Review of hydraulic relationship between site area lakes and the main groundwater aquifer, Crandon. November 8, 1984

Schuff, Richard G.; Rock, William T.
Madison, Wisconsin: [s.n.], November 8, 1984

B. Ramharter
BEAR/3

State of Wisconsin \ DEPARTMENT OF NATURAL RESOURCES

Carroll D. Besadny
Secretary

BOX 7921
MADISON, WISCONSIN 53707

November 8, 1984

IN REPLY REFER TO: 4400

Mr. Barry Hansen
Permitting Manager
Exxon Minerals Company
P.O. Box 813
Rhinelander, WI 54501

RE: Review of "Hydraulic Relationship Between Site Area Lakes and the Main Groundwater Aquifer, Crandon Project"

Dear Mr. Hansen:

The Department has reviewed the lake report prepared by Dames and Moore for Exxon Minerals, dated September 20, 1984, and received by the Department on September 25, 1984. The Department, in paragraph D on page 7 of its November 14, 1983 letter from Richard Schuff, and in later meetings, has indicated water budgets of the lakes potentially affected by mine dewatering should be prepared. The Dames and Moore report only addresses some of the components of the water budgets. The following comments will provide guidance which should allow Exxon to complete the analysis needed to evaluate mine dewatering impacts upon the project area lakes.

1) A lake water budget consists of determining all inputs and outputs through the lake and any associated changes in storage as reflected in fluctuating lake levels. These components include: incident precipitation, evaporation, lake bottom seepage, surface inflows and outflows. The surface inflows should consider overland flow and channelized stream flow. The Dames and Moore report did not address evaporation, surface inflows, or surface outflows. Seasonal flucuations in the individual components were not discussed. Maximum impacts are likely to occur during a season of high evaporation and low precipitation following a year when lake storage (lake level) is also at low levels. This scenario should be evaluated.

2) The evaporation component should be evaluated using field data gathered from other lakes studied in Northern Wisconsin. Lake level data from the Crandon Project Lakes should be correlated with other lake levels and corresponding evaporation rates. The USGS, WGNHS and University of Wisconsin may be sources of information. Research conducted at Trout Lake Biological Station north of Woodruff may be a source of information. Annual fluctuations as well as average values should be considered.

3) The evaluation of hydraulic connection between the lake and aquifer should have utilized the potentials measured during the two lake boring programs. The Dames and Moore report (Table 1) utilized hydraulic potentials interpolated from groundwater monitoring wells located as much as 1200 feet from the lake. It is unclear why interpolated values were used in Table 1 but actual potentials measured during the lake boring programs were used later in the report in a correct fashion to evaluate seepage rates.

4) The thickness of lake sediments acting as a seepage barrier could be more precisely delineated by examining the boring logs in detail. It is most probable that the firm silt or clay sediments are controlling seepage. The thickness of loose organic rich sediments will be an insignificant barrier to seepage. The sediment thickness, l, used in seepage calculation should be reduced to include only the firm low permeability sediments. (Refer to attachment 1 for guidance in evaluating this parameter).

5) Based on the interpolation procedure discussed in point 3, Dames and Moore conclude Duck, Skunk and Deep Hole Lakes are not hydraulically connected to the groundwater aquifer. The Department believes lake borings made in February 1984 demonstrate the lakes are hydraulically connected. The reasoning is flawed on page 6 of the report, where differences in hydraulic potential between the lake surface and nearby aquifer is said to indicate that a hydraulic discontinuity exists between them. It should be noted that as long as a saturated connection exists between the aquifer and the lake, the potential differences will cause a movement of water between the two ie. a hydraulic connection. The effect of the increase of this potential difference due to mine dewatering is the reason for the Department having requested Exxon prepare a lake water budget.

6) The calculation of seepage travel times as expressed in Table 4 is incorrect. The specific discharge was calculated, not seepage velocity (average linear velocity as used in Freeze and Cherry, 1979). The seepage velocity can be determined by dividing the specific discharge by the effective porosity of the seepage controlling lake sediments. The effectivity porosity of these lake sediments is probably less than 0.25. This would produce seepage velocities four or greater times those used to calculate the travel times listed, thus producing travel times of 25% or less than those listed. It is unclear what the usefulness of the calculation of travel times is in evaluating the water budget of the lakes.

