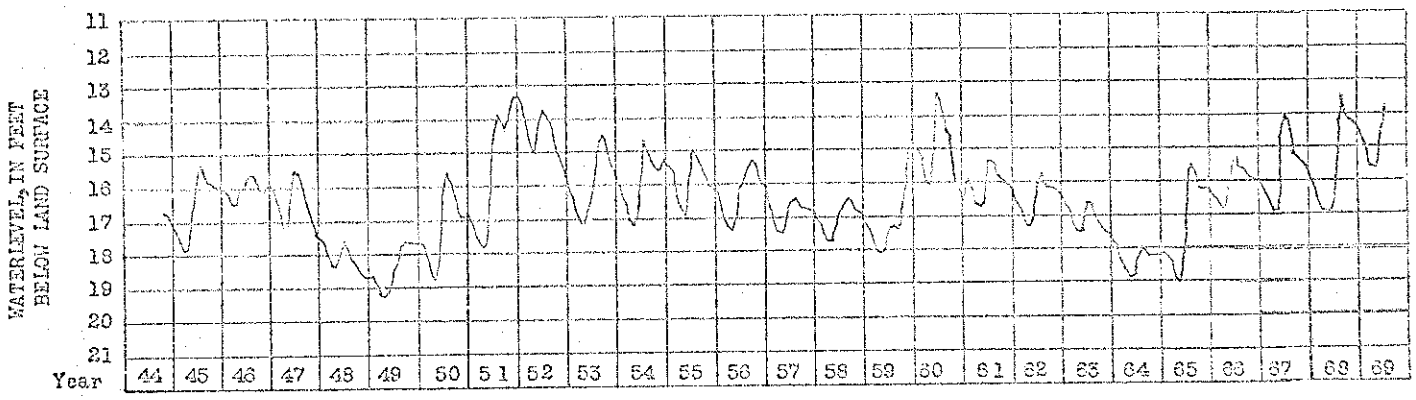


FIGURE 2.-- Hydrograph of observation well Oneida 22, located about 8 miles east of Snake Lake.
(Modified from Devaul, 1967)

The hydrographs of the deep city well and the adjacent shallow well B4 along with the level of Snake Lake (figure 3) show the wells to be in a recharge area as indicated in figure 1. The water level in both wells remains $1\frac{1}{2}$ to 2 feet below that of Snake Lake and the gradient is from the lake toward the wells. Also the decrease in head with depth in the 2 wells shows a downward vertical gradient hence water should be moving into the aquifer.

Formerly, the city well, located about 1000 feet south of Snake Lake and now abandoned, probably caused water to flow from the southern end of the lake through the aquifer and into the well. The lowered water level around the well during pumping would have caused a steep gradient from the lake toward the well, inducing recharge from the lake.

Two groups of 2 wells each at different depths were installed on the east and west edges of the lake (A1-A2 and D1-D2). The wells indicated ground-water discharge conditions on the east and recharge conditions on the west, however, the difference in depth of the wells (approximately 20 feet) was not great and difference in water levels was very slight.

Chemical Quality of Ground Water

Ground water in the Snake Lake area generally is acidic, very soft, and contains only small concentrations of dissolved material which is typical of pitted outwash regions of northern Wisconsin. The permeable nature of the outwash allows ground water to move rapidly through the aquifer and dissolve only small amounts of rock material. The acidic nature of the water probably results from contributions of organic acids from the many marsh deposits in the area.

Water samples for chemical analysis were taken from 18 of the observation wells installed in the vicinity of Snake Lake. Analyses of 4 samples were made at the Wisconsin State Laboratory of Hygiene and of 14 samples at laboratories of the Wisconsin Department of Natural Resources. Results are shown in table 1 along with calculated values and miscellaneous field measurements.

The chemical character of ground water on the west and south side of Snake Lake should be influenced by recharge from the lake as dissolved materials in the lake will move into the aquifer along with the water. Ground water on the east side of the lake receives recharge only from precipitation and its chemical character should be more representative of natural conditions. A comparison of the average concentrations of selected constituents in water from Snake Lake and from ground water on the east or recharge side, and the west and south or discharge side of the lake are shown in table 2. The average concentrations of all constituents are higher in ground water on the west and south side of the lake than in ground water from the east side of the lake. Concentrations in lake water also are higher than in ground water from the east side of the lake. No simple relationship can be made of the chemical character of lake water and ground water on the west and south side of the lake because of changes of chemical environment as lake water moves into the aquifer, seasonal and man made chemical changes in lake and ground water, and residual effects on chemistry of ground water from pollutants introduced into the lake in the past.

