Chapter 2.0: Sections 2.1 thru 2.5. Volume II

Exxon Minerals Company
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CHAPTER 2.0

DESCRIPTION OF THE ENVIRONMENT

The purpose of this chapter is to present a comprehensive description of the physical, chemical, biological, cultural, and socioeconomic environment associated with the Crandon Project. The information contained in this chapter is derived from studies performed to ascertain existing conditions of air quality and meteorology, geology, surface and ground waters, aquatic and terrestrial ecology, history and archaeology, noise, land use and aesthetics, and socioeconomics. The rationale and methodology for each of the studies are presented in the individual sections of the chapter.

In addition to providing basic information for description of the environment, these studies define existing conditions for future comparison with changes potentially caused by construction or operation and will facilitate assessment of potential environmental impacts. Further, these data were incorporated into decisions made during project design and site selection to minimize potential environmental effects and to provide a basis for reclamation planning.

The environmental studies were designed and conducted by a multidisciplinary team of professionals in close coordination with the Wisconsin Department of Natural Resources (DNR) and Exxon Minerals Company personnel. The technical content of the studies was determined based on the 1976 guidelines provided by the State of Wisconsin for the implementation of the Wisconsin Environmental Policy Act of 1972, and discussions with the DNR in association with review and comment of a formal technical plan for the environmental study program. In addition, quality control programs were applied to all phases of the study program.

Environmental studies were initiated in January 1977 and are continuing. These investigations were initially focused from the ore body. Subsequently, as knowledge of the Project evolved to include the potential locations of various facilities, studies and schedules were adjusted to address the associated environmental concerns.

For ease of reference and discussion in this report, various geographic units have been defined for the Crandon Project; these include:

Site Area - This area is defined as those lands bounded on the north by the Swamp Creek Valley, on the east by the Ground Hemlock Lake-Hemlock Creek system, on the south by Rolling Stone Lake, and on the west by the Pickerel Creek lowland system. Except for transportation links, all proposed project facilities will be located within the site area.

Environmental Study Area - This is generally defined as an area of land approximately 8 km (5 miles) in radius and centered on the site area. Potential environmental effects related to project activities primarily will be restricted to the environmental study area. Therefore, the environmental studies were concentrated in this area.

Regional Study Area - This is the land area defined by a circle approximately 40 km (25 miles) in radius and centered on the site area. The regional study area provides a general perspective for the project location relative to northeastern Wisconsin.

Local Study Area - This area encompasses most of Forest and Langlade counties and approximately half of Oneida County. It includes 40 townships, three cities, and a village and covers approximately 6,220 km^2 (2,400 square miles). This geographic unit was defined and used only for the socioeconomic assessment.

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2.1 METEOROLOGY AND AIR QUALITY

The objective of the meteorology and air quality studies was to document the pre-construction meteorological and air quality conditions in the environmental study area. This objective was achieved by monitoring meteorological conditions and concentrations of appropriate atmospheric contaminants. The regional study area is predominantly rural in character and no sizable emission sources were present in proximity to the environmental study area.

Meteorological monitoring was designed to characterize meteorological conditions that might affect the dispersion of airborne contaminants. This monitoring was conducted at three locations. At one major location, continuous recording of wind speed, wind direction, temperature, and precipitation was undertaken. Monitoring was also conducted for background levels of atmospheric sulfur dioxide (SO_2) at the major location and for total suspended particulate (TSP) concentrations at three locations. The sulfur dioxide (SO_2) sampling was included at the request of the Wisconsin Department of Natural Resources (DNR) (Huntoon, 1977a). TSP samples collected at the major location were examined microscopically to characterize the type and, therefore, the source of the particulates. Particulate samples were further analyzed for selected trace element concentrations.

2.1.1 Field and Laboratory Methods

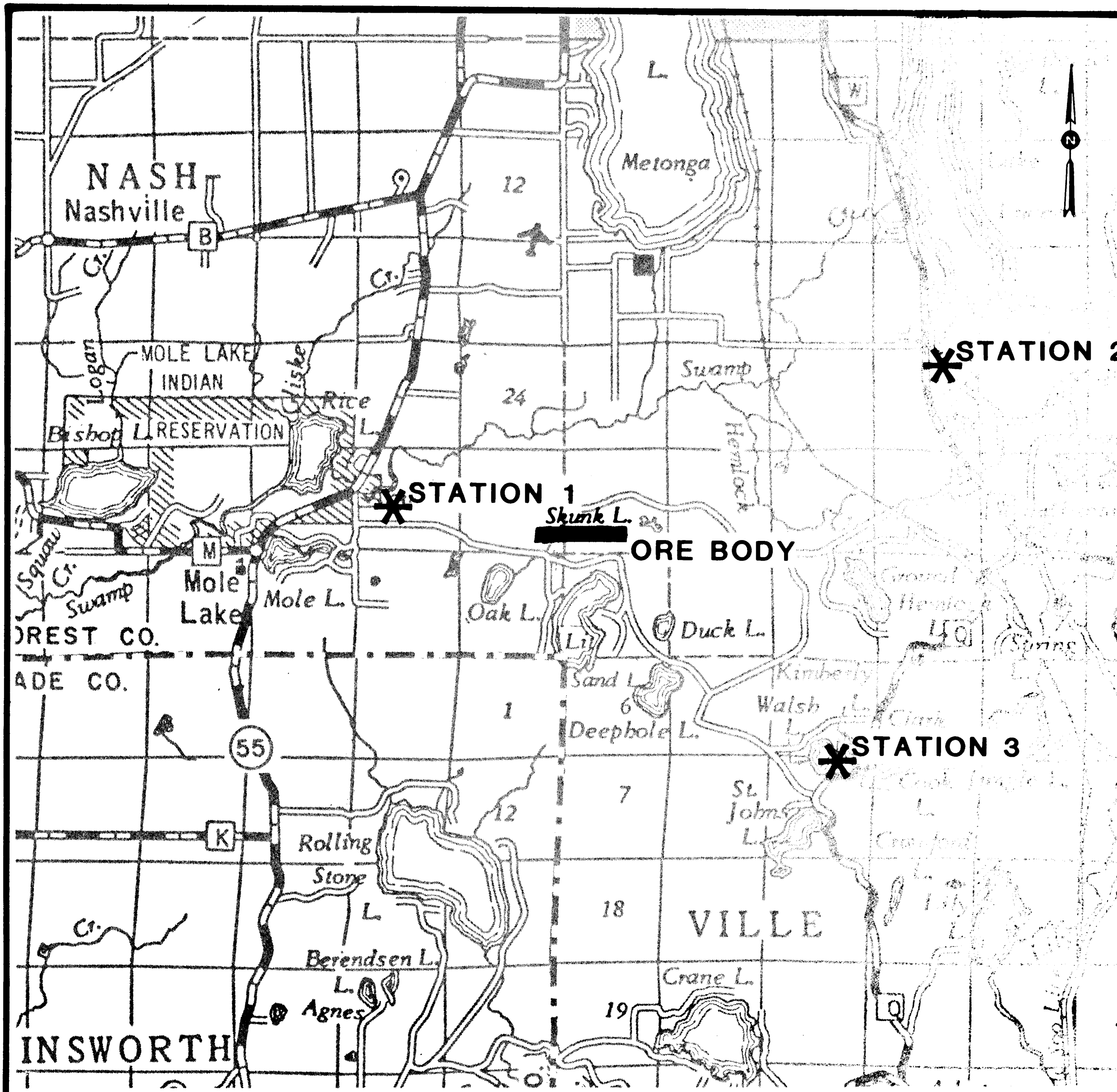
2.1.1.1 Station Locations

Three monitoring stations were operated within the environmental study area (Figure 2.1-1). Station 1 was selected to monitor air quality and meteorology data representative of the environmental study area in accordance with the general guidance provided by the U.S. EPA (1974a). Several potential locations were reviewed in the field to select the location for Station 1. The following criteria were employed:

1) Relatively flat terrain;
2) Accessibility for installation and servicing of equipment;
3) Availability of electric power;
4) More than 30 m (100 feet) from unpaved roads; and
5) Lack of vertical obstructions.

After selection of the location for Station 1, representatives of the DNR visited and approved the location (Huntoon, 1977b). Stations 2 and 3 were added at a later date at the request of, and near the locations suggested by, the DNR (Huntoon, 1977a). These locations were also inspected and approved by the DNR (Kopecky, 1978; Chazin, 1979).

Station 1 was located approximately 3.2 km (2.0 miles) west of the ore body in an open field approximately 61 m (200 feet) north of a paved road (Sand Lake Road). The Universal Transverse Mercator (UTM) coordinates were 346890E and 5038500N. The open field extended at least 200 m (650 feet) in the south through north sectors surrounding Station 1. To the south was Sand Lake Road and an open field beyond the road. To the east and southeast there



0 1 2 MILES

0 1 2 KILOMETERS

KEY:

* STATION LOCATION

BASE MAP REFERENCE: WISCONSIN DEPARTMENT OF TRANSPORTATION, JANUARY, 1978. FOREST CO. AND LANGLADE CO. HIGHWAY MAPS.

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AIR QUALITY AND METEOROLOGICAL MONITORING STATIONS

DAMES & MOORE

FIGURE 2.1-1

were short, widely spaced trees approximately 11 m (35 feet) from the station and a house and farm buildings with trees approximately 61 to 76 m (200 to 250 feet) from the station. To the north-northeast, about 91 m (300 feet) from the station, lay an open field with dense trees beyond.

At Station 1, wind speed, wind direction, temperature, precipitation, TSP, and SO_2 were monitored. The wind sensors at Station 1 were located on top of a 10-m (33-foot) tower. The temperature sensor was located on the same tower 0.3 m (1 foot) below the top. The rain gauge was located on a pole, which was approximately 6.1 m (20 feet) northwest of the tower and 2.1 m (7 feet) above the ground. A platform, 2.4 m (8 feet) above the ground supported the high-volume TSP sampler and an enclosed SO_2 sampler. This platform was approximately 7.7 m (25 feet) west-northwest of the 10-m (33-foot) tower and approximately 3.1 m (10 feet) west-southwest of the rain gauge pole. The criteria used in siting these monitors were in accordance with U.S. Environmental Protection Agency guidelines (U.S. EPA, 1974a) for spacing requirements.

Only TSP was monitored at Stations 2 and 3. Station 2, located approximately 5.5 km (3.4 miles) northeast of the ore body, was in an open field about 30 m (100 feet) east of a paved road (County Road W). UTM coordinates were 355385E and 5040500N. There were no trees within 20 m (65 feet) of the high-volume sampler, which was placed on a platform 2.4 m (8 feet) above the ground. A circular clearing with a radius of approximately 23 m (75 feet) was cut in a heavily wooded area for Station 3, approximately 5.6 km (3.5 miles) southeast of the ore body. UTM coordinates were 354155E and 5034430N. The sampler was on a platform 2.4 m (8 feet) high at the center of the clearing, approximately 61 m (200 feet) from a gravel road (County Road Q).

2.1.1.2 Monitoring Schedule

Air quality and meteorological monitoring in the environmental study area was initiated on March 26, 1977, and continued through December 31, 1978. Meteorological (wind speed, wind direction, and temperature) and air quality (TSP) monitoring began on March 26, 1977 at Station 1. At the request of the DNR (Huntoon, 1977a), monitoring was expanded to include additional parameters and additional locations. Precipitation and SO_2 monitoring were added to Station 1 in November 1977. Two monitoring stations, Stations 2 and 3, were added in January and February 1978, respectively, and included monitoring for TSP only. The TSP samples collected at Station 1 during monitoring in 1977 were further analyzed at the request of the DNR for particulate composition and trace elements selected by the DNR (Huntoon, 1977a). The monitoring period for each parameter is summarized in Table 2.1-1.

The meteorological parameters were monitored with continuous recording instruments. The continuous data were reduced to 1-hour averages or, in the case of precipitation, 1-hour totals. Data recovery was 70 percent for wind speed and direction, 78 percent for temperature, and 60 percent for precipitation.

The suspended particulate samplers were operated 24 hours, from midnight to midnight, every third day. This sampling schedule was selected to coincide with the statewide DNR sampling schedule of every sixth day. Sampling every third day was performed to assure a more statistically reliable

TABLE 2.1-1

MONITORING PARAMETERS AND PERIODS
STATIONS 1, 2, and 3

STATIONS AND PARAMETERS	PERIOD MONITORED
Station 1	
Wind speed and direction	03-26-77 to 12-31-78
Temperature	03-26-77 to 12-31-78
Precipitation	11-03-77 to 12-31-78
Total suspended particulates	03-26-77 to 12-31-78
Microscopic particulate characterization	04-01-77 to 03-31-78
Trace elements analyses	04-01-77 to 03-31-78
Sulfur dioxide	11-24-77 to 11-22-78
Station 2	
Total suspended particulates	01-20-78 to 12-31-78
Station 3	
Total suspended particulates	02-01-78 to 12-31-78

data base. Data recovery was 90 percent at Station 1, 98 percent at Station 2, and 98 percent at Station 3.

Twenty percent of the particulate samples representing a range of TSP concentrations were selected for microscopic particulate characterization. The samples for microscopic examination were selected by analyzing every fifth sample collected during the one year period between April 1977 and March 1978. However, this sampling scheme was varied slightly to assure that a range of concentrations examined included low, medium, and high concentrations. The highest and second highest concentrations in the year were also included. Particulate samples from Station 1 were also composited into quarterly samples at the suggestion of the DNR for the trace element analyses (Huntoon, 1977a). These quarterly composite samples were analyzed for each of the trace elements specified by the DNR (Huntoon, 1977a). The results were reported as quarterly average concentrations for each element.

The DNR also requested that SO_2 be monitored at Station 1 using an SO_2 bubbler (Huntoon, 1977a). The bubbler is used in an integrated sampling technique; that is, the bubbler collects the SO_2 sample over a 24-hour period in an absorbing solution. The SO_2 content of the solution is analyzed, and the results are reported as a 24-hour average concentration. The SO_2 bubbler sampler at Station 1 was operated on the same schedule as the TSP samplers, (that is, every third day). The data recovery equaled 93 percent.

2.1.1.3 Instrumentation

The equipment used to conduct the meteorological monitoring was a Climatronics, Inc. Electronic Weather Station (EWS), equipped with a heated rain gauge. The system accuracy for this equipment is as follows:

SENSOR	THRESHOLD SPEED	ACCURACY
Wind speed	0.33 m/s (0.75 mph)	0.25 m/s (0.5 mph)
Wind direction	0.33 m/s (0.75 mph)	5°
Temperature	N/A	0.5°C (1.0°F)
Precipitation	N/A	0.25 mm (0.01 inch)

Source: Climatronics Corporation.

A Meteorology Research, Inc. (MRI) Model 1072 Mechanical Weather Station was used as an emergency substitute for the Climatronics EWS for wind speed, wind direction, and temperature. It was installed and operated from January 25 to February 28, 1978, and from June 2 until December 31, 1978. The weather station was precalibrated at the factory for wind speed and wind direction and cannot be recalibrated in the field. The temperature recorder was manually calibrated with an accurate thermometer ±2°C (±4°F). The system accuracy for the MRI equipment was as follows:

SENSOR	THRESHOLD SPEED	ACCURACY
Wind speed	0.33 m/s (0.75 mph)	0.5 m/s (1.0 mph)
Wind direction	0.33 m/s (0.75 mph)	4°
Temperature	N/A	0.5°C (1.0°F)*

Source: Meteorology Research, Inc.

*Although this level of accuracy is reported by the manufacturer, the strip chart recording is not recordable to closer than ±2°C (±4°F).

A Weather Measure Corporation Model P-511E rain/snow gauge was also used as an emergency substitute sensor when the EWS rain gauge failed.

It was installed and operated from July 27 to December 31, 1978. The accuracy of this gauge was 0.25 mm (0.01 inch).