7) Laboratory permeability tests were used to establish values for hydraulic conductivity used in seepage estimates. Disturbance of the soil during sampling and the presence of soil heterogeneities in the field are uncertainties which indicate actual field permeability may be significantly greater than the laboratory values used. It is likely actual in situ permeability is greater than the laboratory measurements. For evaluation purposes a range of hydraulic conductivity values which start at 1×10^{-6} cm/sec (1.03 ft/yr) would be appropriate.

8) The report's conclusion that lake seepage losses during mine dewatering are small in comparison to other sources is unsupported. Even assuming a average non-drought year, the lake seepage was calculated to be as much as 125% of precipitation. If a precipitation value corresponding to a drought year was used the percentage would be increased further. A worst case analysis will probably need to assume no surface water flows into the lakes during drought years. In a lake such as Little Sand Lake, where there would be no surface outflow during periods of drought, the water budget would simplify to the evaporation, precipitation and seepage components. Average and worst case analysis for utilizing the above concepts should be made for Little Sand, Deep Hole, Skunk and Duck Lakes.

   A simplification of the water budgets of Little Sand, Skunk, Duck, Deep Hole, and Oak Lakes should be utilized to determine the maximum lake sediment conductivity value which would still sustain present lake levels. The maximum precipitation and inflow values possible, coupled with minimum evapotranspiration values, should be used to compute a sediment conductivity value which will allow complete seepage of all lake inputs. This conductivity value should then be used to compute the maximum lake seepage which would occur during worst case mine dewatering conditions.

9) The Department has prepared a lake seepage analysis utilizing the existing data which is presented in attachment 1. The Department's consultant, Dr. Kenneth Bradbury of the Wisconsin Geological and Natural History Survey, has also provided criticism of the lake seepage report, which is included as Attachment 2.

10) The Department has conducted field investigations with its hydrogeological consultants in order to evaluate reports of springs along the west edge of Little Sand Lake. The investigation indicates there are no active springs or indications of past spring activity in Little Sand Lake. A description of this investigation is presented in Attachment 3.

11) It has been assumed that Rolling Stone Lake will not be affected by reductions in groundwater discharge due to mine dewatering. Exxon must document this by comparing the modeled reductions in flow to the lake compared to other lake budget components. Seasonal low flows must be considered. The "Inland Lake Renewal Feasibility Study for Rolling Stone Lake, 1977," prepared by Northern Lakes Service Inc. may be of use in this analysis.

12) The impacts associated with the potential reductions in lake levels due to mine dewatering indicates the need for the preparation of hydrographic maps of Little Sand, Skunk, Duck, and Deep Hole Lakes. Exxon shall prepare maps with a one foot minimum contour for the upper five feet of the lake bottom. The contour internal can be increased to larger values for the remaining bottom area. Public access points should be indicated.

13) In order to evaluate the maximum lake storage possible, Exxon shall determine the elevation of lake level controlling structures. These elevations should be surveyed to a 0.1 foot accuracy and a description of the controlling structure should be provided. The lake level controlling structure elevation should be compared to historic lake level maximums.

14) The potential for significant lake level reductions indicates the need for evaluation of appropriate mitigative measures. These should include lake water supplements and the use of a hydraulic barrier formed by reinjection of clean groundwater intercepted before flowing into the lower mine workings. Though there is no assurance of Department approval of such measures at this time the EIR review process could be expedited if the hydraulic barrier concept was evaluated using a varying array of injection wells and pumping rates simulated through use of the GEOFLOW model. Secondary impacts associated with both of these mitigative measures should be addressed.

As can be seen from Departmental analyses, the increases in lake seepage due to mine dewatering are significant. These analyses point out the need for further analysis of the lake water budget and specifically indicates that seepage rates are very sensitive to sediment permeability. Please contact Kenneth Wade, Bureau of Solid Waste hydrogeologist at (608) 267-9387 regarding questions about this letter.