The chemical character of ground water on the south and west sides of the lake may be affected also by contamination from the land surface because of the location in a populated area. For example water from wells B1, B2, and E2, (table 1) show very high concentrations of chloride and sodium that are probably carried into the aquifer from the land surface; possibly from salt applied to highway 47 in the winter time. Analysis from these wells are not included in the sodium and chloride averages in table 2.

The analysis of water from well E4 (table 1) represents the chemical character of water moving through the dam to Arrowhead Lake.

Except for chlorides in the above-mentioned analyses for B1, B2 and E2, and iron, all parameters tested for are within limits recommended for drinking water by the U. S. Public Health Service (1962).

Table 1. Chemical analyses of ground water in the Snake Lake Area.
(All values except pH in parts per million)

Source (Well)	Date of Collection	Well depth (feet)	Temperature °F	Iron, Total (fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3) calc.	Sulfate (SO_4)	Chloride (Cl)	Nitrogen: Total Organic (N)	Nitrogen: Free Ammonia (N)	Nitrogen: Nitrites (N)	Nitrogen: Nitrates (N)	Phosphorus, Sol. (P)	Phosphorus, Total (PO_4)	Dissolved Solids, (Calc.)	Hardness, Total ($CaCo_3$) (Calc.)	Alkalinity, Total ($CaCo_3$)	Specific Conductance (Micromhos, 25°C)	pH	Dissolved Oxygen	Analysis by
A1	3-19-69	33	--	--	--	2.2	1.53	1.75	.40	31	7	1.0	.18	.06	.009	0.2	.12	0.4	32	12	25	60	7.1	--	DNR
A2	3-19-69	12	40.61	--	--	8.2	11.3	46.0	4.85	256	45	18	2.66	3.59	.044	0.1	.21	0.5	260	66	210	490	6.2	--	DNR
A3	3-19-69	12	41	--	--	8.8	7.4	22.0	2.45	122	34	6	1.35	1.11	.015	0.1	.11	1.9	143	52	100	270	6.3	0	DNR
A4	12-10-68	17	41	1.1	.05	37	5	1.2		59	43	3	--	--	.01	3.84	.005	--	136	114	48	--	6.55	--	WSLH
A6	3-19-69	18	--	--	--	0.7	0.63	3.22	0.60	27	35	1	.3	.08	.002	0.2	.25	2.8	172	4	22	60	6.6	6.0	DNR
B1	3-19-69	12	42	--	--	34.8	28.0	76.0	5.50	110	14	355	.64	5.98	.012	0.1	.09	0.7	568	203	90	1550	6.1	0	DNR
B2	3-19-69	26	45.5	--	--	16.8	13.9	90.0	4.62	31	82	431	.42	1.02	.018	0.3	.11	0.3	655	100	25	1550	6.3	2.0	DNR
B3	3-19-69	24	45.5	--	--	13.5	11.4	42.0	3.85	24	83	3	.52	.21	.013	0.8	.10	0.8	55	80	20	520	6.1	3.0	DNR
C1	12-10-68	24	45.5	4.6	.05	2.5	1.0	1.2		10	2.5	2	--	--	.004	.08	.01	--	19	8	8	--	6.7	--	WSLH
C2	3-20-69	18	42.5	--	--	0.7	0.68	0.87	0.60	24	35	10	.25	.09	.008	0.1	.09	1.0	61	5	20	50	6.6	--	DNR
C4	3-20-69	23	44	--	--	2.7	1.70	2.32	0.62	15	10	3	.47	.04	.010	0.9	.10	0.5	28	14	12	79	6.5	--	DNR
D1	3-20-69	30	--	--	--	0.45	3.00	1.65	.70	15	18	3	.24	.06	.008	0.1	.08	0.2	.34	14	12	50	6.6	3.0	DNR
D2	12-10-68	13	44.5	5.6	.05	3	1.0	1.2		11	5	2	--	--	.006	.08	.005	--	24	12	9	--	6.3	--	WSLH
D3	3-20-69	18	41	--	--	1.2	.74	1.22	.52	15	7	5	.29	.08	.015	0.1	.21	1.4	23	6	12	50	6.4	5	DNR
D4	3-20-69	19	42	--	--	0.5	0.41	1.45	6.25	13	12	2	.23	.07	.009	0.1	.14	0.5	29	2	11	50	6.5	5	DNR
D5	12-10-68	24	47	2.64	.05	2	1.	1.0	--	6	7	1	--	--	.004	.24	.01	--	19	6	5	--	6.55	--	WSLH
E2	4-17-69	22	--	--	--	72.5	36.5	73.0	3.82	30.5	31	502	.26	.03	.010	2.3	.10	0.2	743	228	25	1880	6.6	--	DNR
E4	4-17-69	3	--	--	--	1.5	1.0	11.5	2.60	20.7	14	14	2.69	.05	.003	0.3	1.71	3.3	60	8	17	113	6.6	--	DNR

Table 2. Average concentration of selected chemical constituents in water from Snake Lake and in ground water to the east and to the west and south of the lake.