Total suspended particulates were determined using the U.S. EPA designated reference method (U.S. EPA, 1971a). The high-volume samplers used were General Metal Works, Inc. Model GMWL-2000H, equipped with a 7-day clock timer, pressure transducer flow recorder, and variable voltage transformer. The sample collection filters were glass fiber filters having a 99 percent collection efficiency for particles of 0.3 μm diameter. The filters were conditioned in a desiccation chamber and were weighed on a Torbal Model EA-1 analytical balance (accuracy ± 0.05 mg).

The atmosphere was sampled for SO_2 using the EPA approved and designated reference pararosaniline method (U.S. EPA, 1971b). A Research Appliance Company 3-Gas Sampler was used, which is an all-weather sampler for wet-chemical sampling using chemical absorption. It was equipped with a thermoelectric heating and cooling chamber for the reagent. However, during extremely cold weather it was housed in a heated shelter so that the vacuum pump would start at the designated sampling time.

2.1.1.4 Analytical Procedures

Total Suspended Particulates - The high-volume particulate samples were analyzed for TSP content according to the reference method for determination of suspended particulates in the atmosphere (U.S. EPA, 1971a). The glass fiber filters used in these samples were desiccated and weighed before and after sampling in the Centralized Meteorological Instrumentation Laboratory in the Dames & Moore Park Ridge, Illinois office. These filters were protected during shipment to and from the field in a manila folder sealed inside a Ziploc plastic storage bag.

Particulate Characterization - Particulate characterization was accomplished with a polarizing microscope (Nikon Model MS, 40X and 400X magnification). Each sample was transferred from the filter media to a microscope slide using a dissecting needle that was immersed in mounting liquid and used to lift a portion of the particulate matter from the surface of the filter. Each slide was initially inspected to determine the distribution of particulates. One field, which was judged to be representative of the slide, was selected and completely analyzed. All particles within this field were counted with the assistance of a Whipple disc. The number of particles counted varied from 10 to 239.

Particle types were identified by morphology using the McCrone Particle Atlas (McCrone and Delly, 1973). Particle size range was determined using an eyepiece graticule calibrated by an optical micrometer in 10 μm units. Particle counts were performed using an optical grid. The results were reported as the percent of the sample area covered by each type of particle.

The particles in the sample were identified and classified as either minerals, combustion products, or biological matter and they were further classified by particle size (larger or smaller than 30 μm). This technique provides a convenient measure of the relative amounts of each particulate type, but it does not account for the differing densities of various particles. Therefore, a particle with low density, such as most biological matter, could cover a relatively large surface area in the sample, but contribute only a small amount to the total weight of the sample.

Trace Elements - At the request of the DNR (Huntoon, 1977a), trace element analyses were performed quarterly on composite samples of all high volume filters exposed at Station 1. This was accomplished by combining a portion of each filter collected during the quarter into a single composite sample for chemical analysis. When this composite was analyzed, the results were then representative of the average concentration of all sampling days during the quarter.

Sampling was conducted every third day yielding nominally 30 samples each quarter. After all 30 samples in a quarter were weighed and the TSP calculations completed, the filters were composited for chemical analysis. Since this analysis is destructive, only one-third of each filter was used for the analysis. The remaining two-thirds were preserved for possible future reference. Using a template and a wheel-type cutter, exactly one-third of the exposed area of each filter was cut from the filter and placed in the composite sample. It was important that exactly one-third of the exposed area be taken in the sample so that each sampling date contributed an equal amount to the composite. Lead, one of the trace elements analyzed, in ambient particulate matter collected on hi-vol filters has been shown to be uniformly distributed across the filter suggesting that it is unimportant which third of the filter is used (Sec. 7.2.1.1 of U.S. EPA, 1978a).

Since glass fiber high volume filters can have a high background concentration of several of the trace elements, blank composites were prepared in the same manner. For each sampling quarter, 30 unexposed filters from the same manufacturing batch were cut using the template and cutter. This was important because the subsampling equipment and associated handling could contribute some trace elements to the samples. The blanks were therefore composited in exactly the same manner as the exposed samples.

Each of the blank and the sample composites were then analyzed by Aqualab, Inc. as a single sample. The results were reported as the weight of each trace element contained in the composite sample and in the composite blank.

The concentration in the atmosphere of each trace element was calculated by first subtracting the amount of each trace element in the composite blank from the amount of that trace element found in the composite sample. This corrected for the background found in the glass fiber filter. The concentration of each trace element in the atmosphere was calculated in the same manner as TSP was calculated. The total volume of air sampled was one-third of the sum of the individual volumes for each of the 30 sampling days from which the composites had been made. The results were reported in units of nanograms of trace elements per cubic meter of air sampled during the calendar quarter.

The method used for lead, cadmium, copper, and zinc analyses was adapted from the draft, "Tentative Reference Method for the Determination of Lead in Suspended Particulate Matter Collected from the Ambient Air" (U.S. EPA, 1977a). This method has since been approved and published by the EPA as the reference method for lead in ambient air (U.S. EPA, 1978a). There are no EPA approved methods for atmospheric trace elements other than lead. Metals in the particulate sample were solubilized by extraction with nitric acid. The metal content of the sample was then analyzed by atomic absorption spectrometry. The lower limit of detection was calculated as two times the standard deviation of the four composite blank samples. Limits of detection for lead, cadmium, copper, and zinc were 12, 3, 1, and 20 ng/m^3 of air sampled, respectively.

The cold vapor generation procedure and atomic absorption spectrometry outlined in "Manual of Methods for Chemical Analysis of Water and Wastes" (U.S. EPA, 1974b) were used to determine mercury concentrations. The lower detectable limit of the method was calculated to be 0.02 ng Hg/m^3 of air sampled.

Arsenic levels were determined using the gaseous hydride generation method and atomic absorption spectroscopy (U.S. EPA, 1974c). The lower detectable limit of this method was calculated to be 0.03 ng As/m^3 of air sampled.

Asbestos content was not analyzed because no asbestos was found in the waste rock that would be disturbed by mining and exposed to the atmosphere. See section 2.2, Geology for details.

Sulfur Dioxide - Sulfur dioxide was collected in an absorbing reagent. The exposed samples were stored in a refrigerator to prevent exposure to elevated temperatures until they could be shipped in insulated containers to the laboratory. Subsequently, the samples were logged, inspected, and transmitted to Aqualab, Inc. for analysis. The entire sampling procedure, including the analysis, was performed in accordance with the reference method for the determination of SO_2 in the atmosphere (U.S. EPA, 1971b). Flowrates and other sampling data were recorded on the site inspection checklist by field personnel. The SO_2 concentrations were calculated from the field data and the laboratory analyses. The lower detection limit of this method for short-term sampling (1 to 3 hours) is given as 25 μg SO_2/m^3 with lower limits possible by using longer sampling periods. Using the 24-hour sampling period, the lower detection limit may be as low as 2.6 μg/m^3. None of the samples collected exceeded either the 25 or the 2.6 μg/m^3 limits. At the request of the DNR (Bradisse, 1978), the detection limit was taken to be 25 μg/m^3, and all data below this concentration were reported as one-half that value.

2.1.1.5 Quality Control

Quality control procedures were utilized by field and laboratory personnel during the meteorology and air quality study as a means of assuring that the study was completed according to currently accepted standards and methods.

Field Procedures - Daily logs of field activities were maintained by individual field personnel. Data sheets used for field work included calibration records for meteorological and air quality equipment and site check forms for the SO_2 sampler, the particulate sampler, and the meteorological system.

Calibration of the meteorological and air quality monitoring equipment was scheduled and performed upon installation and on a quarterly basis thereafter. Calibration records were forwarded to the DNR when each calibration was complete. The DNR observed the calibration of the air quality monitors and audited the entire air quality monitoring operation, both laboratory and field, to insure the data generated met DNR requirements (Table 2.1-2). In addition, when maintenance was performed on an instrument,

TABLE 2.1-2

DATES OF DNR CERTIFICATION AUDITS

FACILITY	DATE AUDITED	POLLUTANT	DATE CERTIFIED
Dames & Moore Laboratory	09-14-77[a]	TSP, SO_2	10-13-77[a]
Station 1	01-25-78[b]	TSP	11-01-77[a]
Station 2	01-25-78[b]	TSP	12-15-77[c]
Station 3	04-24-78[b]	TSP	12-13-77[c]
Station 1	04-24-78[b]	SO_2	04-24-78[b]

[a]Huntoon, 1977b.

[b]Kopecky, 1978.

[c]Chazin, 1979.

it was recalibrated. Each instrument was inspected for signs of malfunction during site checks every third day. All air quality monitoring data collected during the study were certified by the DNR.

The high-volume particulate samplers were calibrated according to the reference method using calibrated flow restrictor plates and a water manometer. The SO_2 sampler was flow calibrated and leak checked according to the reference method with a calibrated bubblemeter and a stopwatch. The meteorological equipment was calibrated according to the manufacturers' procedures using a digital voltmeter, mercury thermometer, magnetic compass, and measured precipitation volumes. Calibrations were performed on the dates indicated in Table 2.1-3.

Strip charts, TSP filters, and SO_2 samples were temporarily stored at Dames & Moore's field office in Crandon and periodically mailed to the Centralized Meteorological Instrumentation Laboratory in Dames & Moore's Park Ridge, Illinois office. Field personnel maintained records of all samples mailed for later comparison with office logs to guard against sample loss. Samples were mailed in insulated containers to avoid exposure of SO_2 samples to high temperatures. Upon arrival of samples, they were logged in at the laboratory. TSP samples and the strip charts were analyzed at the laboratory and SO_2 samples were transferred to Aqualab, Inc. for analysis.

<u>Laboratory Procedures</u> - Chemical laboratory analyses for trace elements and the determination of SO_2 were conducted by Aqualab, Inc. Quality control procedures for SO_2 included balance checks, reagent preparations, water purity tests, standardizations, and calibration curve measurements in accordance with the reference method (U.S. EPA, 1971b).

TABLE 2.1-3

CALIBRATION DATES FOR METEOROLOGY AND AIR QUALITY INSTRUMENTATION AT STATIONS 1, 2, AND 3 (MARCH 1977 - JANUARY 1979)

HI-VOL 1	HI-VOL 2	HI-VOL 3	SULFUR DIOXIDE	METEOROLOGICAL
03-26-77				
				06-22-77
06-25-77				
07-22-77				07-22-77
09-17-77				
10-03-77				10-03-77
			11-24-77	
12-08-77				12-08-77
		12-13-77 (Installed 02-03-78)		
	12-15-77 (Installed 01-20-78)			
			01-24-78	01-24-78
02-03-78				
			02-24-78	
				02-28-78
04-03-78	04-03-78	04-03-78		
				05-18-78
			06-02-78	
				06-29-78
				07-21-78
07-29-78				
	07-30-78	07-30-78		
08-08-78	08-08-78	08-08-78		
				08-14-78
	08-28-78			
09-24-78	09-24-78	09-24-78		
11-06-78	11-06-78	11-06-78	11-06-78	11-06-78
01-16-79	01-16-79	01-16-79	01-18-79	01-18-79

All laboratory analyses completed by Aqualab, Inc. were subject to review and verification procedures as outlined in the Aqualab, Inc. Quality Assurance Manual.

To identify each high-volume particulate sample, a bound notebook was maintained in the Centralized Meteorological Instrumentation Laboratory in the Dames & Moore Park Ridge, Illinois office. Entries consisted of the filter identification number and pre- and post-sampling weights. This information was also included on the filter identification label on the storage bag for each filter. Visual inspection of the filter for abnormalities was conducted and comments were recorded in the notebook. After weighing the exposed filters, they were arranged and stored by identification number, which corresponded to the date the sample was collected.

Pertinent sample history and analytical data for each particulate sample were recorded on standard laboratory sheets. The microscope slides prepared for the analysis of these samples were fixed with a permanent identification label. These slides were then organized and stored in a container labeled with a description of the contents.

To maintain proficiency and consistency in the analysis procedure for particulate characterization, each time a set of samples was analyzed the previously analyzed samples were reviewed by reexamining the slides prepared from the previous samples. In addition, an independent analysis of one sample was provided by S. Palenik of Walter C. McCrone Associates, Inc.

Data Analyses - Calculations of the TSP concentrations were performed with a verified computer program. Input data to the program were spot checked for accuracy by a Dames & Moore employee other than the original investigator. The highest observed concentration each month was reverified by checking all input data, visually inspecting the exposed filter for any abnormalities, and reweighing the exposed filter to verify its accuracy.

The meteorological data were keypunched and then processed by an editing program to identify outliers and questionable data based on trends and climatologically reasonable values. Each datum identified by the editing program was then checked from the original strip chart recording to determine its validity.

Accuracy and Precision - This monitoring was performed before the U.S. EPA required the calculation of accuracy and precision statistics (U.S. EPA, 1979). Therefore, accuracy audits and collocated sampling were not performed for this purpose. The DNR did audit the samplers as previously described, which fulfilled the intent, if not the specifics, of the EPA accuracy audit program.

2.1.2 Climatology

The climate of the regional study area is continental, modified slightly by Lake Michigan 129 km (80 miles) to the east and Lake Superior 150 km (93 miles) to the north. During most of the year, this area is in the path of eastwardly moving pressure systems in the prevailing westerly air movements. Terrain in the vicinity of the site area is rolling but does not greatly inhibit air movement.

Temperatures are mild to warm during the summer and cold during the winter. Summer days are generally mild; however, temperatures may exceed 35°C (95°F) on the hottest few days of the year during the infrequent occasions when tropical air fully penetrates the region. Summer nights are generally cool, with temperatures dropping to 10 to 16°C (50 to 60°F). Winter temperatures generally range from -18 to -4°C (0 to 25°F) and occasionally will be below -34°C (-30°F) (National Oceanic and Atmospheric Administration, 1974).

Moisture content of the air is generally moderate during the summer and low during the winter. Humidity, cloudiness, and fog incidence are noticeably higher than they would be in the absence of Lakes Superior and Michigan, but the lakes are too far from the environmental study area to appreciably affect precipitation.

The heaviest precipitation occurs during early summer and the least during mid-winter, averaging 776.7 mm (30.58 inches) per year (Black, 1981). Precipitation is caused by both localized thunderstorms and frontal systems during summer. During winter, precipitation, mostly in the form of snow, is caused exclusively by passing weather systems. The stronger of these systems usually passes too far south of the environmental study area to cause precipitation, and the systems that do pass near the site usually result in snowfall that, while it occurs rather frequently, is usually quite light because of the lack of atmospheric moisture. The heaviest snowstorms often occur during March when the stronger storms move farther north than they do during mid-winter. Snowfall averages between 1,016 and 1,524 mm (40 and 60 inches) per year (Environmental Science Services Administration [ESSA], 1968).