Sincerely,
Bureau of Solid Waste Management

Richard G. Schuff

Richard G. Schuff, P.E., Chief
Residuals Mgt. & Land Disposal Section

Bureau of Water Supply

William T. Rock by Roger Gilman

William T. Rock, P.E., Chief
Private Water Supply Section

KW:ms/4489Q

Attachments 1, 2, and 3

cc: A. Wilson - NCD
R. Gerhardt - WS/2
L. Wible - ADM/5
K. Bradbury - WG&NHS
J. Krohelski - USGS
M. Anderson - U.W.-Geology Dept.
B. Ramharter - BEAR/3
C.W. Fetter - U.W.-Oshkosh
Systems Management Section
Bill Krug - USGS
Native American Coord. EE/5
Dale Simon - WR&Z/5
Bob Read - BEAR/3
Bob Sonntag - WR&Z/5
James Derouin - Madison
Kevin Lyons - Milwaukee
Don Zuidmulder - Green Bay
Kathy Falk - DOJ
Gordon Reinke - SW/3
Susan Steingass - Madison

Attachment 1

Evaluation of Seepage From Little Sand, Duck Skunk, Oak, and Deep Hole Lakes

The analysis of lake seepage is dependent on the following three parameters: thickness of lake sediments controlling seepage, difference in hydraulic potentials between the lake and the underlying aquifer, and the hydraulic conductivity of the lake sediments.

I. Thickness of Lake Sediments

Examination of the lake borings indicates soft loose black organic silts (OL) make up the upper sediments. The lower sediments tend to be firm silt or silty clay (ML, CL) soils. Only the lower firm soils will be significant in controlling seepage due to their lower conductivity. The table below summarizes the sediment type for the Little Sand Lake (LSL) borings.

Boring Name	LSL1	LSL2	LSL3	LSL4	LSL5	LSL6	Average
Loose, soft sediments (ft)	16.5	12.0	14.5	12.0	3.0	8.0	11.0
Firm sediments (ft)	21.0	15.5	16.0	26.0	26.0	14.0	18.1
Total thickness (ft)	37.5	27.5	30.5	33.0	19.0	22.0	28.25
Difference in lake/aquifer potentials (ft)	8.54	7.21	-	8.27	-	11.24	8.82

Inspection of boring logs gave the following values for thickness of seepage controlling sediments for the other lakes: Duck Lake (20 feet), Skunk Lake (1.5 - 2.0 feet), Oak Lake (13.0 feet), and Deep Hole Lake (17 feet). The existing hydraulic potential differences between the lake and the underlying aquifer are given for those borings for which they could be calculated.

II. Difference in Hydraulic Potentials Between Lake And Underlying Aquifer

The existing potential was taken from the piezometric water levels measured during the lake boring programs and the measured lake surface elevations. The maximum potential difference which could be developed during mine dewatering is determined by examining the boring logs to find the lowest elevation of the seepage controlling lake sediments.

The lowest elevation represents the minimum potential because if groundwater levels are lowered below this point unsaturated conditions should begin to develop below the sediments and hydraulic continuity will be broken between the lake and groundwater aquifer. The following table summarizes the existing and maximum potential differences at the project area lakes:

Lake Name	Little Sand	Duck	Skunk	Deep Hole	Oak
Surface elevation (ft) MSL	1591.91	1611.8	1598.0	1605.4	1633.5
Bottom of seepage controlling sediments (minimum potential)	1542.41	1557.0	1587.5	1570.0	1584.5
Existing aquifer potential	1583.09	1594.7	1594.0	1587.9	1584.5
Existing difference in potentials	8.82	17.1	4.0	17.5	49.0
Maximum difference in potentials	49.5	54.8	10.5	35.4	49.0

III. Hydraulic Conductivity of Lake Sediments

Laboratory measurements of lake sediment samples obtained by the boring programs gave conductivity values ranging from 1.3×10^{-6} cm/sec to 1.6×10^{-8} cm/sec. Obtaining and testing the samples in the laboratory is likely to cause some disturbance of the sample resulting in compaction which can produce conductivity values less than those of the actual in-field material. Heterogeneities within the sediments will probably produce a bulk permeability which is greater than that produced by individual tests of the lab specimens. Because of these uncertainties a range of hydraulic conductivity values from 1×10^{-6} cm/sec (1.03 ft./year) to 1×10^{-7} cm/sec (0.10 ft./year) will be used for analysis of lake seepage.