Constituent	Groundwater East of Snake Lake		* Surfacewater in Snake Lake (2/5/69)		Groundwater West & South of Snake Lake	
	Average Concentration PPM	No. of Samples	Average Concentration PPM	No. of Samples	Average Concentration PPM	No. of Samples
Sodium (Na)	.9	7	27.5	8	27.8	4
Potassium (K)	1.6	4	3.3	8	4.18	6
Chloride (Cl)	3.5	7	45	8	7	4
Total organic Nitrogen	.31	4	1.36	8	.98	6
Nitrite (N)	.008	7	.034	8	.012	7
Nitrate (N)	.23	7	.10	8	1.07	7
Dissolved Solids (calc)	29	7	--	--	148	4
Hardness (calc)	7.5	7	--	--	120	4
Alkalinity ($CaCo_3$)	.11	7	26	8	74	7

* Water samples taken at 8 different sites in the lake from various depths ranging from 3 to 18 feet below lake surface.

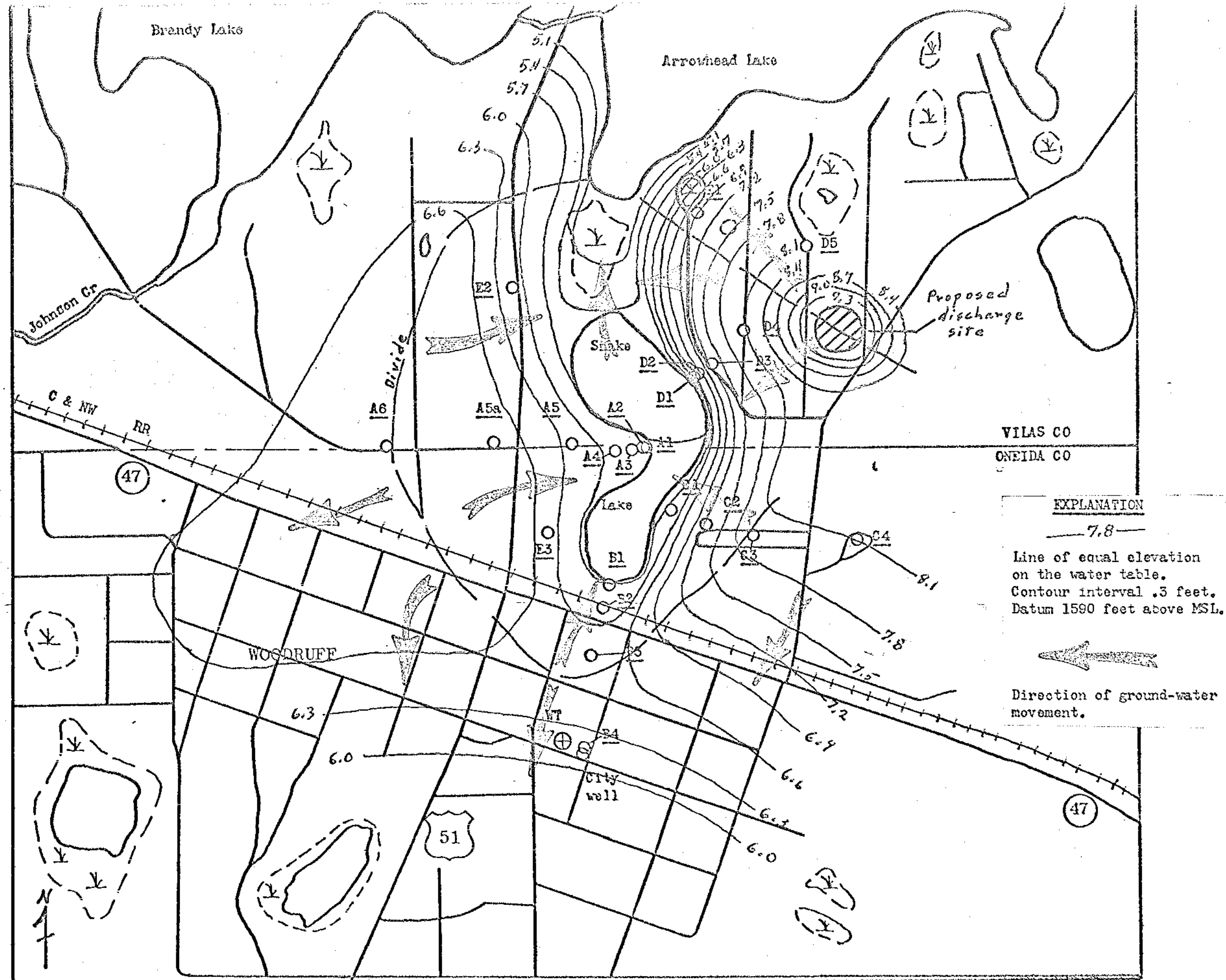
Inferred Ground-Water Conditions under Lake Management

