STATE OF SOUTH DAKOTA
Ralph Herseth, Governor

STATE GEOLOGICAL SURVEY
Allen F. Agnew, State Geologist

SPECIAL REPORT 2

GEOLOGY OF THE SHALLOW WATER SUPPLY AT MADISON, SOUTH DAKOTA

by
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UNION BUILDING
UNIVERSITY OF SOUTH DAKOTA
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INTRODUCTION

Present Investigation

The geologic field work on which this report is based was undertaken by the South Dakota State Geological Survey at the request of the city of Madison, for the purpose of finding a better municipal water supply. The present city water supply is of adequate quantity but the quality of the water is very poor.

The city at present obtains its water from seven shallow wells in an outwash deposit near the south edge of town (pl. 1). This outwash originates in Lake Herman and extends southeasterly through Lake Madison; beyond the Madison area it follows Skunk Creek and joins the Big Sioux outwash near Sioux Falls, South Dakota. The present city wells range in depth from 24 to 50 feet and are large-diameter gravel-packed wells.

A reconnaissance of the area within ten miles of Madison was made, and it was determined that the only practical shallow water supply for the city would have to come from the outwash deposit that is already being tapped by the city, or from Lake Herman or Lake Madison. The outwash deposit was mapped by reconnaissance methods on air photos, and about 40 test holes were drilled to determine the thickness and texture of the outwash materials, and to obtain water table information. In addition, several earth resistivity measurements were made to supplement the drill hole information, and samples of water and gravel were collected for analysis. The South Dakota State Water Resources Commission, in cooperation with the State Geological Survey, drilled and cased a well which is to be used as an observation well; also, the city of Madison drilled a well nearby, used as a source of water for analysis.

The preparation of this report was greatly facilitated by the cooperation of the people in and around Madison, especially Mr. Lyle Spiering, acting city manager, and Messrs. Severson and Hunter of the Madison Daily Leader. The work was performed under the supervision of Dr. Allen F. Agnew, State Geologist, during the summer and fall of 1958.

Location and Extent of Area

The city of Madison has a population of a little over 5000 (1950 census), and is located in Lake County, in east-central South Dakota. The area is in the Western Lake section of the Central Lowlands physiographic province, and is on the western side of the Coteau des Prairie (Prairie Hills).

Climate

The climate, characterized by a wide temperature range, has an average yearly temperature of 46°F., and an average yearly precipitation of 23 inches.

Topography and Drainage

The topography and drainage of the area is typical of that left by the last ice sheets; the area is poorly drained and contains many closed depressions. The few streams are small and intermittent, and lakes and "pot holes" are abundant. The two largest lakes in the area are Lake Herman, which covers about 2½ square miles just west of Madison, and Lake Madison, which covers more than four square miles southeast of Madison.

GENERAL GEOLOGY

The surface deposits in this area were laid down by the sixth of the seven major ice advances that covered eastern South Dakota. These deposits are called drift, which is divided into till and outwash. Till is the material carried by the ice itself, and consists of boulders, pebbles, sand, silt, and clay; it makes up most of the surface deposits in this area. The outwash was deposited by the meltwaters of the glacier, and consists of boulders, pebbles and sand; the finer fractions were washed away.

The outwash deposits form excellent reservoirs of shallow water and the city of Madison is drawing its present supply of water from such a deposit. This outwash originated from an ice front that lay west of Lake Herman, and was deposited in two channels: the largest channel extends eastward from Lake Herman and passes just south of Madison; the smaller channel originates northwest of Madison and passes southeasterly through the city, joining the larger channel near the southeastern city limits (pl. 1). The combined channel trends southeasterly through Lake Madison.

SHALLOW GROUND WATER

Movement of the Ground Water

Elevations taken on the water table in the outwash deposits show that the direction of water movement is from west to east. The water level in Lake Herman was 1644.5 feet above sea level in August 1958, and in Lake Madison it was 1620.0. The water moving from Lake Herman southeastward through the outwash channel to Lake Madison drops 24½ feet in five miles, giving an average gradient of 4.9 feet per mile. However, the gradient is less between Lake Herman and the city wells (in the southeastern part of town), as the water level drops only 2.5 feet per mile.