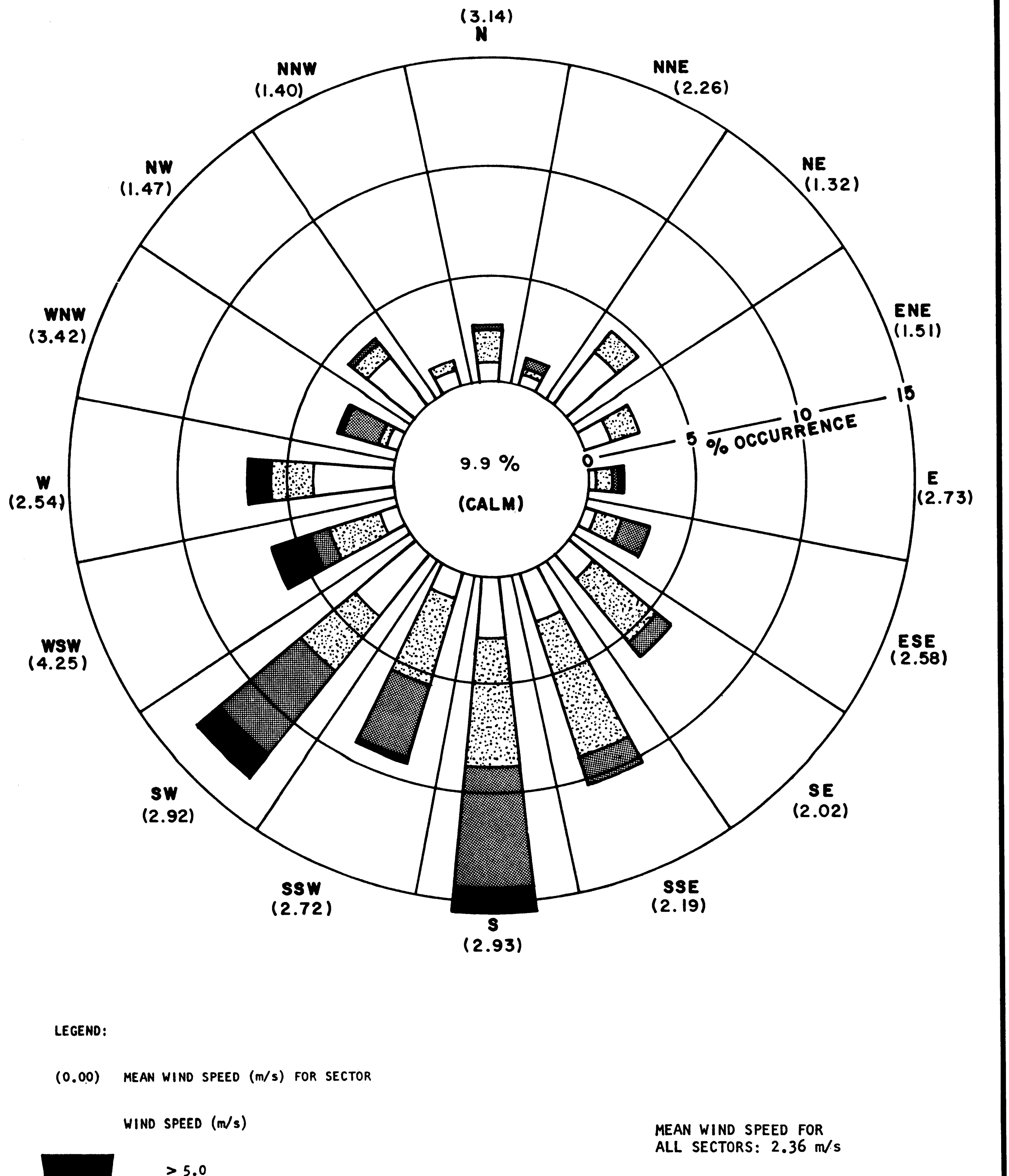
There are no long-term precipitation chemistry records for Wisconsin. In the autumn of 1979, the DNR initiated precipitation event monitoring at several locations around Rhinelander. The results, through March 1980, have been pH values ranging from 3.6 to 6.1 with most values (80 percent) at pH of 4.6 or less (Wisconsin DNR, 1980). Precipitation pH below 4.6 has been shown to cause damage to lakes in Ontario, Scandanavia, and New York (Wisconsin DNR, 1980). In February 1980, M. Gage of Nicolet College collected three replicate snow samples from each of 20 lake surfaces. The pH of the snowpack was found to range from 4.2 to 4.5 (Wisconsin DNR, 1980).

2.1.3 Meteorology

2.1.3.1 Wind Speed and Direction

Wind roses were used to depict the frequency of occurrence of wind direction and speed in each of 16 compass directions. Figures 2.1-2 through 2.1-8 present wind roses at Station 1 by calendar quarters from April 1977 through December 1978. An annual wind rose (January through December 1978) is presented on Figure 2.1-9.

The wind roses for the individual quarters (Figures 2.1-2 through 2.1-8) show substantial variability in the occurrence of wind directions from quarter to quarter. Even the same quarters in 1977 and 1978 show differences in the observed wind patterns. This is to be expected since weather patterns in any one period (month, quarter, or year) can vary from previous periods. However, some patterns were evident. High frequencies of south through southwest winds were observed in most quarters. West through northwest winds tended to predominate in three of the quarters (July-September 1977, October-December 1977, and January-March 1978). Winds from the easterly directions were minimal except for northeast, which were noticeable in five of



EXXON MINERALS COMPANY
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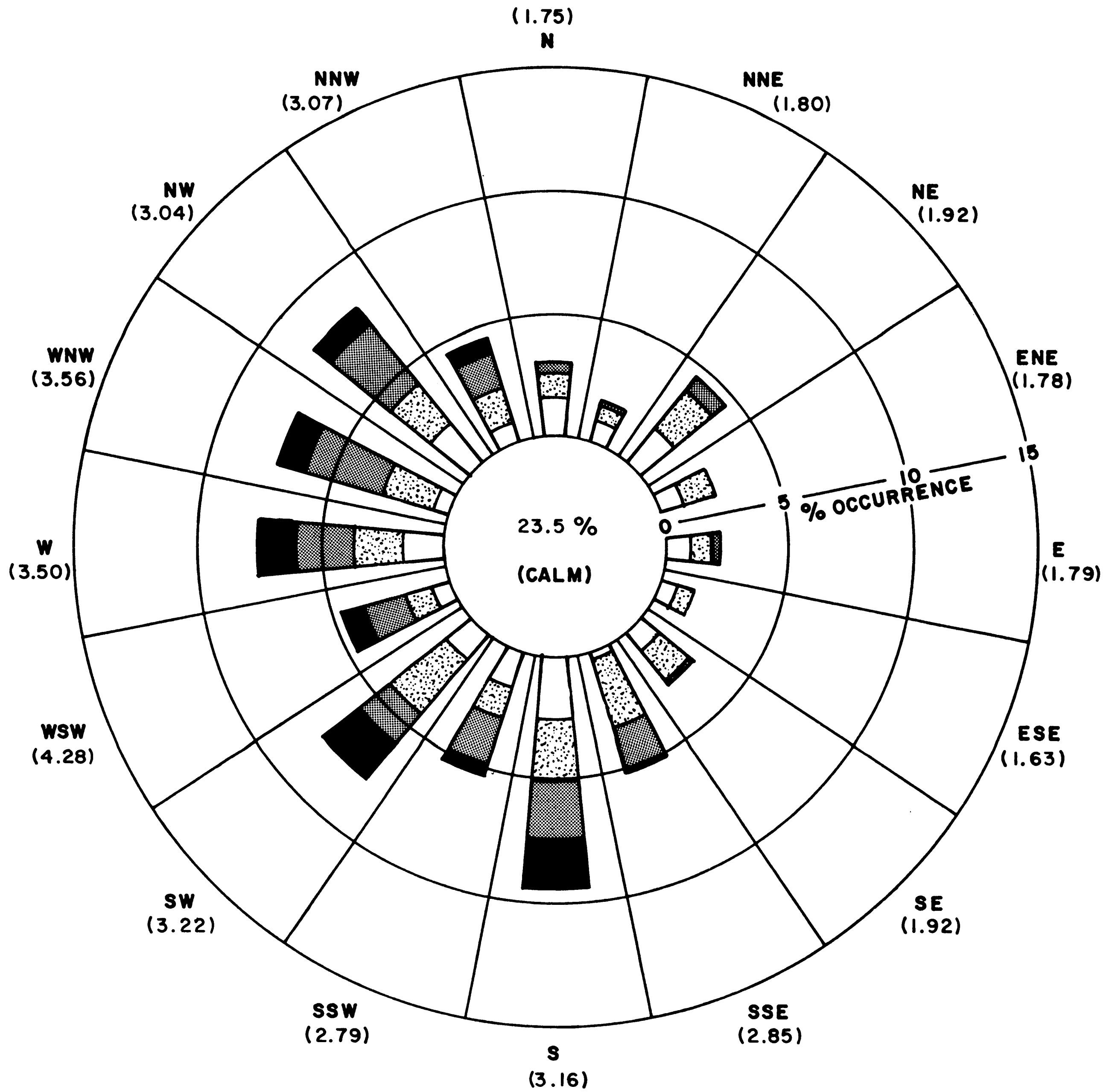
ENVIRONMENTAL STUDY AREA WIND ROSE
APRIL-JUNE, 1977
STATION 1

DAMES & MOORE

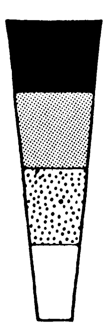
FIGURE 2.1-2



LEGEND:

(0.00) MEAN WIND SPEED (m/s) FOR SECTOR

WIND SPEED (m/s)



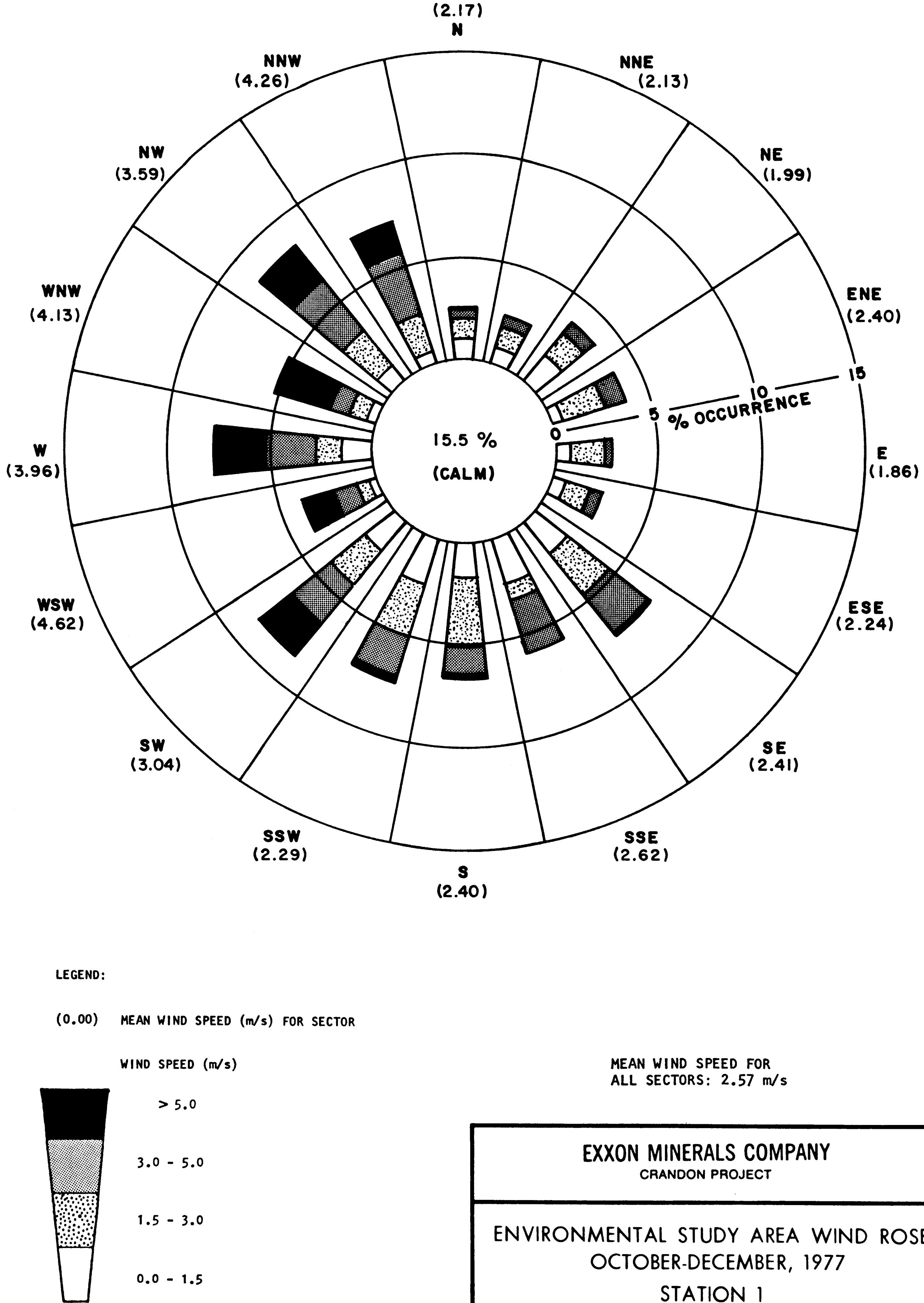
MEAN WIND SPEED FOR
ALL SECTORS: 2.24 m/s

EXXON MINERALS COMPANY
CRANDON PROJECT

ENVIRONMENTAL STUDY AREA WIND ROSE
JULY-SEPTEMBER, 1977
STATION 1

DAMES & MOORE

FIGURE 2.1-3



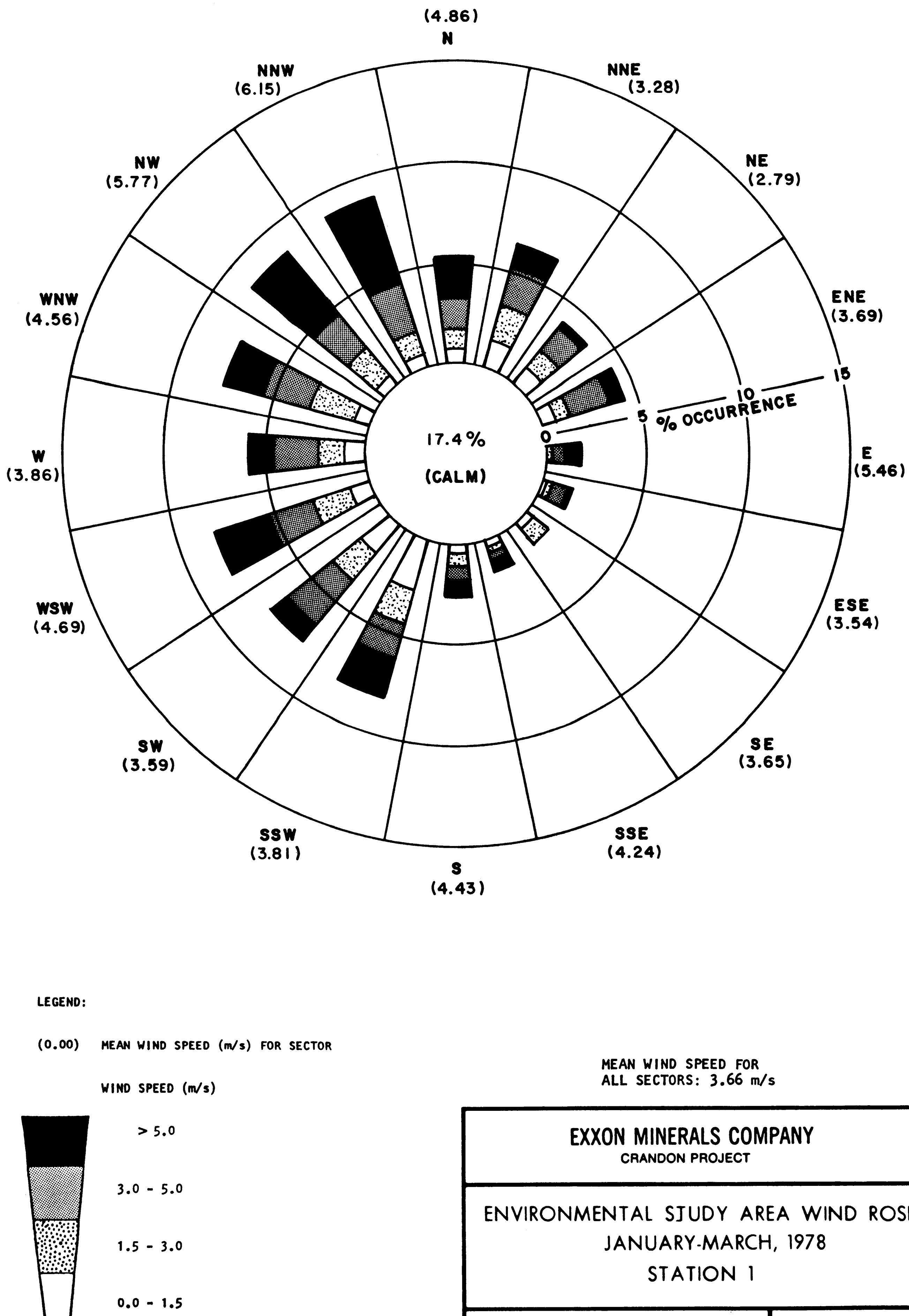
MEAN WIND SPEED FOR ALL SECTORS: 2.57 m/s