Proposed management techniques for improving quality of water in Snake Lake have included several methods that would alter the level of the lake. The present plan is to pump water from the lake and lower its level to approximately that of Arrowhead Lake. The following inferred ground-water conditions under lake management are based on that plan. However, regardless of the method used, any appreciable change in lake level will altar ground-water conditions in the area.

By lowering the level of Snake Lake 2-3 feet, ground-water conditions should change from the present movement of ground water through the lake to movement of ground water to the lake around most of its periphery. Water will continue to move from Snake into Arrowhead Lake but will diminish as the difference in elevation between the lakes decrease until the lakes are at the same level. lowering the level of Snake Lake below that of Arrowhead will reverse the flow and water will move from Arrowhead into Snake Lake.

A map of the anticipated configuration of the water table under pumping conditions and with similar levels between Snake and Arrowhead Lakes is shown in Figure 4. The map is only a generalized anticipated configuration and is not an accurate representation of the actual conditions that may occur.

Principal ground-water discharge to Snake Lake is presently, and will continue to be under pumping conditions, from the east side of the lake (figure 4) but lowered lake levels will result in an increase of ground-water discharge to the lake. Under pumping conditions shown in figure 4 the gradient on the east side of the lake will increase to an estimated .006 feet per foot or about 32 feet per mile. The present gradient on the west and south sides of the lake will reverse and ground water will flow toward the lake under an estimated gradient of .02 feet per foot or about 10 feet per mile. The ground water divide presently running through the lake (figure 1) will shift southward and a low



Base expanded from USGS Topographic map
Minocqua 7½ Min Quadrangle, advance sheet.
Scale approximately 1 inch = 723 feet.

FIGURE 4. -- Anticipated configuration of the water table while pumping from Snake Lake.

divide will be established on the south and west sides of the lake in the approximate position shown in figure 4. Movement of ground water will be toward the lake from the divide.

A discharge site for water pumped from Snake Lake is shown on figure 4 and was arbitrarily chosen for purposes of discussion. Water discharged on the land surface will infiltrate to the water table and create a mound at that location. Ground water movement will be radially outward from the mound in all directions. If a discharge site for pumpage is located near Snake Lake where the gradient is presently toward the lake, much of the discharge water will circulate back to the lake through ground-water movement as shown in figure 4.

MANAGEMENT CONSIDERATIONS

Present plans for pumping Snake Lake are to use a trailer mounted and tractor propelled low-lift, high-volume pump rated at 8000 gallons per minute (gpm), actual gallons per minute delivered by the pump will probably be considerably less than 8000 gpm because of friction loss in the several thousand feet of discharge pipe required and because water must be lifted 10-15 feet above lake level. However, rough calculations indicate the pump will be adequate to draw the lake down the required amount. Because ground-water levels are presently at a high stage, the amount of pumpage required to draw the lake level down will also be maximum at the present time (August 1969).

A principal consideration is the site of discharge for the large volume of water pumped from Snake Lake. Soil permeabilities of the Pence-Vilas soils in the Snake Lake area generally range from 2.5 to 10 inches per hour in the upper horizons and are more than 10 inches per hour in the lower horizons (Soil Conservation Service, 1964). This is a rate of downward water movement when the soil is saturated but allowed to drain freely. Assuming an average permeability of 3 inches per hour, the water should infiltrate at the rate of ¼ acre foot per hour per acre or about 1,350 gallons per minute per acre. The discharge site must be of adequate size for proper infiltration; for the assumed conditions four acres would be needed to handle a discharge of 5400 gpm.

