High Water Levels in Ground-Water Dominant Lakes — A Case Study from Northwestern Wisconsin

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ABSTRACT

An investigation into the cause of high lake levels during the early 1970's in a ground-water dominant lake in northwestern Wisconsin was conducted from December 1976 to July 1978, in part to address allegations by shoreline property owners that regulation of water levels in a reservoir 2.4 km south of the lake had caused the high lake levels. High lake levels also coincided with above average precipitation. Data collected during the study allowed the definition of the ground-water flow system around the lake and the calculation of the water budget for the lake. Field data indicated that there is no ground-water flow between the reservoir and the lake and that ground water flowing out of the reservoir is intercepted by a trough in the potentiometric surface. The trough is probably oriented along a permeable fault zone or a buried river valley. A ground-water flow model was used to determine whether increased recharge rates of the magnitude that probably occurred as a result of above average precipitation in the early 1970's would be sufficient to account for the observed rise in lake level or whether regulation of the water level in the reservoir could be expected to affect lake level.

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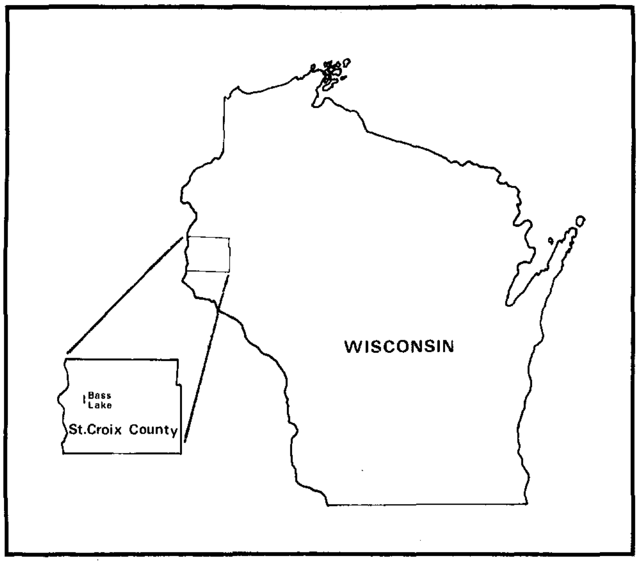

Fig. 1. Location of Bass Lake, Wisconsin.

INTRODUCTION

High lake levels are a recurrent problem in many areas of Wisconsin and property owners often fail to appreciate the hydrologic reality that lake levels fluctuate with precipitation. Efforts at public education have been attempted in Wisconsin by Novitzki and Devaul (1978) among others. At Bass Lake in northwestern Wisconsin (Figure 1), high lake levels occurred in the early 1970's several months after the water level in a reservoir situated about 2.4 km south of the lake had been raised approximately 0.3 m. Property damage around Bass Lake was extensive and homeowners were quick to associate their troubles with the regulation of the water level in the reservoir. It was not an unreasonable hypothesis that Bass Lake and the reservoir were hydraulically connected; and since the water level in the reservoir was 3.5 m higher than the normal level of Bass Lake, the occurrence of flow from the reservoir to the lake was not impossible. The early 1970's was also a period of above average precipitation. However, property owners were skeptical that high precipitation could cause such a marked rise in lake level.

The study described in this paper was initiated in December 1976, in order to investigate the cause of the high water levels in Bass Lake and to determine whether fluctuations in lake level are related to regulation of the reservoir. Hydrogeologic data collected during the study allowed calculation of the hydrologic budget for the lake and definition of the flow system. A ground-water flow model was used to investigate: (1) the expected magnitude of the change in lake level in response to increased recharge rates brought about by high precipitation, and (2) the effect on lake level of changes in the level of the reservoir.