IV. Lake Seepage Calculations for Existing and Dewatering Conditions

Darcy's Law for saturated flow will be used as follows:

$$q = K \frac{\Delta h}{l}$$

q = specific discharge (seepage rate)
K = hydraulic conductivity
Δh = difference in potentials
l = thickness of seepage controlling sediments

A. Little Sand Lake Seepage Rates

Seepage Conditions	Existing		Maximum/Dewatering	
Sediment Conductivity	low	high	low	high
Sediment Thickness (ft)	18.1	18.1	18.1	18.1
Hydraulic Conductivity (ft/yr)	0.10	1.03	0.10	1.03
Potential Differences (ft)	8.8	8.8	49.5	49.5
Seepage Rate (ft/yr)	0.05	0.5	0.28	2.8
Maximum Potential Seepage Increase During Dewatering%			460%	

B. Duck Lake Seepage Rates

Seepage Conditions	Existing		Maximum/Dewatering	
Sediment Conductivity	low	high	low	high
Sediment Thickness (ft)	20.0	20.0	20.0	20.0
Hydraulic Conductivity (ft/yr)	0.10	1.03	0.10	1.03
Potential Differences (ft)	17.1	17.1	54.8	54.8
Seepage Rate (ft/yr)	0.09	0.88	0.28	2.8
Maximum Potential Seepage Increase During Dewatering%			218%	

C. Skunk Lake Seepage Rates

Seepage Conditions	Existing		Maximum/Dewatering	
Sediment Conductivity	low	high	low	high
Sediment Thickness (ft)	1.5	1.5	1.5	1.5
Hydraulic Conductivity (ft/yr)	0.10	1.03	0.10	1.03
Potential Differences (ft)	4.0	4.0	10.5	10.5
Seepage Rate (ft/yr)	0.18	1.83	0.72	7.2
Maximum Potential Seepage Increase During Dewatering%			293%	

D. Deep Hole Lakes Seepage Rates

Seepage Conditions	Existing		Maximum/Dewatering	
Sediment Conductivity	low	high	low	high
Sediment Thickness (ft)	17.0	17.0	17.0	17.0
Hydraulic Conductivity (ft/yr)	0.10	1.03	0.10	1.03
Potential Differences (ft)	17.5	17.5	35.4	35.4
Seepage Rate (ft/yr)	0.10	1.1	0.21	2.1
Maximum Potential Seepage Increase During Dewatering%			91%	

E. Oak Lake Seepage Rates

Seepage Conditions	Existing and Maximum/Dewatering	
Sediment Conductivity	low	high
Sediment Thickness (ft)	13.0	13.0
Hydraulic Conductivity (ft/yr)	0.10	1.03
Potential Differences (ft)	49.0	49.0
Seepage Rate (ft/yr)	0.39	3.9
Seepage Increase During Dewatering%		0%

It should be noted that the maximum seepage rates possible can only be achieved if the underlying aquifer is lowered to the bottom of the seepage controlling lake sediments. The Department has used the maximum mine inflow computer model simulation (Case II, D'Appolonia, 1982) to evaluate the maximum drawdown relative to the sediment bottom elevation. The following table presents this data:

Lake	Maximum Aquifer Drawdown (ft)	Existing Water Table (ft)	Resultant Water Table (ft)	Elevation of bottom of sediments (ft) (ft)
Little Sand	20-59	1578-1585	1526-1558	1542
Skunk	16-20	1592-1595	1572-1579	1588
Duck	20-23	1590-1594	1570-1572	1557
Deep Hole	13-16	1583-1588	1567-1575	1570

The above analysis shows that the maximum drawdown will lower the water table of Little Sand, Skunk, and Deep Hole Lakes to the bottom of the sediments and so indicates their maximum lake bed seepage could potentially increase to that produced by water table declines to the bottom of their lake bed sediments. The sediments of Duck Lake continues13 to 15 feet below the maximum drawdown elevation so maximum seepage head differences will not occur at this lake. The actual maximum seepage rates for Duck Lake listed in Table B should be reduced by 25% to reflect the fact that the water table will not be lowered below the sediments.