Depth to Water Table

The depth to the water table on the outwash ranges from 10 to 23 feet, and averages about 15 feet, as measured during the summer of 1958. The depth may vary from this during other seasons, but probably not appreciably.

Fluctuations of the Water Table

Water table fluctuations in wells in the outwash are not available because records have not been kept; however, the State Geological Survey has kept a continuous record of the fluctuations of Lake Madison since 1936. This record (fig. 1) also shows the fluctuation of the water table in the outwash, as the lake level is part of that water table. The figure shows that Lake Madison went dry in 1936 and again in 1940. This does not necessarily mean the outwash also went dry, as the base of the outwash channel extends for some distance below the floor of the lake.

Hydrologic Properties of the Outwash

The porosity and permeability of the outwash sands and gravels is dependent upon the sorting and shape of the particles. Because of many variables involved and a lack of equipment needed to determine the porosity and permeability, it is impossible to compute these values with a great degree of accuracy. However, an indication of the approximate porosity and permeability can be calculated by screening and determining the percent by weight of the various sizes from surface samples, and by observing the shape of the particles.

Table 1 shows a textural analysis of four sand and gravel samples collected from pits in this area. The fact that 45-80 percent of each sample is from one-fourth to two millimeters in size shows a fair degree of sorting, and means that the gravels