EXXON MINERALS COMPANY
CRANDON PROJECT

ENVIRONMENTAL STUDY AREA WIND ROSE
OCTOBER-DECEMBER, 1977
STATION 1

DAMES & MOORE

FIGURE 2.1-4



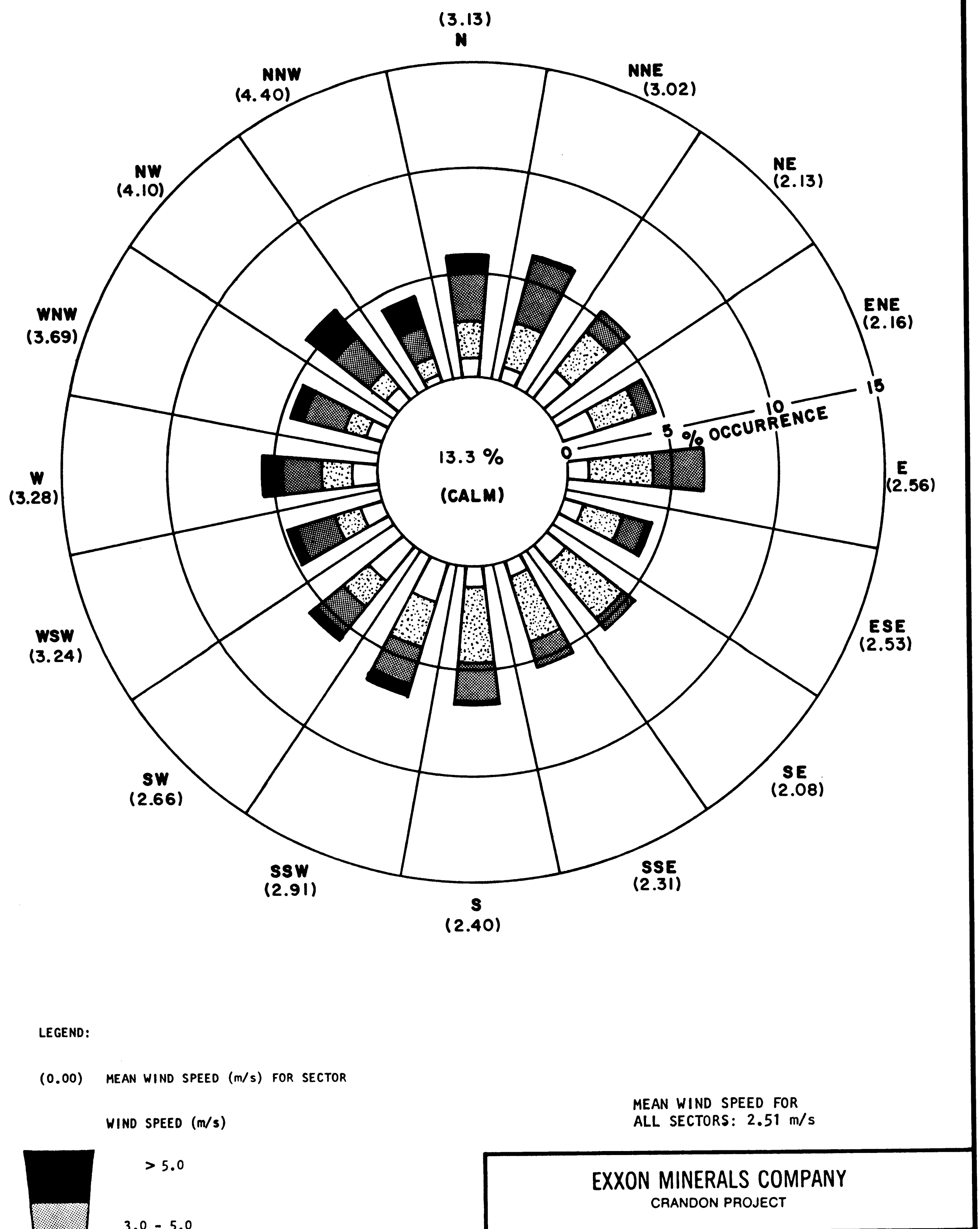
MEAN WIND SPEED FOR ALL SECTORS: 3.66 m/s

EXXON MINERALS COMPANY
CRANDON PROJECT

ENVIRONMENTAL STUDY AREA WIND ROSE
JANUARY-MARCH, 1978
STATION 1

DAMES & MOORE

FIGURE 2.1-5

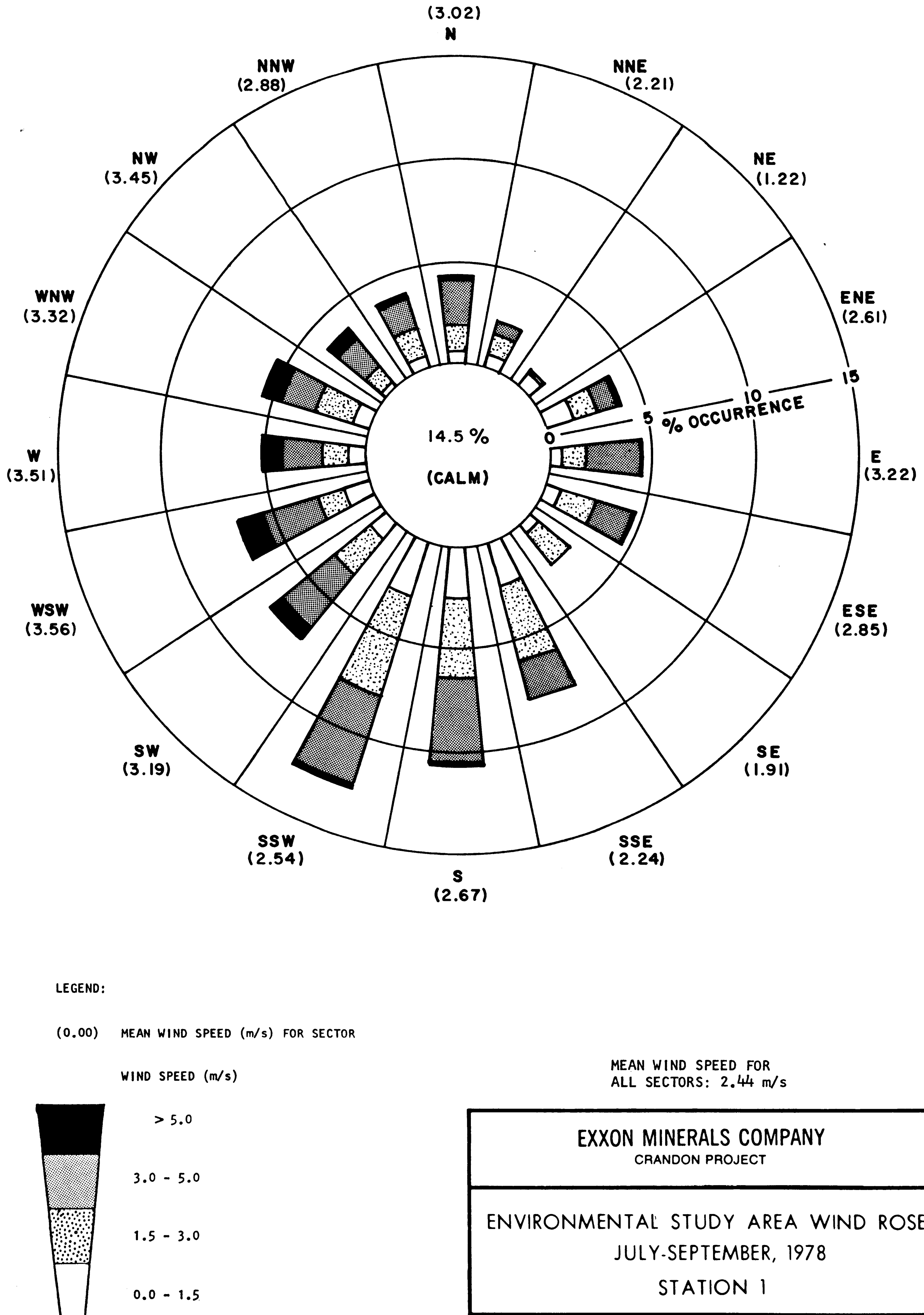


EXXON MINERALS COMPANY
CRANDON PROJECT

ENVIRONMENTAL STUDY AREA WIND ROSE
APRIL-JUNE, 1978
STATION 1

DAMES & MOORE

FIGURE 2.1-6



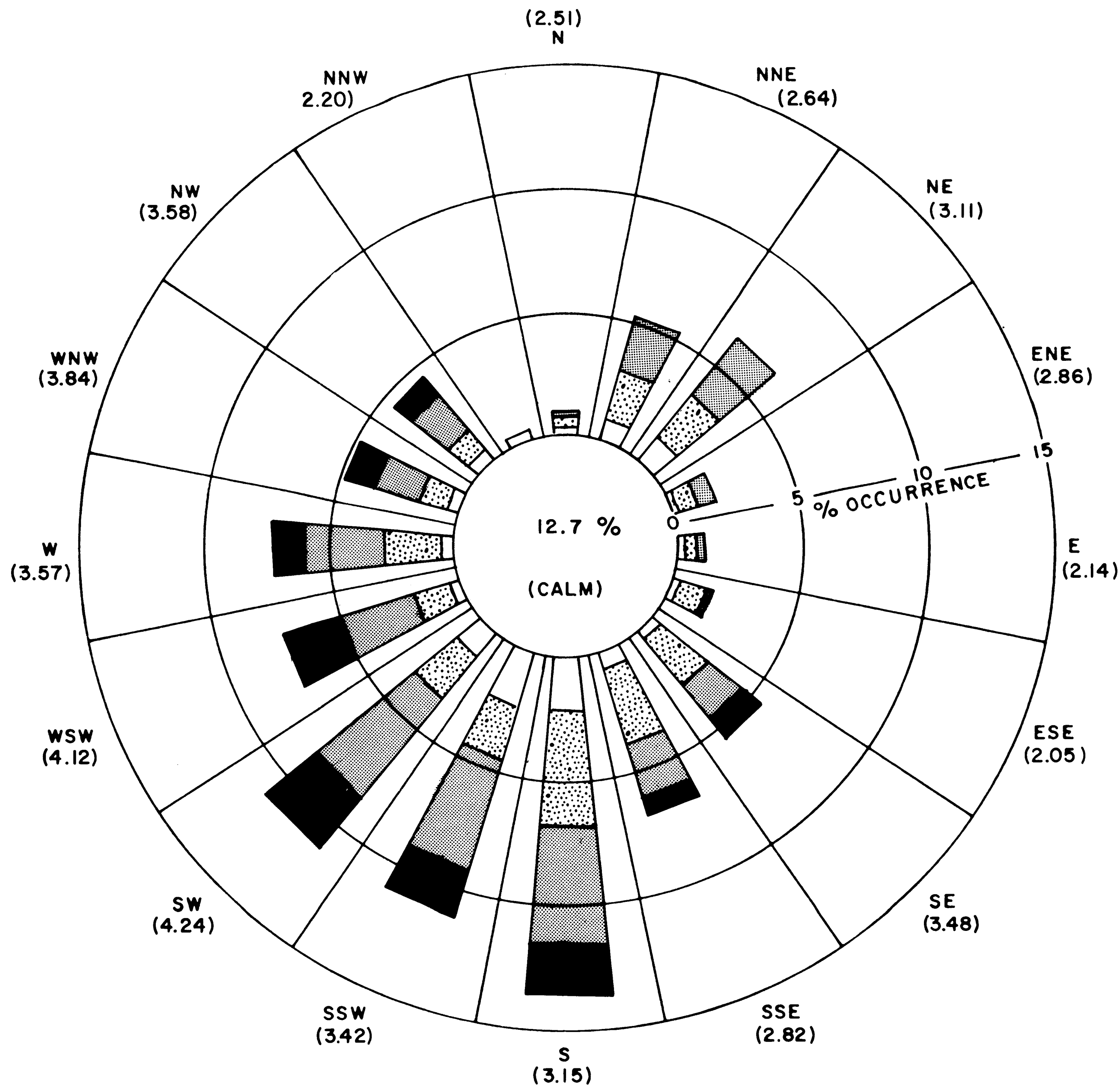
MEAN WIND SPEED FOR
ALL SECTORS: 2.44 m/s

EXXON MINERALS COMPANY
CRANDON PROJECT

ENVIRONMENTAL STUDY AREA WIND ROSE
JULY-SEPTEMBER, 1978
STATION 1

DAMES & MOORE

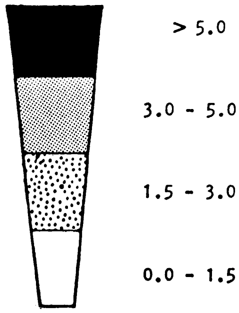
FIGURE 2.17



LEGEND:

(0.00) MEAN WIND SPEED (m/s) FOR SECTOR

WIND SPEED (m/s)



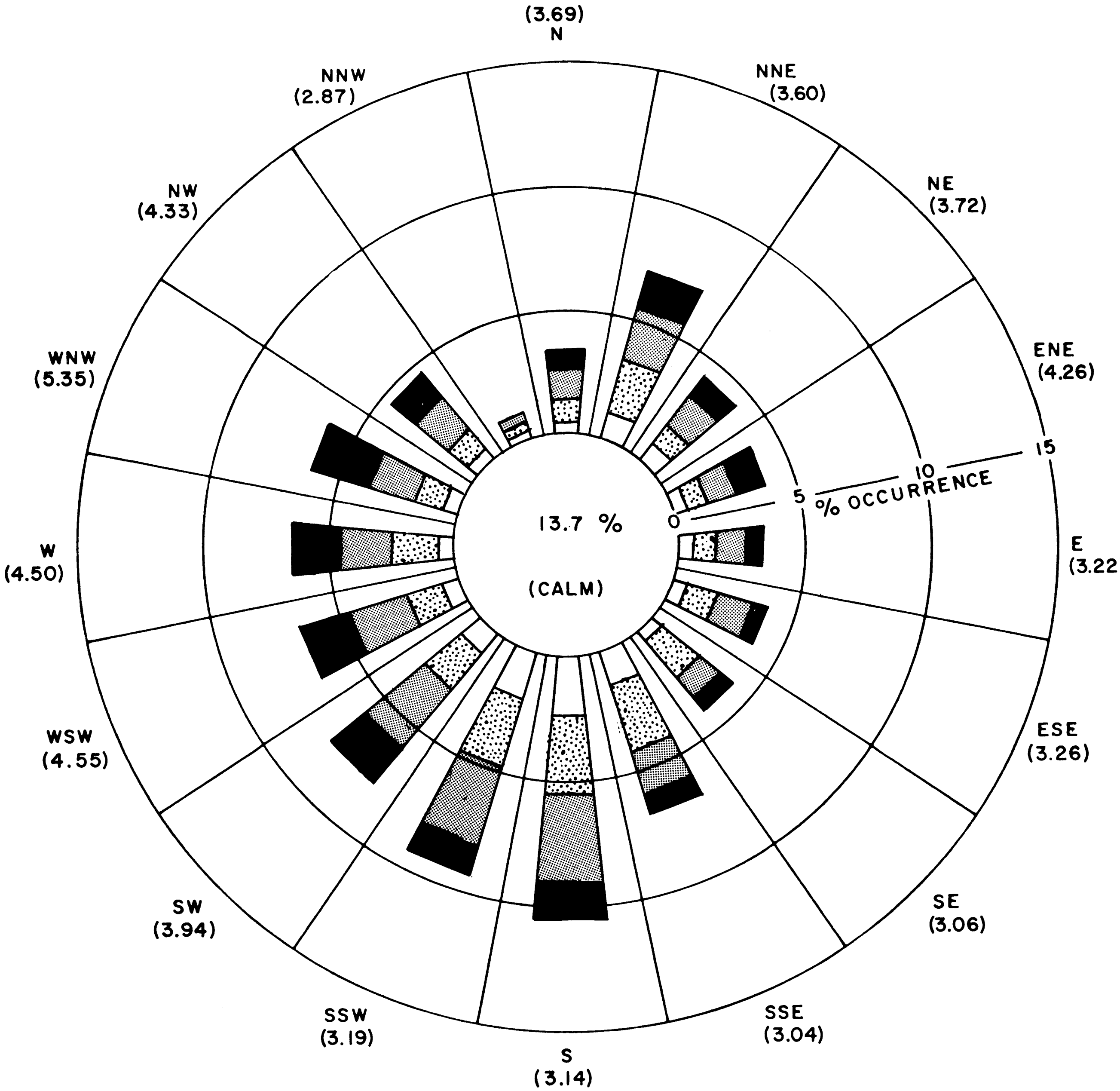
MEAN WIND SPEED FOR
ALL SECTORS: 2.98 m/s