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ATTACHMENT #2.

UWEX GEOLOGICAL AND NATURAL HISTORY SURVEY
1815 University Avenue, Madison, Wisconsin 53706 608-262-1705

MEMO

to: Ken Wade, Dept. of Natural Resources date: 11/5/84

from: Ken Bradbury KRB

Re: Review of Report: Hydraulic Relationship Between Site Area Lakes and the Main Ground Water Aquifer, Crandon Project. Prepared by Dames and Moore for Exxon Minerals Company, Dated Sept. 20, 1984.

The Dames and Moore report is a rather brief summary of information already collected about the Exxon Project Area lakes. It provides no new information or data.

Having been present at a series of meetings between Exxon and the DNR during late 1983 and 1984, it is clear to me that this report does not fulfill the request made by DNR at those meetings. DNR requested Exxon to provide detailed water budgets for all lakes near the mine workings. The budget components to be addressed included precipitation, surface water runoff, evaporation, seepage, and surface water inflows or outflows for each lake. My notes from a meeting in Madison on 12/20/83 indicate that Exxon agreed verbally to provide water budgets for all lakes having no unsaturated zone beneath them, and to provide a detailed cross section utilizing the CDM piezometers in the northwest corner of Little Sand Lake. The Dames and Moore report clearly does not fulfill this request.

Detailed comments follow:

Page 1, Par. 1. Lines 5 and 7. The phrases "movement of water...is limited." and "very restricted hydraulic connection." are so vague as to be meaningless. Is groundwater movement "limited" to small amounts, or is it "limited" by some physical barrier? The term "hydraulic connection" (line 7) is vague and undefined.

Page 1, Par. 2., Line 1. "...degree of hydraulic connection..." is an undefined phrase. It is not clear whether "hydraulic connection" refers to continuity of hydraulic gradients, continuous saturation, movement of water, or to something else. For example, water in the unsaturated zone is usually in hydraulic continuity (by rigorous definition) with water in the saturated zone.

Page 2, Last Line. The time-of-travel equation gives specific discharge, not average linear velocity. Average linear velocity (specific discharge divided by porosity) is the appropriate velocity for time-of-travel calculations. In any case it is not clear what bearing time-of-travel calculations have on lake seepage impacts.

Page 3, First Paragraph. Only in Oak Lake is the groundwater potentiometric surface below the bottom of the lake sediments. The reference to Hillel (1982) is unclear. How was soil suction potential determined? What characteristic curve was used? What water content was used?

Page 4. First Paragraph, lines 11-13. The statement "...difference in water level elevation indicates that these water bodies are hydraulically separated from each other, since connected water sources will seek an equilibrium represented by similar potentiometric elevations." is misleading and generally not true. The difference in water levels indicates only that a hydraulic gradient exists beneath the lakes. If the sediments beneath the lakes are saturated (as they are, with the exception of Oak Lake) then the lakes are hydraulically connected to the groundwater system. The object of Exxon's analysis should have been to quantify the amount of water exchanged through this connection. This amount is expected to be small due to the low permeability of the lake sediments. But the idea that the lakes in the project area are somehow "hydraulically separated" from the rest of the groundwater system is a misconception of the facts.

Pages 4-6 The discussion of "hydraulic connection" based upon differences between lake levels and water levels in wells near the lakes is not relevant. To compare lake levels with well levels up to 140 m away is simply not correct. Such a comparison ignores the effects of horizontal and vertical hydraulic gradients which are often very steep near lakes. A better source of data would have been the lake-bottom piezometric investigations conducted by STS Consultants but not mentioned in this section.