The shallow aquifer in the Bass Lake area consists of glacial drift which is mainly sand and gravel, underlain in the southern part of the area by a dolomite unit of the Prairie du Chien Group and in the north by Cambrian sandstones. The dolomite unit and the sandstones are productive aquifers in this area and are commonly used for residential, municipal and industrial water supplies (Borman, 1976). The reservoir south of Bass Lake was formed by construction of a dam on the Willow River in 1922 and is shown in Figure 2 as Mounds Pond. In the area between Bass Lake and Mounds Pond, the glacial drift is thin and often unsaturated.

FIELD METHODS

Twenty-eight observation wells were completed in the glacial drift and three additional observation wells were drilled into the dolomite (Figure 2). Ground-water levels and lake levels were monitored biweekly from December 1976 to March 1978. Fourteen temporary piezometers were installed through the ice cover in January 1978, in order to determine vertical gradients beneath the lake. An attempt was made to verify these gradients through the use of seepage collectors (Lee, 1977) and portable piezometers (Lee and Cherry, 1978). However, these data are erratic and are believed to be unreliable. The lake sediments consist of silty sand and it has been reported that seepage collectors and portable piezometers do not always function properly in fine-grained sediments (Beauheim, 1980; Cherry, 1979).

Following the procedure described by Masch and Denny (1966), hydraulic conductivities were estimated from grain size distribution of samples collected during installation of the observation wells and from specific capacity data taken from area drillers' logs.

RESULTS OF THE FIELD STUDY

Configuration of the Flow System

A map of the potentiometric surface for November 13, 1977, is shown in Figure 2. Bass Lake is located within a regional flow system in which ground water flows westward and discharges into the St. Croix River located on the Wisconsin-Minnesota border approximately 11 km west of Bass Lake. During the study period, water levels in most observation wells and the lake level fluctuated about 0.3 m. However, the general configuration of the potentiometric surface did not change significantly. The most notable feature in Figure 2 is the trough in the

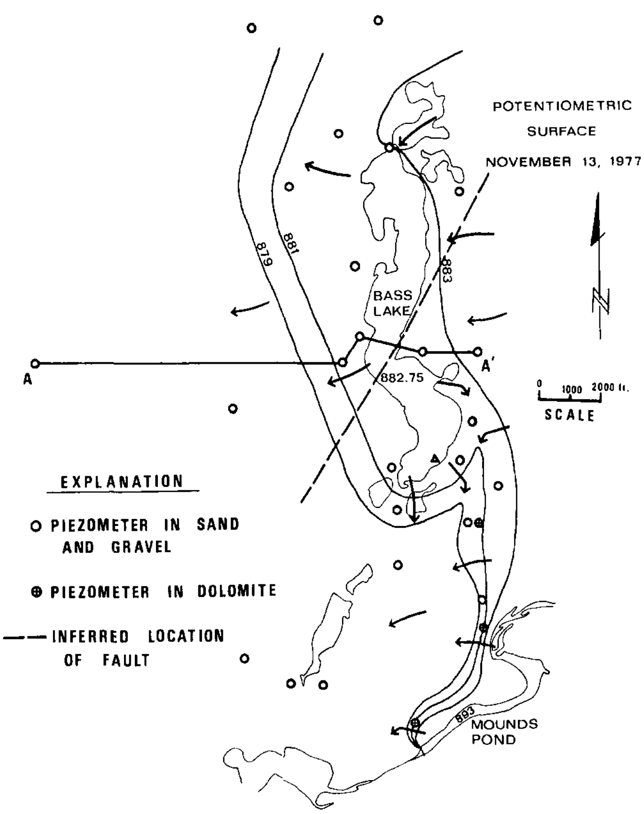

Fig. 2. Potentiometric surface in feet above mean sea level for November 13, 1977. Locations of observation wells are also shown.