Figure 1.--Water Level Fluctuation of Lake Madison

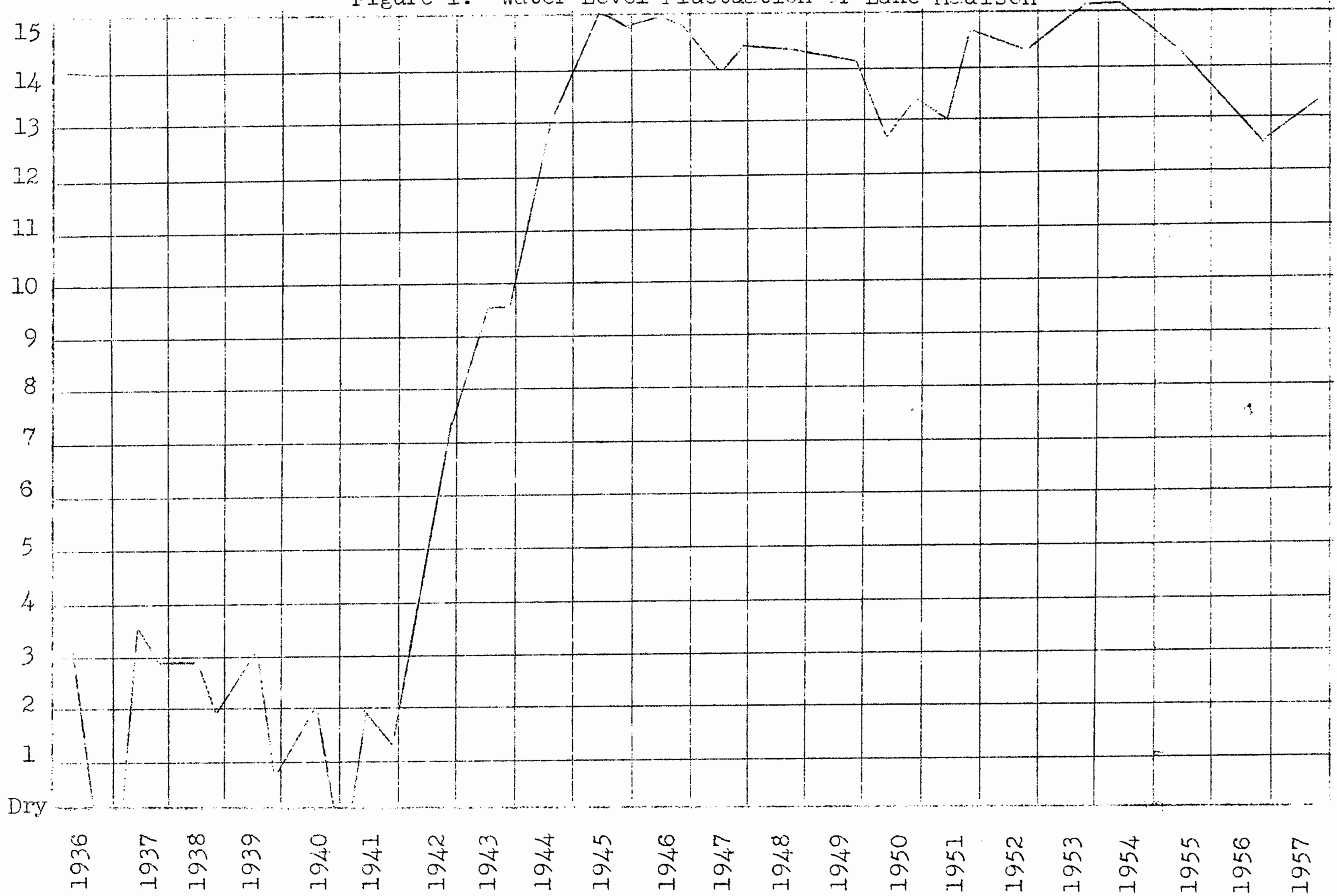


Table 1.--Textural Analysis of Gravel Samples (percent by weight)

Size Range in mm \ Sample Number	1	2	3	4
32-00	5.8	none	none	none
16-32	19.9	1.6	0.6	4.2
8-16	14.4	3.5	0.7	12.8
4-8	9.3	7.6	5.9	13.7
2-4	9.2	12.6	7.5	17.3
1-2	15.7	9.4	16.9	20.9
½-1	13.6	27.0	29.0	18.0
¼-½	5.9	21.9	27.9	10.8
1/8-1/4	2.6	15.5	9.9	1.8
1/16-1/8	1.0	0.5	1.2	0.2
0-1/16	2.6	0.4	0.4	0.3
Total	100.0	100.0	100.0	100.0

Sample Number	Location
1	SE¼ sec. 11, T. 106 N., R. 53 W.
2	SE¼ sec. 16, T. 106 N., R. 52 W.
3	SW¼ sec. 22, T. 106 N., R. 52 W.
4	SE¼ sec. 22, T. 106 N., R. 52 W.

will probably have a relatively high degree of permeability. The particles in general are sub-round to sub-angular, which gives a relatively high degree of porosity, probably 25-35 percent.

Recharge

The recharge of the outwash is accomplished entirely by precipitation in the form of rain and snow. Any precipitation falling within the drainage basins of Lake Herman and Lake Madison will recharge the outwash. The drainage basins of Lake Herman and Lake Madison cover about 120 square miles; thus at least part of the precipitation falling within this basin will recharge the outwash.

One inch of rainfall falling on one square mile of land is equivalent to 2,323,000 cubic feet of water, or more than 17 million (U. S.) gallons of water. This, multiplied by the annual precipitation of 23 inches, times the drainage basin area of 120 square miles, shows that more than 46 billion gallons of water falls on the reservoir drainage basin yearly. Just how much of this water actually reaches and recharges the reservoir is difficult to estimate accurately; however, if only 10 per cent of the water penetrated the outwash, this would result in an annual recharge of more than 4 billion gallons, which should be more than adequate to provide the Madison city water supply.

Lake Herman is probably being recharged also by springs fed from the water table in the end moraines to the west; in this way it is assured of additional recharge unless there is a drastic lowering of the water table in the whole region to below the lake level, which is unlikely.

Discharge

Discharge is accomplished by underflow from the outwash reservoir down the gradient, by pumping from wells, and by natural discharge at the surface through the processes of surface runoff, evaporation and transpiration.