Page 7, Paragraph 2, Line 6. The phrase "...limited hydraulic connectiveness ..." is vague and undefined.

Page 11, Paragraph 1. The statement that Duck, Deep Hole, Little Sand, and Skunk Lake are perched above the water table is incorrect. All the data available to me suggest that the water table (ie, the top of the saturated zone) and the lake surfaces are coincident for these lakes. There is no unsaturated zone beneath these lakes. The observed hydraulic gradients through the fully saturated lake sediments, not to the presence of some hydrologic discontinuity beneath the lakes.

Page 11, Paragraph 6. This statement appears to recommend that a study of runoff to Little Sand Lake is necessary. I believe the DNR intent in requesting this report was for Exxon's consultant to prepare detailed water budgets for all lakes in the project area.

ATTACHMENT #3.

WGNHS GEOLOGICAL AND NATURAL HISTORY SURVEY
1815 University Avenue, Madison, Wisconsin 53706 608-262-1705

MEMO

to: Ken Wade, Jim Krohelski, Roger Gerhardt, Mary Anderson   date: Oct. 22, 1984

from: Ken Bradbury KRB

Re: Summary of field observations at Little Sand Lake, October 1984

On October 9-10, 1984 Ken Wade, Jim Krohelski, and myself conducted a reconnaissance field study of Little Sand Lake. Our objectives were to attempt to locate lake-bottom springs reported by local residents and to determine hydraulic gradients through the lake bed in near-shore areas.

This memorandum is a summary of the observations we made, with some interpretive calculations.

I. Spring Survey

We attempted to confirm reports that springs are present in the bottom of Little Sand Lake. I had received one detailed telephone description of a spring from Mr. Richard Webb who owns a summer cottage on the lake but resides elsewhere. Mr. Webb gave us permission to visit his property, and suggested that springs occurred in a small grassy lake-bottom depression about 40 feet offshore of his property.

We located Mr. Webb's cottage, and did observe two grassy depressions in the sandy lake bed about 40 feet offshore from his property (see attached map). These depressions were circular, about 3 feet in diameter, and in about 2 feet of water. The depressions were about 6 inches deep.

We tested the water in and around these depressions for temperature and electrical conductivity. We were not able to detect any thermal or chemical changes in or near these areas, nor did we see any visual evidence of groundwater discharge (sand boils, for example). We also installed seepage meters and mini-piezometers in the depression area (see below). Data from these devices did not suggest that groundwater discharge was occurring.

We also met Mr. Tom Volmar at the lake. He pointed out an area in the northwest corner of the lake where he remembered encountering very cold water while swimming. Once again we were unable to locate or observe any active springs in this area. Several other residents who we talked to at the lakeshore also said they had often encountered cold areas while swimming, wading, or fishing in the lake, and that they believed these areas were spring discharge points. However, none of these people could direct us to an exact spot, other than again mentioning the general vicinity of Mr. Webb's cabin. In addition, these people stated that they had not observed any physical evidence for groundwater discharge, such as sand boils, in colder areas.

<u>SUMMARY</u>: Although we visited locations where several residents had reported springs in Little Sand Lake, we were unable to locate any active springs in the lake bottom.

II. Seepage Meter Results

We installed four seepage meters in the vicinity of Mr. Webb's cabin to attempt to measure groundwater flow into or out of the lake bottom. The seepage meters were located in 2 to 3 feet of water in the vicinity of the grassy depressions about 40' from shore (see sketch). After installation, each seepage meter bag was filled with 500 ml of lake water and the meters were left overnight, with the following results:

Elapsed Time: 15.25 hours

Meter	Gain or Loss (ml)	Rate ml/hr.
#1 (30 feet from shore)	-140	- 9
#2 (40 feet from shore)	+145	+10
#3 (40 feet from shore)	- 35	- 2
#4 (50 feet from shore)	+100	+ 7
Average	+ 70	+ 5

The seepage meter data are obviously somewhat contradictory. From my personal experience using seepage meters, I conclude that the observed variations are mainly due to errors in measurement and to variations in seepage meter performance, and that the net bottom seepage in the tested area is essentially zero.