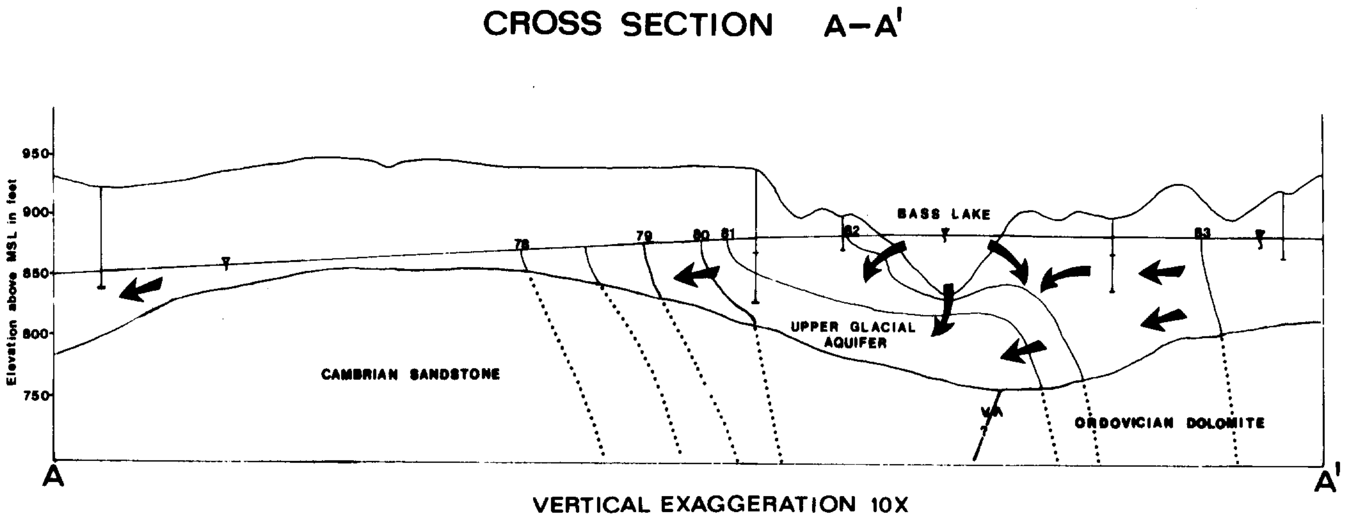

Fig. 3. Schematic diagram of the flow system along line A-A'. Location of the line of cross section is shown in Figure 2. Numbers indicate the potential referenced to a datum located 800 feet above mean sea level. Arrows indicate direction of flow.

potentiometric surface southeast of Bass Lake. Ground water flows toward this trough from Bass Lake and Mounds Pond and then flows down the trough to the southwest. Thus, ground water flowing out of Mounds Pond is intercepted by the trough before reaching Bass Lake.

In the area between Bass Lake and Mounds Pond, the water table is generally in the dolomite and the overlying glacial drift is unsaturated. A geologic map of the area (Borman, 1976) indicates the existence of a fault trending southwest-northeast beneath Bass Lake (Figure 2). The fault is oriented in the same direction as the trough in the potentiometric surface but is inferred to pass beneath the lake somewhat farther north (Figures 2 and 3). Thus, the trough may be structurally controlled and could be oriented along a minor fault, or the major fault may in fact lie somewhat south of its inferred location. Another possibility is that the trough may follow the path of a buried river valley. Areal photographs indicate the presence of an old channel in this area.

Water samples collected from observation wells, Bass Lake and Mounds Pond in November 1977, and July 1978, were analyzed for major cations and anions. The geochemical data (Rinaldo-Lee *et al.*, 1979) support the interpretation of the flow system shown in Figure 2. Specifically, water samples from wells located downgradient from and close to surface-water bodies, exhibited the relatively low concentrations of chloride and sulfate characteristic of calcium-bicarbonate type water, as defined by Back (1961). Wells located farther from surface-water sources exhibited higher concentrations of chloride and sulfate, which are characteristic of a sulfate water type.

Water Budget for the Lake

Bass Lake has no surface-water inlet or outlet and according to Novitzki and Devaul (1978), would be classified as a ground-water flow-through lake. Novitzki and Devaul found that for the lakes they studied, ground-water flow-through lakes exhibited greater fluctuations of water level than either ground-water discharge lakes (lakes with a surface-water outlet) or surface flow-through lakes (lakes with a surface-water inlet and outlet).