EXXON MINERALS COMPANY
CRANDON PROJECT

ENVIRONMENTAL STUDY AREA WIND ROSE
OCTOBER-DECEMBER, 1978
STATION 1

DAMES & MOORE

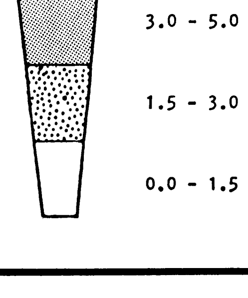
FIGURE 2.1-8



LEGEND:

(0.00) MEAN WIND SPEED (m/s) FOR SECTOR

WIND SPEED (m/s)



MEAN WIND SPEED FOR
ALL SECTORS: 3.24 m/s

EXXON MINERALS COMPANY
CRANDON PROJECT

ENVIRONMENTAL STUDY AREA WIND ROSE
JANUARY-DECEMBER, 1978
STATION 1

DAMES & MOORE

FIGURE 2.1-9

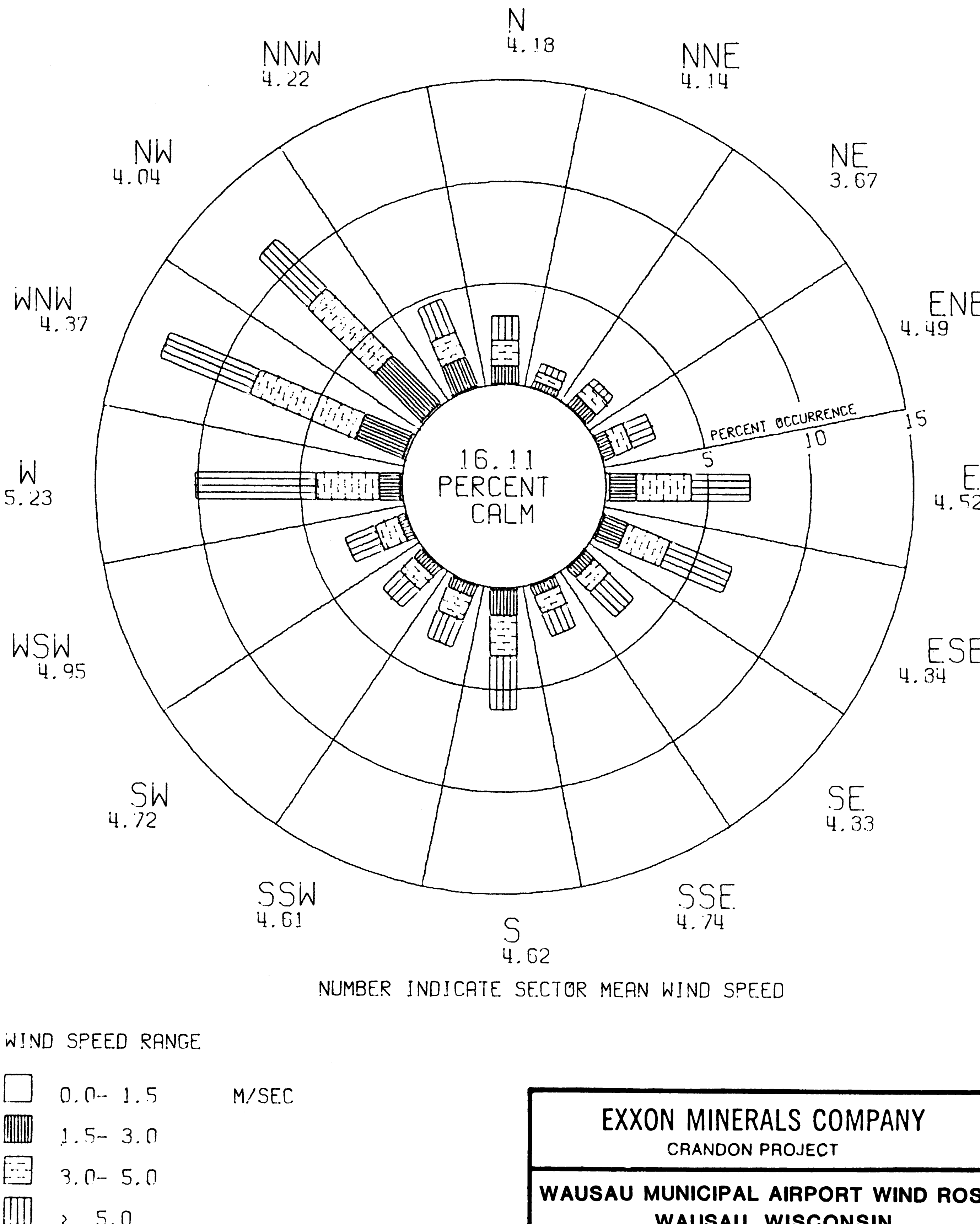
the quarters (April-June 1977, July-September 1977, January-March 1978, April-June 1978, and October-December 1978).

The annual wind rose for 1978 (Figure 2.1-9) indicates the predominant wind direction was from the south (10.3 percent of the time). South-southwest, southwest, and north-northeast were the next most frequently observed directions (9.0, 7.5, and 7.0 percent, respectively).

Mean wind speed observed at Station 1 ranged from 2.24 to 3.66 m/s (5.0 to 8.2 miles per hour) for the individual quarters and averaged 3.24 m/s (7.2 miles per hour) for the 1978 calendar year. Calm wind (less than 0.45 m/s [1.0 mile per hour]) occurred 13.7 percent of the time in 1978, and was almost exclusively observed at night.

The Wausau Municipal Airport at Wausau, Wisconsin is the nearest weather recording station with a long-term continuous recording of wind speed, direction, and other meteorological parameters. It is located 100 km (63 miles) southwest of the environmental study area. Five years of Wausau wind data (1973-1977) have been summarized for comparison to the data observed in the environmental study area.

Quarterly and annual wind roses for 5 years of Wausau data are presented in Figures 2.1-10 through 2.1-14. The quarterly wind roses for Wausau are similar to those for the environmental study area except that in some quarters more southwesterly and northeasterly winds were observed in the environmental study area. The annual wind rose for Wausau (Figure 2.1-14) shows the wind direction frequency of occurrence to be more northwesterly, less southerly, and less northeasterly than the study area annual wind rose (Figure 2.1-9). Mean wind speeds were similar at both sites with Wausau



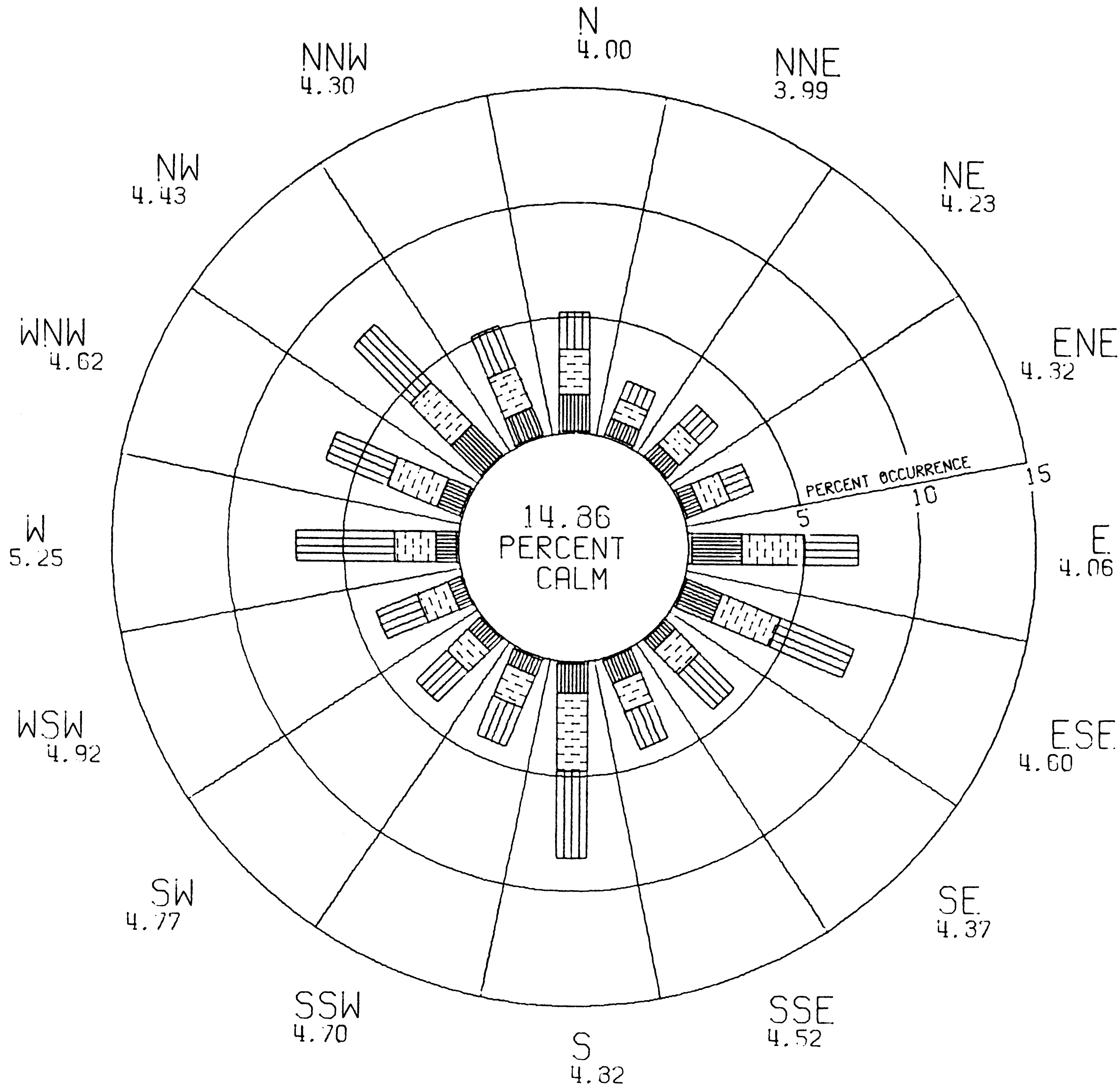
EXXON MINERALS COMPANY

CRANDON PROJECT

WAUSAU MUNICIPAL AIRPORT WIND ROSE
WAUSAU, WISCONSIN
JANUARY THROUGH MARCH,
1973 - 1977

DAMES & MOORE

FIGURE 2.1-10



NUMBER INDICATE SECTOR MEAN WIND SPEED

WIND SPEED RANGE

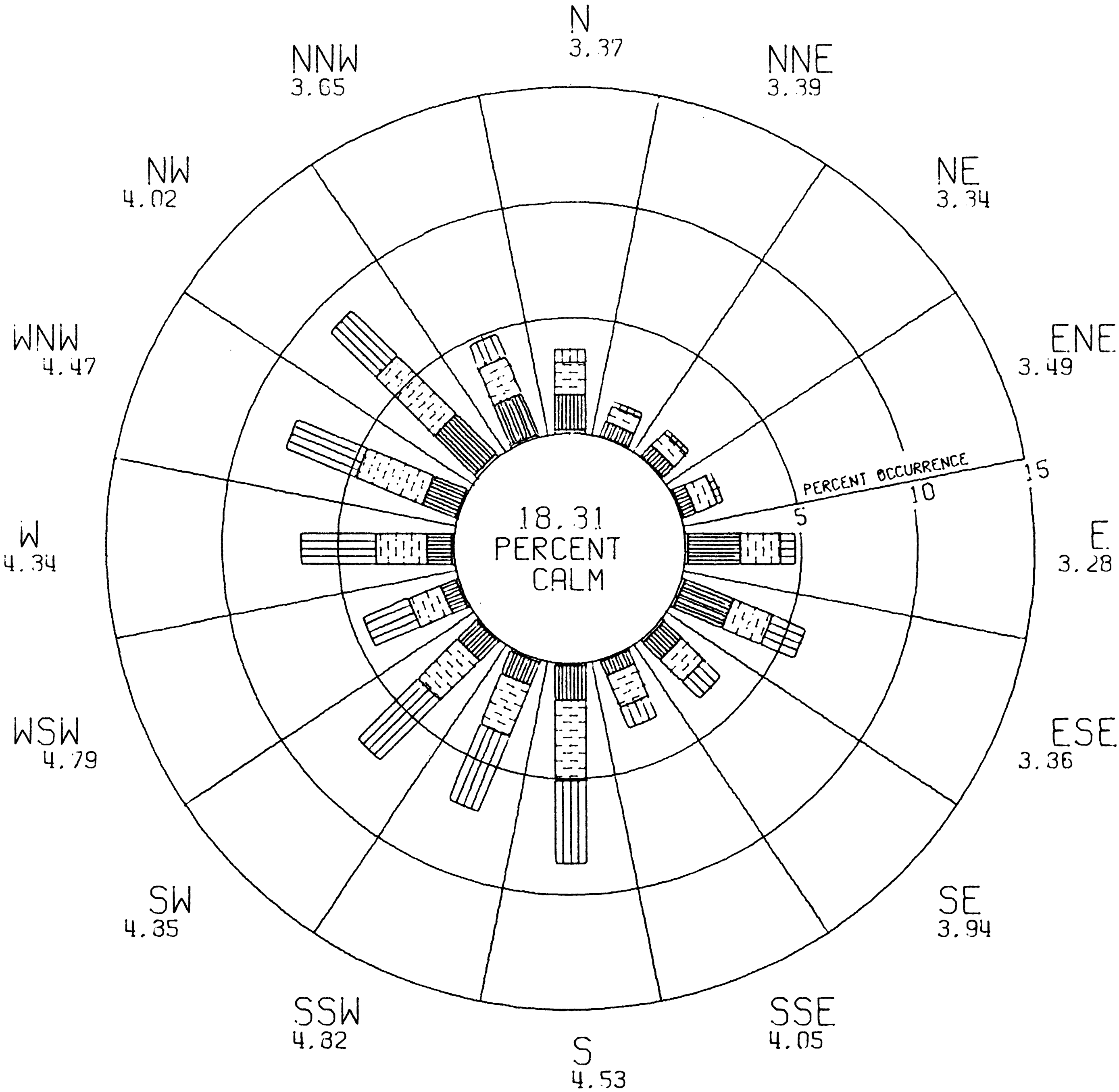
- 0.0- 1.5 M/SEC
- 1.5- 3.0
- 3.0- 5.0
- > 5.0