III. Vertical Permeability Test

We measured the vertical permeability of the lake bed using a thin-walled metal casing (0.4 feet diameter) driven vertically 1.5 feet into the bottom sediments in about 1 foot of water. Inside the casing we installed a small piezometer with a very short screened opening at the level of the bottom of the outer casing. We filled the casing with water and observed the water level fall for over one hour. This falling-head test gave a vertical permeability of 1.6×10^{-4} cm/sec.. The material tested was a poorly sorted silty till, which occurred about 1 foot beneath the lake bed.

IV. Lake Bed Hydraulic Gradients

We measured hydraulic gradients through the lake bottom using mini-piezometers installed at 6 sites (see map). Each mini-piezometer was allowed to stabilize overnight prior to measurement. Results are as follows:

Mini-piezometer No.	Head (relative to lake) (ft)	Penetration (ft)	Gradient
1 (Northwest Shore)	0.00	1.4	0.00
2 Beach (Outer)	-0.01	3.0	-0.003
3 Beach (inner)	-0.09	0.9	-0.10
4 Webb (outer)	-0.16	2.0	-0.08
5 Webb (inner)	-0.73	2.6	-0.28
6 (South Shore)	-0.23	1.9	-0.12
Average			-0.10

Measured gradients range from 0.00 in the northwest corner of the lake to -0.28 (downward) at the Webb property. The average gradient was -0.10 (downward). The mini-piezometers provide very convincing evidence that Little Sand Lake loses water by downward seepage along its western shore.

V. Nearshore Lake Bed Materials

In order to observe geologic materials present in the lake bed, we bored several shallow holes near the Webb property using a hand auger. The logs at two of these holes are as follows:

Hole #1
Location: 40 feet offshore of Webb cottage, in 3 feet of water

Depth	Material
0 - 3 ft	Sand, fine to medium, well sorted
3 - 3.5 ft	Silt, grey, organic

Hole #2
Location: Onshore, 10 feet from shoreline

Depth	Material
0 - 5 ft	Sand, silty, with pebbles (till)

Hole 2 encountered the water table at 2.2 feet below the land surface and 0.11 feet below the lake water surface, giving a horizontal hydraulic gradient of 0.11/10 = 0.01 westward.

VI. Other Observations

We also measured depth to water in several Exxon wells, with the following results:

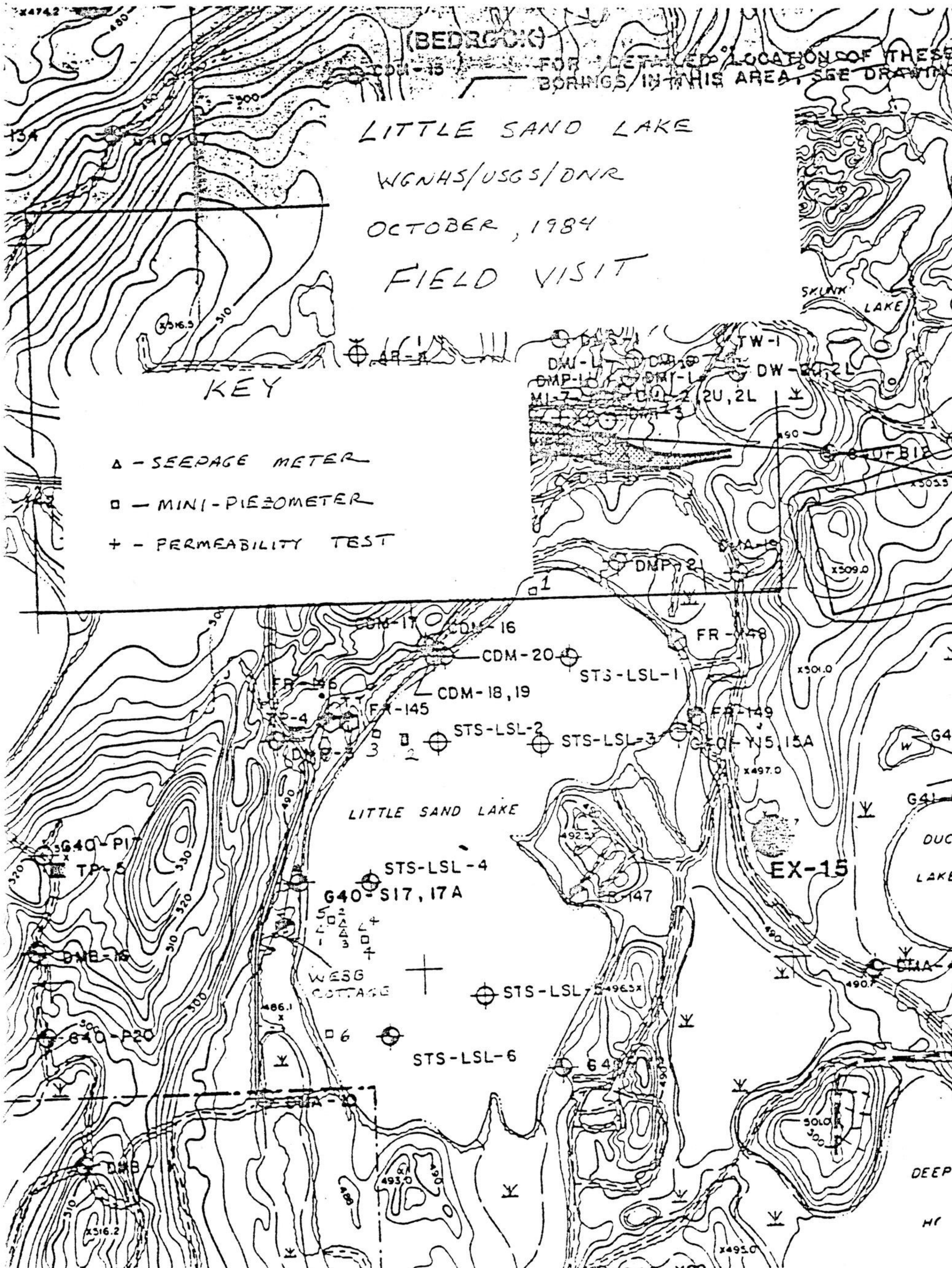
Well	Depth to water
640-S17	20.98 feet
640-S17A	19.03 feet
CDM 16	25.54 feet
CDM 18	Dry
CDM 19	15.15 feet
CDM 20	4.00 feet
CDM 17	Dry

In addition, we located the surface water outlet to the lake in a weedy area in the southwest corner of the lake, and followed a well-defined channel several hundred feet back into the woods. We were not able to locate any berm, dam, or obstruction which might be the main surface water level control. We did not detect any flow in the outlet channel.

VII. Summary

On October 9 and 10, 1984 we undertook a rather qualitative survey of groundwater-surface water relationships along the western shore of Little Sand Lake. We found no springs. We measured consistently downward vertical hydraulic gradients through the lake bottom, which indicates that the lake currently loses water through groundwater seepage. Along the western shore, the water table apparently slopes westward, away from the lake.

KRB:kz


LITTLE SAND LAKE
WGNHS/USGS/DNR
OCTOBER, 1984
FIELD VISIT
KEY
△ - SEEPAGE METER
□ - MINI-PIEZOMETER
+ - PERMEABILITY TEST
(BEDROCK)
BORINGS IN THIS AREA, SEE DRAWING
SKUNK LAKE
TW-1
2U,2L
DMP-2
CDM-16
CDM-20
STS-LSL-1
CDM-18,19
FR-145
FR-149
STS-LSL-2
STS-LSL-3
15,15A
LITTLE SAND LAKE
STS-LSL-4
G40-S17,17A
EX-15
WESG COTTAGE
STS-LSL-6
TP-5
DUCK LAKE
DEEP