In the Madison area most of the discharge is by underflow, by pumping of wells, and by evaporation. Just how much discharge is accounted for by underflow is difficult to determine, but it is probably a significant amount of the total discharge because of the relatively high permeability of the deposits. Most of the discharge by pumping is from the Madison city wells; although the data are limited, it is estimated at 500,000-2,000,000 gallons per day. The discharge by farm wells in this area is insignificant because of the small number of domestic wells and the absence

of irrigation wells. Evaporation probably accounts for a considerable loss of water from the outwash especially in the summer months, as the water table is exposed to the surface elements in Lake Herman and Lake Madison.

Chemical Quality

The present water supply of the city of Madison is far below standard chemical quality (Table 2). The water is very hard and contains too much iron, calcium, sodium sulfates, and total solids.

Because the water contained in the outwash from which Madison draws its supply comes from precipitation, which is relatively pure chemically, the water is deriving the objectionable chemical elements from the outwash gravels through which it flows. The water from Lake Herman is of good chemical quality (Table 2). As Lake Herman is at the head of the outwash, and as the water from Lake Herman flows eastward through the outwash, it can be assumed that the water now being used by the city is acquiring its objectionable chemical qualities from the outwash sediments between Lake Herman and the city wells. A lithologic analysis of the pebble composition of the gravel in this area bears this out (Table 3) by showing a high percentage of iron-bearing pebbles. A chemical analysis of the water from an observation well drilled by the city of Madison in the outwash about half a mile east of Lake Herman shows it to be about the same as the water from the city supply in iron content. However, the total solids, sulfates, hardness and all the objectional chemicals were much lower in the observation well. Therefore it seems likely that the quality of the water in the outwash is better near Lake Herman, as the water will not have traveled through as much of the material from which it can pick up the undesirable chemicals.

Sources

The study of the area around Madison showed there to be three possible sources from which the city could draw its water supply. These are (1) the outwash from which the present water supply is being taken, (2) Lake Herman, and (3) Lake Madison.

There are two reasons why Lake Madison should be ruled out as a source of supply: (1) it dried up during the droughts of the 1890's and 1930's, and (2) the city sewage disposal plant drains into a small creek southeast of the city and this creek then empties into Lake Madison. This would also eliminate as a source of supply the outwash from the disposal plant eastward, thus leaving Lake Herman and the outwash between Lake Herman and the city as the only practical reservoirs.

Table 2.--Analyses of Water Samples in Madison Area

Water Sample	Parts Per Million										
	Ca	Na	Mg	N	Fe	Cl	SO_4	Mn	F	Hard-ness $CaCO_3$	Total Solids
Public Health Drinking Water Standards*	---	---	125	10	0.3	250	250	---	1.5	---	500 to 1000
Lake Herman**	90	73	75	0.4	0.0	12	564	0.7	0.2	533	1046
Observation Well*** sec. 11-106-53	52	4	42	0.9	7.2	Tr	77	0.9	0.4	301	379
City Tap Water***	326	111	96	0	0.7	154	883	2.8	0.1	1206	1952
City Railroad Well**	148	---	67	3.0	0	206	439	---	0.6	642	1332
City Well on South Union Street**	190	---	82	0.5	0.4	269	401	---	0.4	814	1437
Marr's Resort on Lake Madison***	286	59	82	2.0	0	136	670	Tr	---	1052	1576

* Not to exceed
** Analyzed by South Dakota State Department of Health, Pierre, April, 1957
*** Analyzed by South Dakota State Chemical Laboratory, Vermillion, May, 1959

Table 3.--Lithologic Composition of outwash gravel (4-8 mm)

Rock Composition \ Sample Number	1	2	3	4
Chalk	none	none	0.9	0.3
Shale	1.6	21.0	27.8	0.8
Iron concretions	10.9	6.4	5.8	5.0
Granite	30.9	19.7	25.1	27.2
Diorite	0.2	none	none	none
Gabbro	0.8	none	none	none
Greenstone	5.9	1.9	2.2	3.0
Misc. Igneous	4.2	3.6	4.0	5.8
Microgranular	0.4	1.1	none	none
Basalt	3.2	3.2	4.0	4.7
Schist	none	0.6	0.9	1.7
Carbonates	40.0	40.9	27.8	50.0
Chert	0.6	1.1	0.4	1.4
Sandstone	1.2	0.4	0.9	none
Fossils	none	0.4	none	0.3
Total	99.9	100.3	99.8	100.2