EXXON MINERALS COMPANY
CRANDON PROJECT

WAUSAU MUNICIPAL AIRPORT WIND ROSE
WAUSAU, WISCONSIN
APRIL THROUGH JUNE,
1973 - 1977

DAMES & MOORE

FIGURE 2.1-11



NUMBER INDICATE SECTOR MEAN WIND SPEED

WIND SPEED RANGE

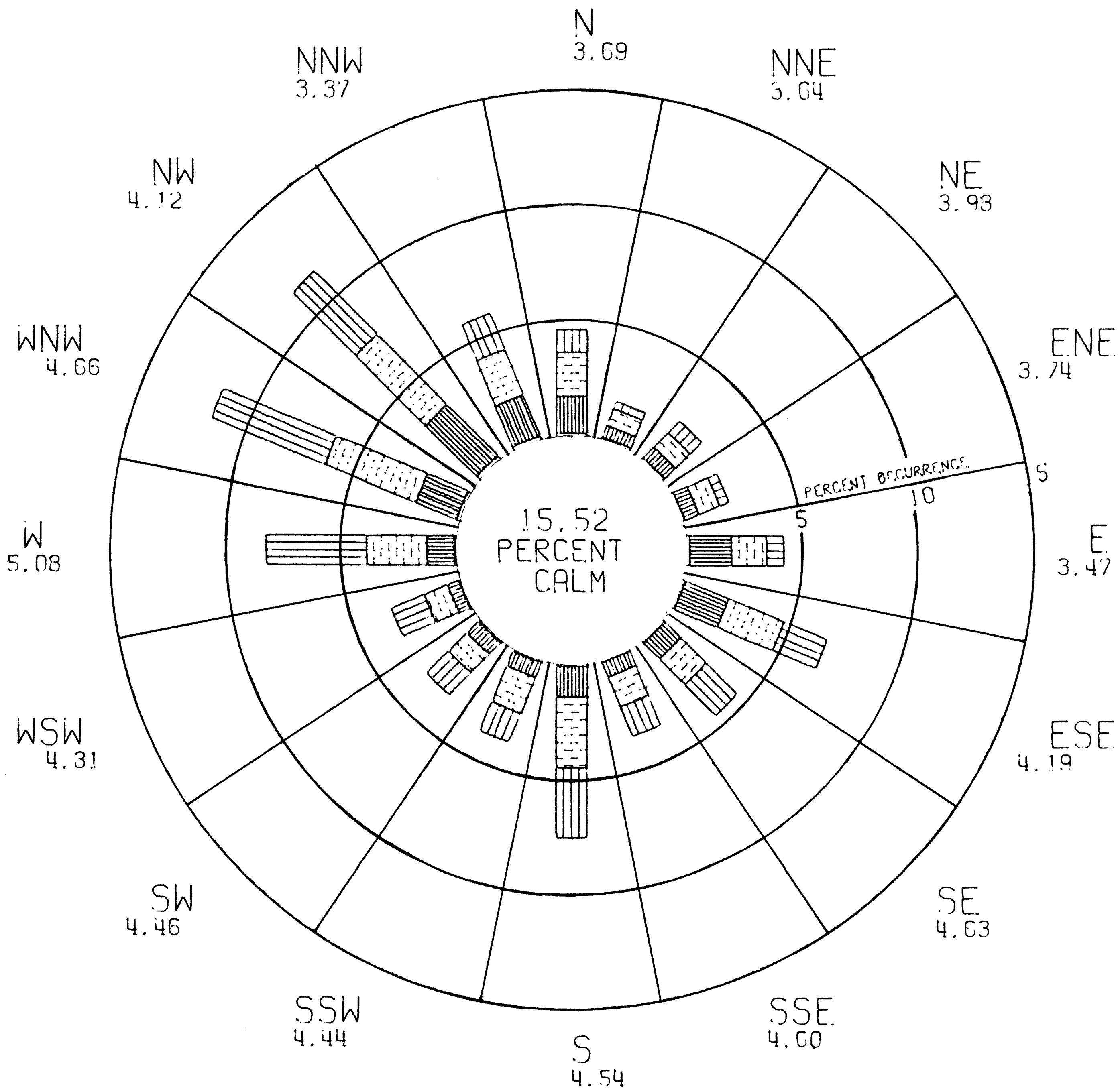
- 0.0- 1.5 M/SEC
- 1.5- 3.0
- 3.0- 5.0
- › 5.0

EXXON MINERALS COMPANY
CRANDON PROJECT

WAUSAU MUNICIPAL AIRPORT WIND ROSE
WAUSAU, WISCONSIN
JULY THROUGH SEPTEMBER,
1973 - 1977

DAMES & MOORE

FIGURE 2.1-12



NUMBER INDICATE SECTOR MEAN WIND SPEED

WIND SPEED RANGE

0.0- 1.5 M/SEC

1.5- 3.0

3.0- 5.0

> 5.0

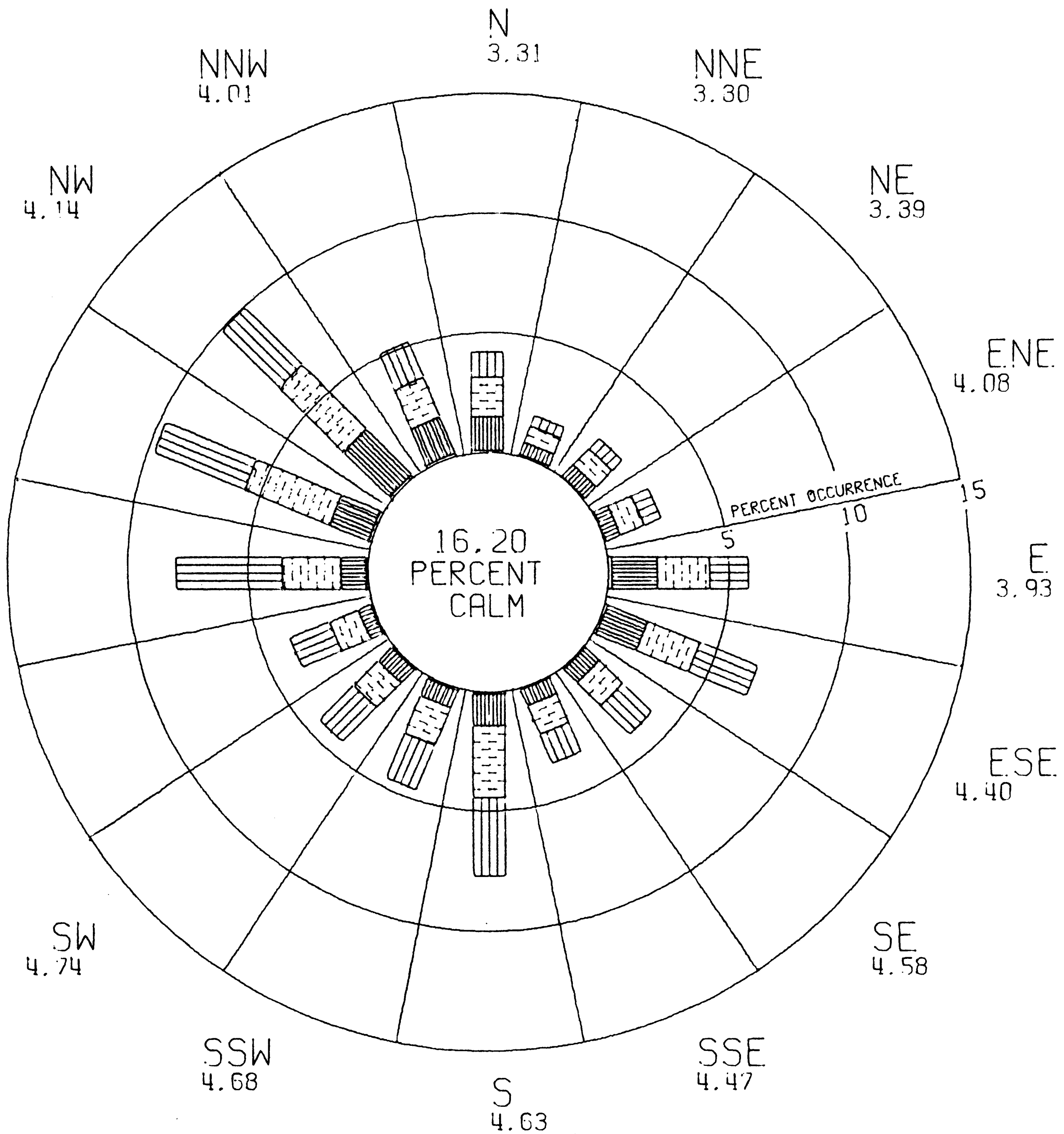
EXXON MINERALS COMPANY

CRANDON PROJECT

WAUSAU MUNICIPAL AIRPORT WIND ROSE
WAUSAU, WISCONSIN
OCTOBER THROUGH DECEMBER,
1973 - 1977

DAMES & MOORE

FIGURE 2.1-13



NUMBER INDICATE SECTOR MEAN WIND SPEED

WIND SPEED RANGE

(blank)	0.0- 1.5	M/SEC
(vertical fine hatch)	1.5- 3.0	
(dashed)	3.0- 5.0	
(vertical hatch)	› 5.0	

EXXON MINERALS COMPANY
CRANDON PROJECT

WAUSAU MUNICIPAL AIRPORT WIND ROSE
WAUSAU, WISCONSIN
JANUARY THROUGH DECEMBER,
1973 - 1977

DAMES & MOORE

FIGURE 2.1-14

averaging 3.70 m/s (8.28 miles per hour) and the environmental study area 3.24 m/s (7.25 miles per hour). Both sites had very high frequency of calm winds with Wausau at 16.2 percent and the study area at 13.7 percent. These calm frequencies are probably more identical than the numbers indicate because calm in the Wausau data is defined as wind less than 1.0 m/s (2.2 miles per hour) and calm in the environmental study area data is defined as wind less than 0.45 m/s (1.0 miles per hour).

2.1.3.2 Temperature

A summary of the observed temperatures from both Station 1 and Nicolet College, located in Rhinelander, 45 km (28 miles) west-northwest of the environmental study area, is presented in Table 2.1-4. Mean monthly temperatures at Station 1 were 1.5°C (2.7°F) colder than those at Nicolet College. Except for the spring of 1977, all seasonal temperatures measured at Station 1 were colder than the long-term (1931-1960) averages for northern Wisconsin (ESSA, 1968).

The highest temperatures recorded were 32.8°C (91°F) at Station 1 and 35.0°C (95°F) at Nicolet College, both during July 1977. The lowest temperatures were -29.4°C (-21°F) in March 1978 at Station 1 and -31.0°C (-24°F) at Nicolet College during December 1977 and again during February 1978. The highest and lowest recorded temperatures in the region are approximately 40°C (104°F) and -40°C (-40°F), respectively (ESSA, 1968).

For comparison to long-term averages, Table 2.1-5 presents average temperatures for Nicolet College and Wausau, Wisconsin. The temperatures measured at Station 1 were 1.5°C (2.7°F) colder than the long-term average at

TABLE 2.1-4

TEMPERATURES (°C) MEASURED AT STATION 1 IN THE ENVIRONMENTAL STUDY AREA AND AT NICOLET COLLEGE, RHINELANDER, WISCONSIN (APRIL 1977 - DECEMBER 1978)

		STATION 1					NICOLET COLLEGE[a]				
YEAR	MONTH	MEAN DAILY MAXIMUM	MEAN DAILY MINIMUM	MONTHLY MEAN	HIGHEST	LOWEST	MEAN DAILY MAXIMUM	MEAN DAILY MINIMUM	MONTHLY MEAN	HIGHEST	LOWEST
1977	Apr.	12.2	- 0.4	6.8	25.6	-14.4	14.4	1.9	8.2	27.3	-14.0
	May	23.3	8.5	16.4	29.4	- 4.4	24.4	10.1	17.3	29.8	- 2.7
	Jun.	--	--	--	--	--	22.7	11.1	16.9	30.4	5.4
	Jul.	25.6	13.5	20.3	32.8	5.6	26.7	16.7	21.7	35.0	9.2
	Aug.	20.8	7.9	15.5	30.0	2.2	21.1	11.7	16.4	30.5	5.4
	Sep.	17.1	8.8	13.1	22.8	2.2	17.6	11.0	14.3	26.2	2.5
	Oct.	11.5	0.7	6.1	18.3	- 3.9	14.0	3.1	8.6	20.4	- 2.3
	Nov.	2.9	- 4.6	- 0.5	13.6	-19.4	4.6	- 3.2	0.7	16.1	-20.5
	Dec.	- 5.1	-15.0	- 9.7	0.3	-21.7[b]	- 4.6	-12.6	- 8.6	5.1	-31.0
1978	Jan.	- 6.5	-17.9	-12.9	- 3.9	-28.9	- 6.1	-16.7	-11.2	1.2	-27.1
	Feb.	- 5.9	-20.2	-12.7	- 0.8	-29.2	- 5.3	-18.9	-12.1	1.4	-31.0
	Mar.	1.2	-12.5	- 5.0	10.6	-29.4	2.4	-10.3	- 3.9	1.2	-27.8
	Apr.	7.6	- 2.5	2.8	20.0	- 6.6	9.4	- 1.3	4.0	21.9	- 7.1
	May	20.2	5.5	13.6	28.9	0.0	19.8	6.7	13.3	29.8	- 4.3
	Jun.	21.0	6.8	14.5	29.4	- 1.7	21.9	10.8	16.4	29.2	1.2
	Jul .	20.9	9.4	16.0	28.9	1.1	22.8	13.9	18.3	28.9	5.5
	Aug.	23.1	9.8	16.7	30.0	2.2	23.9	13.9	18.9	31.1	6.7
	Sep.	18.4	6.8	12.2	30.6	- 5.0	20.5	10.5	15.5	31.1	1.1
	Oct.	9.0	- 1.1	3.9	18.9	- 1.1	11.1	3.3	7.2	20.6	- 3.3
	Nov.	6.2	- 5.5	0.4	21.1	- 5.5[b]	3.8	- 5.5	- 0.8	20.6	-22.7
	Dec.	- 8.6	-18.7	-13.6	- 8.6	-18.7	- 6.1	-15.0	-10.5	1.6	-26.1

[a]Black, 1978.

[b]On-site sensor out of service on the day the lowest temperature was recorded at Nicolet College.

TABLE 2.1-5

LONG-TERM AVERAGE TEMPERATURES (°C) AT NICOLET COLLEGE, RHINELANDER, WISCONSIN AND WAUSAU MUNICIPAL AIRPORT, WAUSAU, WISCONSIN

	NICOLET COLLEGE (1908-1980)[a]			WAUSAU MUNICIPAL AIRPORT (1973-1977)[b]				
MONTH	MEAN DAILY MAXIMUM	MEAN DAILY MINIMUM	MONTHLY MEAN	MEAN DAILY MAXIMUM	MEAN DAILY MINIMUM	MONTHLY MEAN	HIGHEST	LOWEST
Jan.	- 6.1	-17.2	-11.7	- 6.0	-16.7	-11.3	11.1	-31.7
Feb.	- 3.3	-15.6	- 9.4	- 1.5	-12.7	- 7.1	12.2	-31.7
Mar.	2.8	- 9.4	- 3.3	4.1	- 5.8	- 0.8	18.3	-23.3
Apr.	11.1	- 0.6	5.3	12.6	0.9	6.8	28.3	-14.4
May	18.3	6.1	12.2	19.8	7.2	13.5	31.1	- 2.8
Jun.	23.9	11.1	17.5	24.5	12.0	18.3	32.8	1.7
Jul.	24.4	12.2	18.3	26.1	14.6	22.0	36.1	7.2
Aug.	25.0	12.8	18.9	25.7	13.6	19.7	36.1	4.4
Sep.	19.4	7.8	13.6	19.7	8.3	14.0	34.4	- 2.2
Oct.	14.4	3.9	8.9	14.4	3.0	8.7	32.8	- 8.9
Nov.	4.4	- 3.9	0.3	4.6	- 4.3	0.2	21.7	-23.9
Dec.	- 3.6	-12.8	- 8.0	- 3.8	-13.0	- 8.3	10.0	-27.8

[a]Black, 1981.