Movement of ground water away from the discharge site for pumpage may limit the rate of pumpage from the lake. If the movement of ground water is too slow the ground will become water logged or be saturate to the land surface and the water will move as over land runoff. Data is not available to accurately determine ground water movement away from the site. However, the following rough calculation was made from assumed values.

A circular mound on the water table at the discharge site is assumed to have an area of 4 acres. If the mound is 10 feet high at the center, the gradient from the center to the edge of the mound would be .0425 feet per foot. The coefficient of transmissivity of the outwash sands is assumed to be 100,000 gallons per day per foot. By use of Darcy's law, the amount of ground water moving across the circumference of the 4 acre circle would be about 4,370 gallons per minute. This figure is very roughly the amount of water that can be discharged on the ground without water logging the soil and is comparable to soil infiltration rates.

Another consideration is possible soil clogging at the discharge site. Small particles of silt, sand, weeds, organic matter, plankton and other materials in the lake water tend to clog the pore spaces of the soil and reduce soil permeabilities as the water infiltrates. This problem can be controlled, at least partially, by either alternating discharge sites or by periodic breaking up of the upper soil layer by plowing, scraping, or cultivating. Because of the lack of specific data on infiltration rates over extended periods it is estimated that the rate may be as low as 1000 gpm per acre or as much as 1500 gpm per acre.

Mounding of the water table underlying the discharge site may cause recirculation of the water back to Snake Lake. This problem is illustrated in figure 4. Mounding of ground water at the discharge site shown in figure 4 would cause a steep gradient toward Snake and Arrowhead Lakes. As much as 50% of the water that infiltrates to the water table could recirculate back to Snake Lake if that discharge site were used. It is suggested that the area east of Woodruff and south of highway 47 would be an appropriate site. The area presently has a relatively steep ground-water gradient southward toward Lake Minocqua and recharge from lake pumpage should tend to move in that direction. A large enough area to allow alternate disposal of the water in several different sites will help prevent soil clogging and water logging in the discharge area.

Ground-water levels at the discharge site of pumpage from Snake Lake should be monitored to determine direction of movement away from the site and the build up of the water table. The water levels will help determine the quantity of water that can be applied to the site and whether water is being recirculated to Snake Lake. Monitoring of water levels in the lake area also should continue to determine effects of pumping on water levels adjacent to the lake.

Quality of ground water also should be monitored at the discharge site in addition to the established sampling points to help determine the effectiveness of pumping in removing nutrients from the lake. Water temperatures should be measured with extreme accuracy at all sampling points as an aid in determining hydrologic changes.

REFERENCES

Devaul, Robert W., 1967, Trends in Ground-water levels in Wisconsin through 1966: University Extension, the University of Wisconsin Geological and Natural History Survey Information Circular No. 9, 109 p.

Hole, F. D., and Schmude, K. O., 1959, Soil Survey of Oneida County, Wisconsin: Wisconsin Geological and Natural History Survey Bull. No. 82, Soil Series No. 57.

Thwaites, F. T., 1956, Wisconsin Glacial Deposits: University Extension, the University of Wisconsin Geological and Natural History Survey, map.

U. S. D. A., Soil Conservation Service, 1964, Engineering test data and interpretations for major soils of Wisconsin: U. S. Dept. of Agriculture in cooperation with State Highway Commission of Wisconsin, Bureau of Public Roads and Soil Survey Division of Wisconsin Geological and Natural History Survey, p. 70.

U. S. Public Health Service, 1962, Drinking Water Standards 1962: U. S. Dept. of Health Education and Welfare, Public Health Service Pub. 956, 61 p.

APPENDIX A

Well Construction and Elevations of Observation Wells

Well No.	Elevation Top of casing above MSL	Length of casing (feet)	Length of screen (inches)	Top of Well above Land Surface (feet)
A1	1602.11	32	18	1.3
A2	1602.01	11	18	.9
A3	1604.71	11	18	1.8
A4	1606.32	16	18	2.0
A5A	1608.76	20	24	.6
A6	1612.00	16	30	1.5
B1	1601.29	10	30	2.0
B2	1611.20	24	30	2.6
B3	1612.87	22	30	3.6
B4	1610.44	20	24	
C1	1612.42	22	30	1.0
C2	1609.25	16	30	1.2
C3	1617.77	23	30	2.0
C4	1613.15	21	30	1.2
D1	1599.88	28	30	1.0
D2	1599.32	11	30	.6
D3	1605.93	16	30	1.5
D4	1609.79	17	30	1.3
D5	1610.01	22	30	3.5
E1	1606.54	16	24	2.6
E2	1611.58	20	24	.6
E3	1611.15	20	24	2.0
City Well	1612.26	?	?	1.4
Staff Gage	1596.11*	-	-	-