The ground-water component of the water budget for Bass Lake was computed directly by applying Darcy's Law to four segments around the perimeter of the lake and indirectly by computing the ground-water component as the residual in the water balance equation for the lake. In the direct approach, the hydraulic conductivity of the material around the lake was estimated from grain size analyses and specific capacity data to be 15 m/day. The hydraulic gradient was approximately uniform within each of the flow segments around the perimeter of the lake. The depth of communication between the lake and the aquifer was assumed to be equal to two lake depths (20 m). This assumption has since been demonstrated to be a reasonable one for Bass Lake (Munter, 1979). Calculations using the direct method indicated that in June 1977, an average of 1.7×10^3 m^3/day of ground water entered the northern portion of the lake and 4.2×10^3 m^3/day left the lake. Thus, during June 1977, the amount of ground water leaving the lake exceeded the amount entering the lake by 7.5×10^4 m^3.

In applying the indirect method, evaporation was estimated from pan data collected at the U.S. Weather Bureau station at Trempealeau Dam, Wisconsin, located 153 km southeast of Bass Lake. Precipitation was estimated using data from New Richmond, Wisconsin, 10 km northeast of Bass Lake. The results of the water budget calculations for two periods are shown in Table 1. Note that in June 1977, the amount of ground water leaving the lake exceeded the amount entering the lake by 6.0×10^4 m^3. This figure compares favorably with the amount computed directly from Darcy's Law. During the period December 1975 to November 1976, there was only 38.7 cm of precipitation, or roughly 50 percent of the annual average. This time period coincided with the severe drought in the Midwest. Consequently, the difference in the amount of ground water entering and leaving the lake during this one-year period was approximately the same as the amount calculated for just one month (June) of 1977, a year of normal precipitation.

The lake level fell during both time periods for which a water budget was computed and ground-water outflow exceeded ground-water inflow. In a normal year evaporation could be expected to be around 76 cm (Geraghty *et al.*, 1973) while average annual precipitation in the Bass Lake area is around 73 cm. Therefore, in a normal year when the lake level is stable, ground-water outflow will be somewhat less than ground-water inflow.

Table 1. Water Budget for Bass Lake

June 1977	
Precipitation (P)	12.4 cm
Evaporation (E)	11.0 cm
Decline in lake level ($-\Delta S$)	2.4 cm

$$GWI - GWO + (P - E)\,A = (\Delta S)\,A$$

where:

GWI	=	ground-water inflow
GWO	=	ground-water outflow
A	=	area of the lake
	=	1.57×10^6 m^2
GWI − GWO	=	$-(P - E + \Delta S)\,A$
GWI − GWO	=	-6.0×10^4 m^3

Dec. 1975 – Nov. 1976	
Precipitation (P)	38.6 cm
Evaporation (E)	60.2 cm
Decline in lake level ($-\Delta S$)	24.7 cm
GWI − GWO = -4.9×10^4 m^3	

CONCLUSIONS OF THE FIELD STUDY

The map of the potentiometric surface and geologic data suggest that the presence of a discontinuity in the bedrock (i.e., a deep-seated fault or a buried river valley) between Mounds Pond and Bass Lake results in a trough in the potentiometric surface which causes ground water flowing through the dolomite to be diverted to the southwest away from Bass Lake. Thus, there is no hydraulic connection between Mounds Pond and Bass Lake through the shallow flow system and the presence of the discontinuity would make the possibility of a deep flow system between Mounds Pond and Bass Lake unlikely. Moreover, the water budget calculations demonstrate that all the water leaving the lake by means of evaporation and ground-water outflow is accounted for by precipitation and ground-water inflow to the lake through the shallow aquifer system.

COMPUTER MODEL

Introduction

The field data provided evidence that there was no hydraulic connection between Mounds Pond and Bass Lake during 1977-78. However, there were three remaining questions which could be addressed most effectively through the use of a ground-water flow model. The questions were:

(1) What was the effect of the construction of the dam in 1922 on the flow system around Bass Lake?