[b]NOAA, 1973-1977b.

Nicolet College and 2.7°C (4.9°F) colder than the long-term average at Wausau. During the period of monitoring at Station 1, Nicolet College temperatures were 0.1°C (0.2°F) colder than the long-term average for Nicolet College.

2.1.3.3 Precipitation

Precipitation was measured at Station 1 from November 1977 through December 1978 (Table 2.1-6). Difficulties in operating a remote station precluded obtaining a continuous record during this period. The rain gauge at Station 1 recorded 60 percent of the hourly precipitation totals during the 14-month monitoring period. These data were used in making comparisons with the precipitation records at Nicolet College.

A summary of the monthly precipitation from Nicolet College is presented in Table 2.1-6. The data from Station 1 and Nicolet College on days when the rain gauge at Station 1 was operating were used in a statistical regression analysis of the monthly totals. The results of this analysis indicated that precipitation at Station 1 was approximately 37 to 82 percent of that recorded at Nicolet College (Figure 2.1-15). However, considering the variability of precipitation in short-term records of 1 or 2 years, it is likely that over a period of several years the precipitation in the environmental study area would approach the average recorded at Nicolet College.

Precipitation at Nicolet College during the 1978 calendar year totaled 747.7 mm (29.44 inches), which approximates the long-term (1908-1980) annual average of 776.7 mm (30.58 inches) (Black, 1981). The winter season (December 1977 through March 1978) was one of the driest on record, with the total precipitation in March (2.5 mm [0.10 inch] at Nicolet College) being the

TABLE 2.1-6

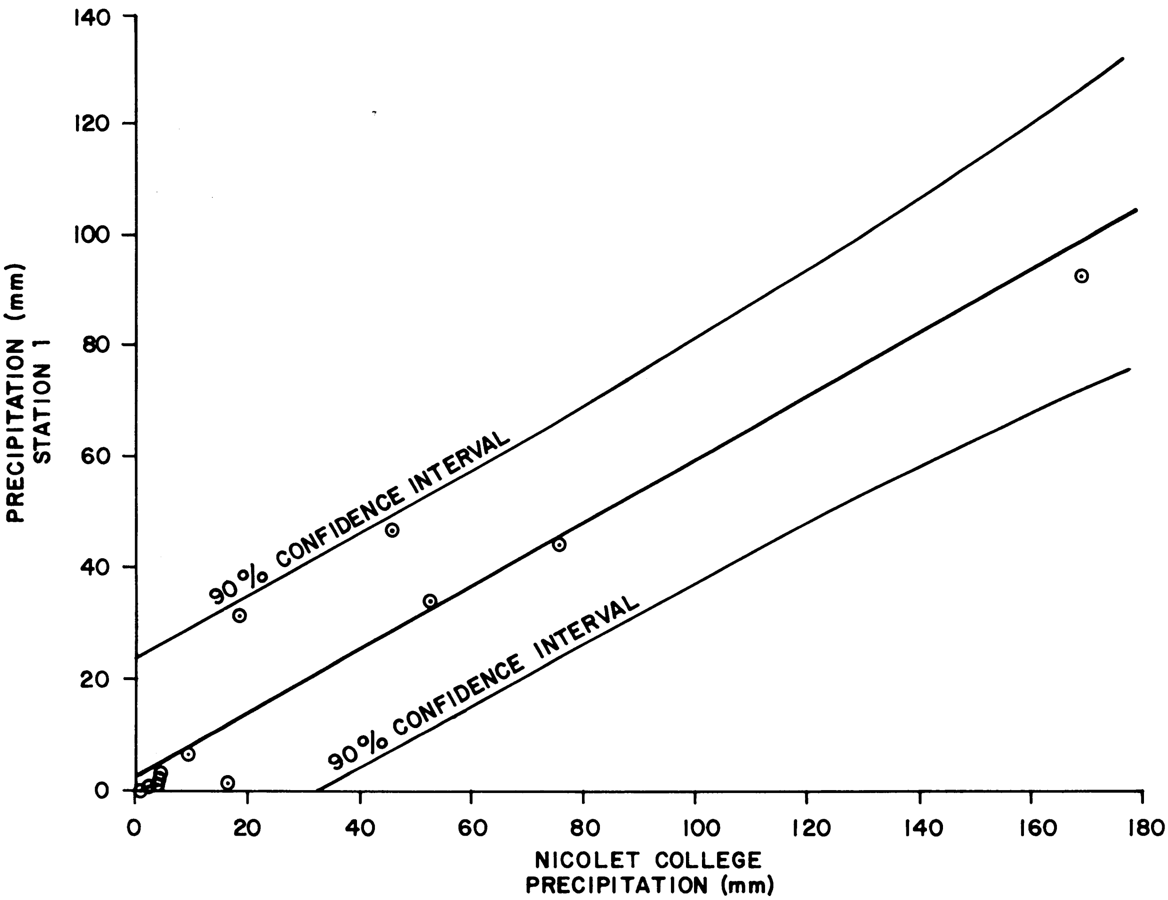
SUMMARY OF MONTHLY PRECIPITATION TOTALS
STATION 1 AND NICOLET COLLEGE
(NOVEMBER 1977 - DECEMBER 1978)

MONTH	STATION 1 DAYS OF RECORD	TOTAL PRECIPITATION (mm)[a] STATION 1	TOTAL PRECIPITATION (mm)[a] NICOLET COLLEGE[b]	NICOLET COLLEGE MONTHLY TOTALS(mm)[b]
Nov. 1977	27	44.2	75.7	86.9
Dec.	8	1.3	3.8	18.0
Jan. 1978	13	0.0	0.2	5.3
Feb.	23	0.8	4.6	5.3
Mar.	30	0.2	2.5	2.5[c]
Apr.	28	46.5	46.0	57.6
May	14	31.2	18.3	85.8
Jun.	0	0.0	0.0	80.5
Jul.	5	1.8	14.0	161.3
Aug.	30	93.2	169.7	169.9
Sep.	19	33.5	52.6	104.6
Oct.	8	2.3	3.8	20.8
Nov.	17	7.1	9.4	34.8
Dec.	18	0.0	1.3	19.3

[a]Total precipitation at this location measured for days of record at Station 1.

[b]Black, 1978.

[c]Record minimum precipitation (since 1908).



EXXON MINERALS COMPANY
CRANDON PROJECT

REGRESSION ANALYSIS OF MONTHLY PRECIPITATION TOTALS AT NICOLET COLLEGE AND STATION 1 (mm/MONTH)

DAMES & MOORE

FIGURE 2.1-15

lowest recorded total since 1908. During this month, Station 1 received only 0.2 mm (0.01 inch). Precipitation totals during July and August 1978 were 60 to 80 percent above normal, and the remaining months were near normal.

For comparison to long-term averages, Table 2.1-7 presents the average monthly precipitation totals for Nicolet College and Wausau, Wisconsin. The Wausau annual average precipitation for the 5-year period referenced was 41.9 mm (1.65 inches) less than the 73-year period of record at Nicolet College.

2.1.4 Dispersion Meteorology

A discussion of dispersion meteorology and meteorological data used in air quality modeling for the Crandon Project is presented in the application for an Air Pollution Control permit.

2.1.5 Background Levels

2.1.5.1 Total Suspended Particulates

Total suspended particulate concentrations were monitored at all three stations shown on Figure 2.1-1. Monitoring was initiated at Station 1 in April 1977, was expanded to Stations 2 and 3 in January 1978, and continued at all three stations through December 1978. The TSP concentration data are presented in Appendix 2.1A. At each station the sampler was operated for a 24-hour period every third calendar day in phase with the state-wide sampling schedule (every sixth day) established by the DNR.

The data from this sampling program are summarized in Table 2.1-8 for comparison to the Wisconsin Ambient Air Quality Standards. The highest

TABLE 2.1-7

LONG-TERM AVERAGE PRECIPITATION TOTALS (mm) AT NICOLET COLLEGE, RHINELANDER, WISCONSIN AND WAUSAU MUNICIPAL AIRPORT, WAUSAU, WISCONSIN

MONTH	NICOLET COLLEGE (1908-1980)[a]	WAUSAU MUNICIPAL AIRPORT (1973-1977)[b]
Jan.	26.8	20.9
Feb.	24.9	24.1
Mar.	37.5	76.0
Apr.	58.8	90.1
May	84.2	94.8
Jun.	114.7	71.8
Jul.	97.8	73.2
Aug.	104.0	87.0
Sep.	95.0	67.5
Oct.	59.0	37.7
Nov.	46.8	53.2
Dec.	27.2	38.5
Annual Total	776.7	734.8

[a]Black, 1981.

[b]NOAA, 1973-1977b.

TABLE 2.1-8

TOTAL SUSPENDED PARTICULATE CONCENTRATIONS
AT STATIONS 1, 2, and 3 ($\mu g/m^3$)
(APRIL 1977 - DECEMBER 1978)

CALENDAR QUARTER	GEOMETRIC MEAN STATION 1	STATION 2	STATION 3
Apr. - Jun. 1977	20.6	-	-
Jul. - Sep. 1977	18.6	-	-
Oct. - Dec. 1977	13.2	-	-
Jan. - Mar. 1978	11.5	11.1	11.6
Apr. - Jun. 1978	20.0	17.5	21.8
Jul. - Sep. 1978	18.8	19.1	20.9
Oct. - Dec. 1978	17.2	15.9	16.8

CONCENTRATIONS	STATION 1	STATION 2	STATION 3
Highest 24-Hour	99	65	74
Second Highest 24-Hour	77	61	73
Annual Geometric Mean[a]	16.6	15.9	17.9

WISCONSIN AMBIENT AIR QUALITY STANDARDS (WISCONSIN ADMINISTRATIVE CODE, 1975)	24-HOUR AVERAGE[b]	ANNUAL GEOMETRIC MEAN
Primary	260	75
Secondary	150	60

[a]Calendar year 1978.

[b]Not to be exceeded more than once per year.

24-hour concentrations at the three stations ranged from 65 to 99 $\mu g/m^3$, and the second highest 24-hour concentrations ranged from 61 to 77 $\mu g/m^3$. These concentrations are far below the Wisconsin primary and secondary standards of 260 and 150 $\mu g/m^3$, respectively. The geometric mean TSP concentrations ranged from 15.9 to 17.9 $\mu g/m^3$ at the three monitoring stations during the 12 months of concurrent monitoring in 1978. An additional 9 months of monitoring were performed at Station 1 in 1977 that resulted in a geometric mean of 16.9 $\mu g/m^3$. Geometric means at the stations are less than 31 percent of the secondary annual standard of 60 $\mu g/m^3$.

The highest TSP concentrations occurred during spring and summer when agricultural operations were greatest. Total suspended particulate levels were lowest during periods of snow cover, when 24-hour concentrations were as low as 2 $\mu g/m^3$. Concentrations were similar at all three monitoring locations, with concurrent 24-hour concentrations often within 5 $\mu g/m^3$.

2.1.5.2 Particulate Characterization

Twenty percent of the 24 TSP samples collected at Station 1 from April 1977 through March 1978 were examined microscopically to identify the types of particulates. The individual sample data are presented in Appendix 2.1B.

The results of the particulate characterization study are summarized by quarter in Table 2.1-9. Minerals, consisting mostly of quartz, calcite, and clays characteristic of soil erosion, represented a large fraction (45 percent). Biological matter, consisting of pollen, trichomes, wood fibers, insect parts and plant debris, was also a large fraction (45 percent).

TABLE 2.1-9

PARTICULATE CHARACTERIZATION AT STATION 1
APRIL 1977 - MARCH 1978

DATES	PERCENT BY AREA					
	SIZE < 30 μm			SIZE > 30 μm		
	MINERAL	COMBUSTION	BIOLOGICAL	MINERAL	COMBUSTION	BIOLOGICAL
April - June 1977	5	1	14	14	2	64
July - September 1977	24	1	39	9	0	28
October - December 1977	60	8	2	27	2	1
January - March 1978	20	17	0	23	8	31
Annual	27	7	14	18	3	31

Only 10 percent of the samples consisted of combustion products, primarily in the form of soot. The mineral content was highest in autumn, combustion products were highest in winter, and biological matter was highest during spring and summer. The size fractions of all particles examined over the entire data collection period were about evenly divided between particles >30 μm and those <30 μm. Combustion products 30 μm and greater were observed on significantly fewer samples than were particles less than 30 μm. A larger percentage of biological products 30 μm and greater were observed than those less than 30 μm. Except for low density biological particles, particles larger than 30 μm have an appreciable settling velocity and do not remain suspended in the atmosphere for more than a few minutes (Stern, 1976).

Of the samples examined, the one representing the highest TSP concentration during the 1-year period (April 1977 - March 1978) was collected on July 6, 1977, and contained 65 $\mu g/m^3$. On that day, construction activities were observed on the road adjacent to Station 1, creating dusty conditions at the station. The sample contained 93 percent quartz and calcite and a trace of clay and wood fibers. The sample representing the second highest concentration during 1977 (59 $\mu g/m^3$), however, was mostly pollen and plant debris. An analysis of the sample indicated the presence of a small number of different types of particles characteristic of a rural area with little nearby industry and relatively light vehicular traffic (Palenik, 1977).

2.1.5.3 Trace Elements

The TSP samples from Station 1 were analyzed for selected trace element content (Pb, Zn, Cd, Cu, Hg, and As) for the period April 1977 through

March 1978. A composite sample of all TSP samples from each calendar quarter was analyzed for these elements. The results of these analyses for each element are presented in Table 2.1-10. The trace elements frequently could not be detected.

Lead was detected in greater concentration (based solely on ambient atmospheric contributions) than any of the other trace elements (the highest quarterly average concentration was 110 ng/m^3) but was still far below the National Ambient Air Quality Standard for lead of 1,500 ng/m^3 per calendar quarter (U.S. EPA, 1978b).

Copper concentrations averaged 210 ng/m^3. However, this may not represent actual ambient concentrations because the samples collected by the high-volume samplers were potentially contaminated by copper that eroded from the copper armature of the sampler motor. This was not anticipated prior to performing the analyses, but has been recently reported by other researchers (American Public Health Association, 1977; McMullen and Faoro, 1977).

Mercury and arsenic concentrations were the lowest of the trace elements measured. Mercury was below the detection limits in two of the four quarters and averaged 0.021 ng/m^3. Arsenic averaged only 0.82 ng/m^3.

Cadmium and zinc concentrations were below the level of detection during all four quarters.

Asbestos content was not analyzed because no asbestos was found in the waste rock that would be disturbed by mining and exposed to the atmosphere. See section 2.2, Geology for further discussion.

TABLE 2.1-10

TRACE ELEMENT CONCENTRATIONS* AT STATION 1
(APRIL 1977 - MARCH 1978)

ELEMENT	QUARTER 4/77-6/77	QUARTER 7/77-9/77	QUARTER 10/77-12/77	QUARTER 1/78-3/78	ANNUAL 4/77-3/78
Lead	33	17	110	28	47
Zinc	<20	<20	<20	<20	<20
Cadmium	<3.1	<3.1	<3.1	<3.1	<3.1
Copper	280	270	150	150	210
Mercury	0.043	0.024	<0.017	<0.017	0.021
Arsenic	0.79	0.66	0.65	1.2	0.82

*All concentrations expressed as nanograms per cubic meter (ng/m^3).

2.1.5.4 Sulfur Dioxide

Background levels of atmospheric SO_2 were monitored at Station 1. The data from this study are presented in Appendix 2.1A. None of the SO_2 samples indicated that ambient 24-hour SO_2 concentrations exceeded the lower limit of detection (25 $\mu g/m^3$). For consistency with DNR data reporting procedures, all 24-hour SO_2 concentrations were reported as half of the lower limit of detection. All concentrations were far below the Wisconsin ambient 24-hour and annual SO_2 standards of 365 and 80 $\mu g/m^3$, respectively (Wisconsin Administrative Code, 1975).