Sample Number	Location
1	SE¼ sec. 11, T. 106 N., R. 53 W.
2	SE¼ sec. 16, T. 106 N., R. 52 W.
3	SW¼ sec. 22, T. 106 N., R. 52 W.
4	SE¼ sec. 22, T. 106 N., R. 52 W.

Lake Herman did not dry up during the recent droughts and, as it is probably spring-fed, it should make an excellent reservoir for a city supply.

The outwash channel between Lake Herman and the eastern city limits of Madison covers about three square miles and contains an average thickness of 30 feet of sand and gravel, of which the lower 13 feet is water-saturated. Assuming an average porosity of 30% for the outwash sediments, it is estimated that this outwash segment contains approximately 2,250,000,000 gallons of water.

As Lake Herman is part of this reservoir of water, the water in the lake should be included in the estimated total reservoir capacity. No depth figures for the lake are known, but if an average depth of 20 feet is assumed, a reservoir capacity of 4,380,000,000 gallons of water is present. This gives a total of 6,630,000,000 gallons of water in the Lake and outwash deposit together. This is adequate to supply a city the size of Madison or larger under normal conditions, provided that irrigation and other types of discharge are not increased.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study by the State Geological Survey show that Lake Herman and the outwash from this lake eastward to the city of Madison are the only practical sources of a municipal supply of shallow water near Madison. This is contrary to the belief of some local residents who have shallow wells in and near the city but not in the outwash, which produce water of good quality. However, these wells are producing from small sand lenses in the till and, as these lenses do not have sufficient capacity or recharge to supply the city, they could not be considered as sources for the municipal supply. Another local misconception is that the first wells drilled by the city produced water of good quality, and that these wells were subsequently contaminated by drilling additional wells. This is not the case, as an analysis in 1937 of the water from the first well drilled shows the same poor quality then as now. Some residents also believe that the sewage disposal plant is contaminating the city water supply, but this cannot happen, as the sewage is emptied far downstream and down the hydraulic gradient from the present city wells.

Of the two possible sources for a shallow municipal water supply, the outwash is probably more desirable than Lake Herman because the sands will provide natural filtration for the water, which would not be the case if raw water from the lake were used.

As has been previously shown, the water near the west end of the outwash is of better quality than that nearer the city; therefore, the most desirable location for a city supply is west of town in section 11, just east of Lake Herman. The water at this location will probably have to be filtered or aerated for iron removal, and chlorinated; the chemical analysis shows that it would not have to be treated otherwise, as it contains only small amounts of other undesirable chemicals.

It is therefore recommended that the city do further testing for thickness of deposits and water quality in the outwash just east of Lake Herman, as it is believed that a city water supply of better quality is obtainable in this area than is being furnished by the present source. It is further recommended that the city obtain a water permit from the State Water Resources Commission, that the city check with the State Board of Health with regard to construction of a water system and bacteriological analyses, and that the city employ an engineering firm licensed in South Dakota to handle the planning and execution of the work.

SOUTH DAKOTA GEOLOGICAL SURVEY
ALLEN F. AGNEW, STATE GEOLOGIST

STATE OF SOUTH DAKOTA
RALPH HERSETH, GOVERNOR

EXPLANATION

OUTWASH (terrace where dotted)