(2) What would be the effect on Bass Lake of lowering the water level in the reservoir by as much as 3 m?

(3) Would increased recharge rates, such as those that occurred in the early 1970's, be sufficient to increase the level in Bass Lake significantly?

The flow system around Bass Lake was simulated using the two-dimensional transient model developed by Trescott, Pinder and Larson (1976). The model was calibrated by adjusting hydraulic conductivities until the observed flow pattern was reproduced. The boundary conditions and nodal spacings used in the model are shown in Figure 4. As constructed for this study, the model simulated heads in the aquifer beneath the lake rather than lake level. Additional details on the modeling procedure are given by Rinaldo-Lee (1978).

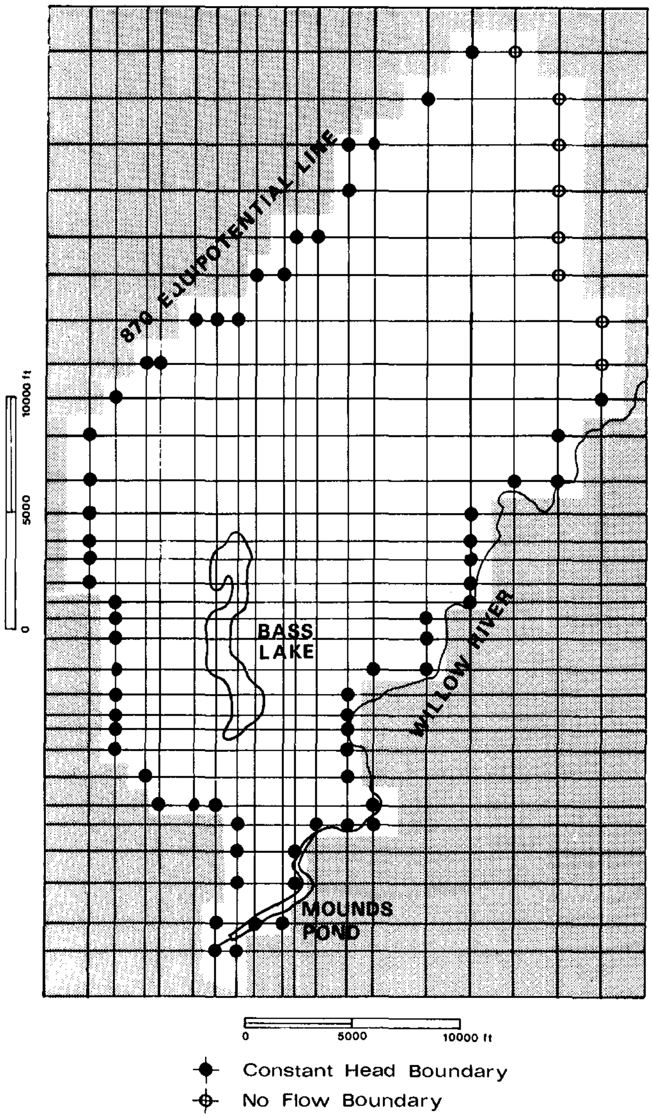

Fig. 4. Nodal spacing and boundary conditions used in the model.

Results

The boundary conditions along the Willow River were adjusted in order to simulate the flow pattern before the dam was constructed. The results of this simulation indicate that the flow pattern without the dam was essentially the same as shown in Figure 2. The trough in the potentiometric surface was still present although somewhat less pronounced. Raising the water level to its present elevation along the Willow River at Mounds Pond had only a slight effect on Bass Lake, causing less than a 0.01-m increase in lake level. Lowering the present water level of Mounds Pond by 3.0 m had no effect on the lake level.