*Elevation of 0 on gage

APPENDIX B

Water levels in observation wells, in feet below top of well

Well Number	Oct 14 1968	Nov 4 1968	Dec 10 1968	Feb 6 1969	Mar 17 1969	Mar 19 1969	Mar 23 1969	Apr 3 1969	Apr 9 1969	Apr 16 1969	Apr 30 1969	May 7 1969	May 20 1969	June 5 1969	June 24 1969	July 18 1969
A1	5.06	5.23	5.38	5.68	5.96	5.97	5.67	5.74	5.27	4.88	4.58	4.55	4.57	4.59	4.72	3.96
A2	5.42	4.81	5.02	5.41	5.70	5.72	5.57	5.64	5.15	4.77	4.49	4.47	4.48	4.50	4.62	3.87
A3	7.21	7.23	7.61	--	8.25	8.22	8.17	8.26	7.70	7.43	7.16	7.14	7.15	7.19	7.32	6.56
A4	8.90	9.07	9.26	9.66	9.99	9.98	9.92	9.99	9.39	9.12	8.84	8.82	8.83	8.86	9.00	8.15
A5A	--	--	--	--	--	--	--	--	--	11.81	11.53	11.50	11.48	11.56	11.75	10.76
A6	15.86	16.05	16.43	--	17.19	17.21	16.52	16.57	16.28	15.68	15.14	15.13	15.08	15.14	15.36	14.66
B1	3.89	4.04	4.52	4.79	5.10	5.04	4.98	5.08	4.57	4.30	4.08	4.02	4.02	4.02	4.15	3.36
B2	13.95	14.04	14.45	14.90	15.23	15.14	15.19	15.25	14.85	14.49	14.23	14.17	14.14	14.14	14.24	13.47
B3	15.75	15.88	16.32	16.62	17.17	17.15	17.06	17.17	16.80	16.31	16.11	16.09	16.05	16.01	16.14	15.48
B4	--	--	--	--	--	--	--	--	--	14.64	14.35	14.31	14.27	14.26	14.32	13.87
City Well	16.10	--	16.62	--	--	--	--	--	--	16.91	--	--	16.53	--	--	--
C1	14.57	14.73	14.98	--	15.71	--	15.72	15.78	15.44	14.89	14.58	14.55	14.56	14.57	14.69	14.05
C2	11.77	11.91	11.87	--	12.61	--	12.55	12.62	12.27	11.73	11.40	11.38	11.40	11.40	11.52	10.78
C3	19.70	19.84	20.17	20.62	20.94	--	20.98	21.04	20.77	20.22	19.85	19.82	19.83	19.82	19.92	19.48
C4	14.82	15.03	15.21	--	--	--	15.78	16.11	15.86	15.38	15.04	14.98	14.97	14.92	14.96	14.62
D1	2.30	2.39	2.64	2.99	3.28	3.27	3.29	3.34	3.01	--	2.06	2.08	2.12	2.10	2.20	1.49
D2	1.72	1.84	2.09	2.44	2.74	2.70	2.70	2.74	2.43	--	1.51	1.51	1.54	1.54	1.64	.99
D3	8.34	8.47	8.71	--	9.36	--	9.33	9.39	9.08	8.48	8.09	8.09	8.13	8.11	8.20	7.50
D4	12.17	12.27	12.42	--	13.03	--	13.04	13.10	12.86	12.24	11.84	11.86	11.92	11.89	11.89	11.14
D5	12.75	12.86	12.94	13.18	13.43	--	13.43	13.48	13.11	12.32	12.23	12.22	12.30	12.22	12.30	11.26
E1	--	--	--	--	--	--	--	--	--	9.44	9.41	9.49	9.52	9.19	9.71	8.69
E2	--	--	--	--	--	--	--	--	--	14.85	14.36	14.30	14.35	14.40	14.65	14.05
E3	--	--	--	--	--	--	--	--	--	14.28	14.00	13.96	13.91	13.95	13.11	13.09
*Staff Gage	--	--	--	--	--	--	--	--	--	1.71	1.68	1.70	1.58	1.44	1.34	1.92

*Readings show height of Snake Lake in feet above datum of 1596.11 feet above mean sea level.