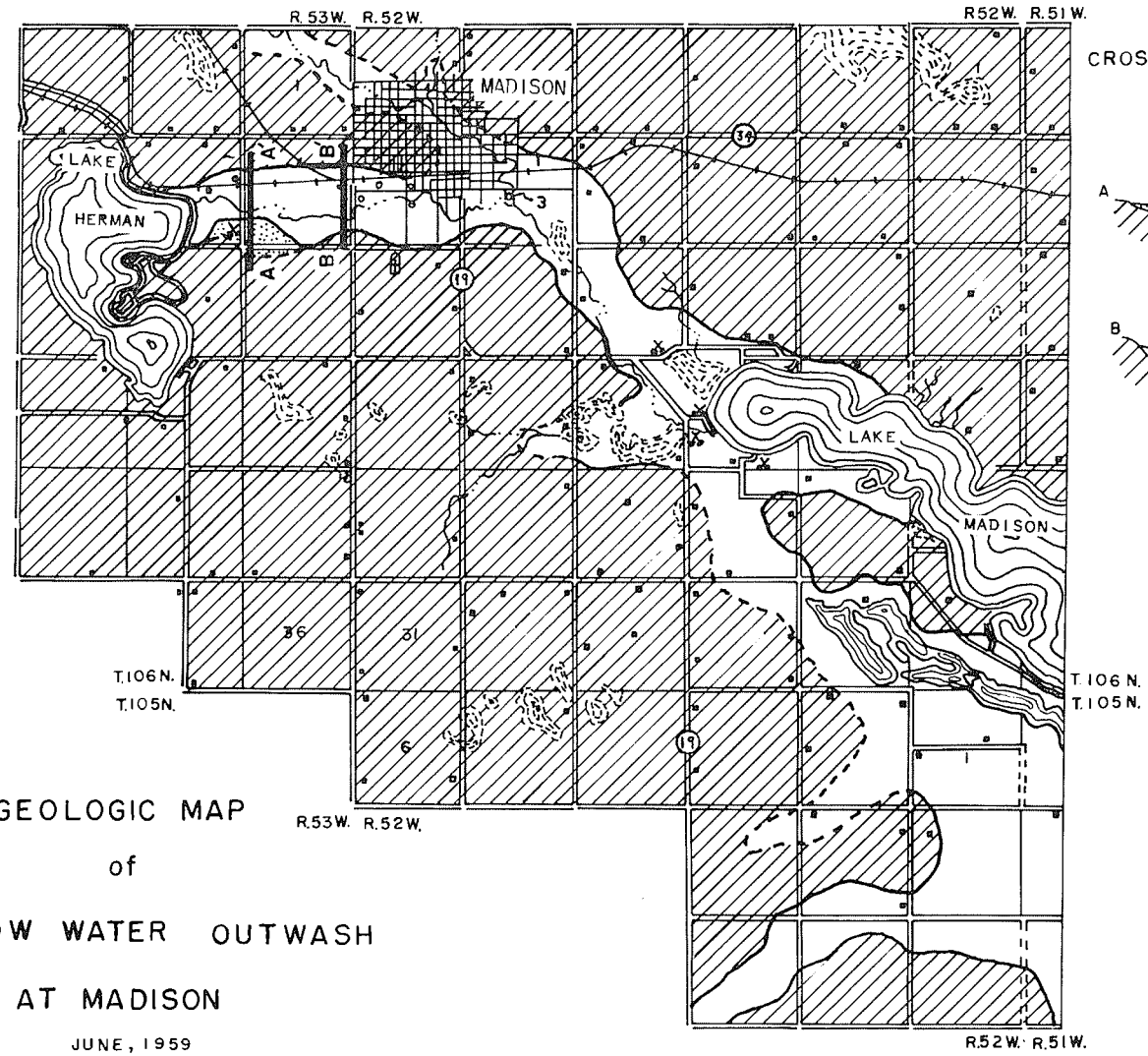
TILL

observation well

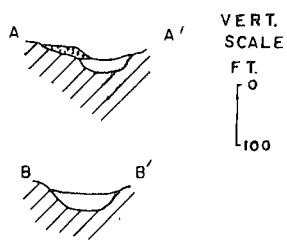
city well

SCALE IN MILES

0 1 2 3



CROSS - SECTIONS



GEOLOGIC MAP of SHALLOW WATER OUTWASH AT MADISON

JUNE, 1959