The model was also used to examine the effect on lake level of an increase in recharge rate such as would occur during an unusually wet year. According to precipitation records for New Richmond, Wisconsin, average annual precipitation during the eight-year period from 1968-1975 was 81.2 cm or 8.5 cm above the long-term average of 72.7 for the period 1954-1975. It is also noteworthy that during the previous eight-year period (1960-1967), the average yearly precipitation was 69.4 cm or 3.3 cm per year less than the long-term average. In 1975, the yearly precipitation was 107.7 cm, which is 35 cm greater than the long-term average and is the highest annual precipitation on record at New Richmond. The water level of Bass Lake increased steadily during the early 1970's and reached its highest elevation during the spring of 1976, and then began to decline (Figure 5).

A comparison of the cumulative departure from mean monthly precipitation with lake level changes (Figure 5) suggests that fluctuations in lake level are correlated with precipitation. Moreover, fluctuations in ground-water levels around the lake mimic fluctuations in lake level. The model was used to determine whether an increase in ground-water recharge rate such as might have occurred in 1975 would be sufficient to increase lake levels significantly. The recharge rate for 1975 was arbitrarily set at 35 cm, i.e., equal to the amount of precipitation in excess of the long-term average, which amounts to 33 percent of the total annual precipitation for 1975. This was a conservative estimate because an analysis using the method described by Thornthwaite and Mather (1957) indicated that recharge may have been as high as 45 cm during that year. The normal recharge rate was estimated to be 9.1 cm per year or 13 percent of the long-term average annual precipitation (Rinaldo-Lee, 1978). Results of the simulation showed that after one year with

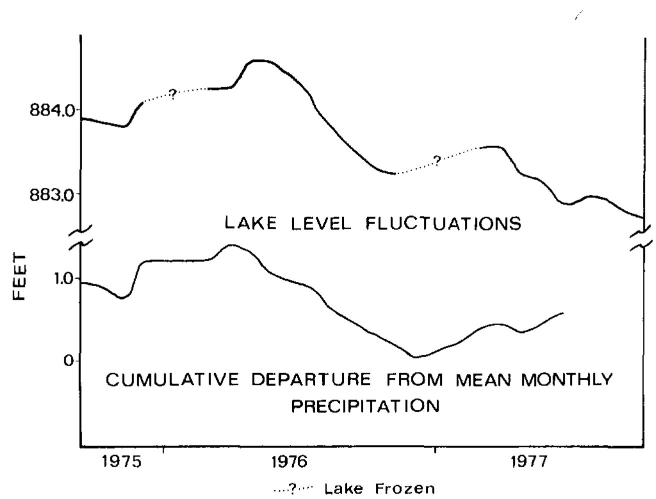

Fig. 5. Comparison between lake level fluctuations and cumulative departure from mean monthly precipitation.

a recharge rate of 35 cm/year, the lake level would rise 0.7 m.

The total rise in lake level during 1975 is unknown because a staff gage was not installed on the lake until August 1975. The lake level rose 0.19 m between August and late November when the lake froze over. Based on observations of high water mark on buildings, 0.5-1.0 m appears to be a reasonable estimate of the rise in lake level during 1975.

Conclusions

The results of the simulations suggest that increased recharge brought about by above average precipitation in 1975 was sufficient to account for the observed increase in lake level. The construction of the dam on Mounds Pond may have had a slight effect on lake level in the 1920's but lowering the current elevation of Mounds Pond by three meters would have no effect on the lake. Thus, regulation of water level of Mounds Pond would not solve the problem of high water levels in Bass Lake.

RECOMMENDATIONS

The results of this study indicate that changes in precipitation may cause significant changes in the water level of a ground-water dominant lake such as Bass Lake. Allowances for relatively marked fluctuations in lake level must be made when planning shoreline development around ground-water dominant lakes. As an aid in estimating the lake levels that can be expected in the future, precipitation records of the area should be examined and an inquiry should be made into the magnitude of past fluctuations in lake level. If sufficient data are available, a computer model of the ground-water flow system around the lake can be used as a tool in estimating the highest lake level which would occur in response to increased recharge rates.

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