2.1.6 Existing Air Quality Monitoring Programs

There are no state or federal air quality monitoring programs operated within 40 km (25 miles) of the Project site. The nearest SO_2 and TSP monitoring is in Rhinelander 45 km (28 miles) west-northwest of the site area. The monitoring conducted in Rhinelander is for surveillance of a specific pollution source and therefore records levels much higher than ambient conditions in the site area.

The nearest ozone (O_3) and oxides of nitrogen (NO_x) monitoring was in Marathon County, approximately 76 km (47 miles) southwest of the site area. No relevant nitrogen oxide data are available from a rural monitoring location in the Northwoods. This monitoring was conducted by an industrial source, and was not certified by the DNR. The monitoring was discontinued on May 1, 1981; however, the maximum 1-hour average ozone concentration for the first 4 months of 1981 was 108 $\mu g/m^3$. This was well below the Wisconsin air quality standard for ozone of 235 $\mu g/m^3$. The average oxides of nitrogen concentration for the same period was 7.9 $\mu g/m^3$, also well below the Wisconsin air quality standard of 100 $\mu g/m^3$ for an annual average nitrogen dioxide concentration (Wisconsin DNR, 1981).

Ozone is also monitored by the DNR in Manitowish Waters, Vilas County, 110 km (69 miles) northwest of the site area. The maximum 1-hour average concentration recorded in the summer of 1981 was 155 $\mu g/m^3$, also below the 235 $\mu g/m^3$ standard (Wisconsin DNR, 1981). Ozone and nitrogen dioxide concentrations at the Project site would be expected to be at or below these levels.

There are no monitoring data for carbon monoxide or volatile organic compounds in northern Wisconsin.

2.1.7 Existing Local Pollution Sources

2.1.7.1 Point Sources

There are only a few existing point sources within 50 km (31 miles) of the Project site. The nearest sources are in the City of Crandon and Conner Forest Industries, a hardwood dimension and flooring mill, 18 km (11 miles) northeast of the site area in Laona. This mill has wood and natural gas fired industrial boilers exhausting through 61-m (200-foot) stacks and sawdust drying process emissions exhausting through 10- to 15-m (33- to 50-foot) stacks. The total annual emissions are shown in Table 2.1-11 under Forest County.

In Langlade County there are two sources in Antigo 43 km (27 miles) southwest of the site and one source in White Lake 36 km (22 miles) south-southeast of the site. The emission quantities for these sources are

TABLE 2.1-11

EMISSIONS OF EXISTING POINT SOURCES OF AIR POLLUTION (tons/year)[a,b]

SOURCE NAME AND CITY	PARTICULATE MATTER	SULFUR OXIDES	NITROGEN OXIDES	CARBON MONOXIDE	HYDROCARBONS
Forest County					
Conner Forest Industries, Laona	577.02	28.72	191.69	38.33	38.30
Langlade County					
Vulcan Corporation, Antigo	14.86	4.75	31.70	6.34	295.20
Kraft Inc., Antigo	1.04	0.20	13.20	1.29	0.23
Yawkey-Bissell Hardwood Flooring Co., White Lake	99.00	6.75	45.00	9.00	9.00

[a]Wisconsin DNR, 1982.

[b]Average annual emissions are determined by the DNR.

shown in Table 2.1-11. Vulcan Corporation in Antigo manufactures sporting goods. Its sources are wood-fired boilers and paint drying, which exhaust through 11- to 27-m (36- to 90-foot) stacks. Kraft Inc. is a milk processing plant also in Antigo where natural gas and oil-fired boilers exhaust through 12- to 18-m (40- to 60-foot) stacks. Yawkey-Bissell in White Lake is a hardwood flooring operation which uses wood-fired boilers and 15- to 30-m (50- to 100-foot) stacks.

Fugitive dust emissions estimates are not available for any of these sources. All of the sources are in compliance with the air pollution rules and regulations of the DNR.

2.1.7.2 Line Sources

The roads and highways in the environmental study area are nearly all paved and are lightly travelled. A description of the transportation network including traffic volumes is presented in section 2.9, Land Use and Aesthetics. These conditions result in relatively small emission quantities from the vehicles using the highway network. For example, State Highway 55 from County Road K to Lake Metonga has the highest traffic volume in the environmental study area (Figure 2.9-6). This 15-km (9.3-mile) distance of highway has an average daily traffic of 805 vehicles. Based upon this traffic volume and average emission factors for 1979 (U.S. EPA, 1977b), the annual emissions from Highway 55 were:

Emission	Quantity (tons/year)
Carbon monoxide	110
Hydrocarbons	18.4
Nitrogen oxides	11.7
Sulfur oxides	0.6
Particulate matter	1.5

2.1.7.3 Area Sources

There are no documented area sources of air pollution within the environmental study area (DeBrock, 1982). The only potential area sources are agriculture and residential heating. However, both of these potential area sources are minor due to the limited amount of agriculture and the sparse population density. Motor boats, snowmobiles, and aircraft are also minor area sources of pollution, but they do not alter air quality in the environmental study area.

2.1.8 Planned Pollution Sources

The start-up date for the Crandon Project is 1990. Neither Exxon nor the DNR is aware of any planned pollution sources other than the Crandon Project that would be in operation in the environmental study area by that date (DeBrock, 1982). There may be some minor sources introduced into the area by 1990, but minor sources are not usually known until a few months before their start-up.

2.1.9 Sensitive Receptors

Sensitive receptors of air pollution include schools, hospitals, recreation areas, and residences. The nearest sensitive receptor is the Mole Lake School. Section 2.9 presents a comprehensive discussion of recreational and residential/institutional land uses in the environmental study area.

Residences are scattered throughout the environmental study area. They are generally widely scattered except for concentrations of residences around the numerous lakes and on the Mole Lake Indian Reservation, 3 km

(2 miles) west of the ore body (Figure 2.1-1). There are no hospitals within the environmental study area.

There are several public access recreation areas in the environmental study area. These are described in section 2.9, Land Use and Aesthetics.

2.1.10 Odors

There are no known sources of odorous emissions within the environmental study area. The DNR has not received any odor complaints from residents within the environmental study area or its surrounding environs (DeBrock, 1982).

2.1.11 Summary and Conclusions

The following results and conclusions are based on data obtained from monitoring in the environmental study area during the period April 1977 through December 1978 and from data collected at Nicolet College in Rhinelander and the Central Wisconsin Airport near Wausau.

Meteorology:

1. The predominant wind direction was from the south through southwest, with an average wind speed of 3.24 m/s (7.2 miles per hour).

2. Temperature was within the range of expected normals.

3. Precipitation was approximately 37 to 82 percent of concurrent values at Nicolet College.

Air Quality:

1. Total suspended particulate concentrations ranged from 31 to 48 percent of the Wisconsin ambient air quality standards.

2. Concurrently measured total suspended particulate concentrations were similar at all three monitoring stations.

3. Particulate characterization indicated that 45 percent of the particulates were minerals, 45 percent biological, and only 10 percent combustion products.

4. Particulate size fraction (over the entire data collection period) was about evenly divided between particles larger and smaller than 30 μm, respectively.

5. Lead concentration was approximately 7 percent of the National Ambient Air Quality Standard.

6. Selected trace elements were analyzed in the particulate samples and their concentrations were often not detectable.

7. Sulfur dioxide was not detectable ($<25\ \mu g/m^3$) in the atmosphere of the environmental study area.

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2.2 GEOLOGY

The Crandon deposit is situated in Precambrian volcanic rocks of the Rhinelander-Ladysmith greenstone belt that strikes easterly across northern Wisconsin. The Crandon sulfide deposit is identifiable for a distance of approximately 1,524 m (5,000 feet) along strike and approximately 732 m (2,400 feet) below the bedrock surface. Its thickness varies from 0.3 m (1 foot) on the west to 76 m (250 feet) near its center (Schmidt et al., 1978). In the study region, the Precambrian bedrock is overlain by as much as 91 m (300 feet) of glacial drift. Glacial depositional landforms and irregular erosion of this glacial drift results in the rolling topography that characterizes the area.

The geological study for the Crandon Project was designed to document geology in the area of the deposit. Specifically, the study had three purposes:

- To document bedrock conditions in the environmental study area;
- To document the stratigraphy of the glacial overburden in the environmental study area; and
- To estimate the maximum potential level of earthquake-induced ground motion for the site area.

Major emphasis was placed on the mapping of surface and near-surface glacially derived deposits. This was achieved through the use of aerial photographs, field examination of material exposed in road cuts, and the examination of samples collected from test borings drilled in the environmental study area. Laboratory tests were performed on selected samples to aid in the correlation of the various glacial deposits. Tests included analysis of grain size, clay mineral content, pH, moisture content, color, and carbonate pebble content. The methodologies employed in the geologic investigations are described in subsections 2.2.1 and 2.3.1.

2.2.1 Field and Laboratory Methods

2.2.1.1 Preliminary Investigations

A literature search and review were conducted that included interviews with technical people who had conducted or were conducting related studies within the environmental study area. In this way, the major geological aspects of the environmental study area were reviewed and additional needs for data defined.

Aerial photographs, topographic maps, and exposures of glacial deposits were studied for the purpose of preparing a surficial geology map of the environmental study area. Exposures of glacial deposits in the environmental study area were investigated during field reconnaissance. The surface distribution and relative positioning of the various glacial deposits were further defined by geologic interpretation of aerial photographs and topographic maps. The resulting surficial glacial geology map was then used as a basis for subsurface investigations. Additional information on the process by which the surficial glacial geology map was prepared, and the technical resources utilized in this process, is presented in subsection 2.2.2.2 and in a geotechnical report by Golder Associates (1981) entitled "Geotechnical Review, Crandon Project Waste Disposal System."

2.2.1.2 Drilling Program

Overburden drilling programs were conducted to obtain subsurface information in the environmental study area and the site area. The initial drilling program began in February 1977 and subsequent drilling activities have continued intermittently through April 1984. Boring locations were selected to provide both a general understanding of the glacial materials within the environmental study area and a more precise understanding of the glacial materials within the site area. The final location of each boring was dependent on the available subsurface information, the location of proposed structures, and accessibility. The borings provided information on thickness of glacial material and stratigraphy. Samples for testing various physical properties of the soil material were also obtained from the borings.

DM-series Borings - This drilling was supervised directly by Dames & Moore geologists, hydrologists, and soils engineers to insure the integrity of samples collected, to describe the sample conditions, and to provide the necessary judgments should changes in drilling procedures be needed. Personnel from the DNR visited the site and observed the drilling procedures. The Dames & Moore geotechnical personnel classified soils and weathered bedrock in the field by visual examination, and maintained a detailed log to serve as a basis for selecting samples for testing. Three soil samples were generally collected in the upper 3.0 m (10 feet) and every 1.5 m (5 feet) thereafter, or at major soil changes. In the event of difficult sampling conditions (for example, encountering a boulder), the soil sample at a particular interval was deleted based on the judgment of the Dames & Moore geotechnical personnel. Based on a knowledge of the area, geology sample intervals were occasionally increased to 3.0 m (10 feet) or more to avoid unnecessary duplication of samples in a known material.

The borings were made with rotating drilling equipment using circulating drilling fluids. Soil samples were collected by driving a Dames & Moore Type U (American Society for Testing and Materials [ASTM] D-3550) or a standard split spoon sampler (ASTM D-1586). Dames & Moore Type U samples were collected when relatively undisturbed samples were desired for laboratory testing. Standard split spoon samplers were used when relatively undisturbed samples were not required. In rare instances, rotary drill cuttings were also retained.

G-series Borings - This drilling was supervised by Golder Associates' engineers, geologists and technicians who logged all borings and described all samples. The borings were made with rotating drilling equipment using circulating biodegradable drilling fluids. Soil samples were generally taken every 1.5 m (5 feet) to a depth of 30.5 m (100 feet) and every 3 m (10 feet) below a depth of 30.5 m (100 feet). A split spoon sampler was used to obtain disturbed samples and undisturbed samples were collected by thin-walled sampling tubes (ASTM-D1587-67).

STS-series Borings - These borings were supervised by Soils Testing Services (STS) hydrologists and were advanced with rotating drilling equipment using circulating drilling fluids. The borings were continuously sampled with either a thin-walled sampling tube, a split spoon sampler, or an Osterberg sampler. The Osterberg sampler incorporates a mechanism for developing a partial vacuum at the top of the sample in the sampler tube and assists in better retention of the sample.

BE-series Borings - This drilling was also supervised by an Exxon employee. Drilling by Braun Engineering of Duluth, Minnesota was performed from January through April 1981. The borings were made with rotating drilling equipment using circulating biodegradable drilling fluids. Soil samples were generally taken every 3 m (10 feet). A split spoon sampler was used to obtain disturbed samples. Drill logs were prepared by Braun Engineering staff from driller/technician field logs. Single or double piezometers were installed in all holes.

CDM-series Borings - This drilling was also supervised by an Exxon employee. The borings were advanced using direct rotary methods, and samples were collected with a split spoon sampler. The total length of holes sampled varied with each hole. Several borings were sampled from the ground surface to bedrock. In the other borings, the sampling interval was generally the 9 m (30 feet) of soil above bedrock. The sampling interval was every 1.5 m (5 feet) except in the holes which were sampled over their entire length. In these, the upper 15 m (50 feet) were sampled at 3-m (10-foot) intervals.

The borings were drilled 3 to 6 m (10 to 20 feet) into the bedrock to allow geophysical logging of the contact between the bedrock and glacial overburden. The geophysical borehole logging was performed under the supervision of a CDM hydrologist. The data were recorded on light-sensitive film which was used to make blueline copies of the logs.

EX-series Borings - All drilling activity and piezometer installations were directly supervised by STS's hydrologists in 1984. Split spoon samples were logged on site. Drill cuttings were collected to aid in lithologic interpretations. Holes were advanced with rotary drilling equipment using circulating bentonitic muds. Split spoon soil samples were generally collected every 3 m (10 feet) except when a hole was being drilled for geophysical logging. Borings were generally drilled to the bedrock contact. On two occasions, holes were advanced up to 9 m (30 feet) into bedrock to record bedrock weathering data and for piezometer installation.

Geophysical logging was performed on several holes and monitored by both STS and Exxon personnel. Split spoon sample data, drillers' comments, drill cuttings, geophysical logs, and split spoon sieve analysis curves were used to produce interpretive stratigraphic logs.

Multiple completion piezometers were installed in all holes. Installation was in accordance with DNR standards and was supervised by STS. Installation and quality control were spot verified by the DNR.

Bedrock Holes - Bedrock drilling programs were conducted to delineate the ore deposit, to provide samples for metallurgical and rock mechanics testing, to evaluate the site, and to investigate the hydrologic regime of the site. Over 250 bedrock core holes have been drilled in the deposit and proposed mine waste disposal vicinity. Core drilling began in 1975 and continued intermittently until 1981.

The ore body was drilled on a 60-m (200-foot) grid both horizontally and vertically. Under the direction of an experienced drill supervisor, the following site-specific techniques were developed to control grid accuracy:

1) Three different drill rigs were used to complete each hole. Overburden drilling was accomplished using a tophead drive air rotary rig. A 200-mm (8-inch) hole was mud drilled and cased with 150-mm (6-inch) casing. This allowed rapid penetration of the sand and gravel overburden and facilitated a straight hole.

2) A second tophead drive hammer drill was used to advance the hole to the approximate depth of mineralization. A very rigid stabilizing system was used to prevent hole drift. By modifying the stabilizing system, rod pressures and direction

of rotation, the hole could, in effect, be directionally drilled.

3) The remainder of the hole was NQ cored. A combination of stabilizing systems, size and length of core barrels, and varying rod pressures was used to deflect the hole into the plane of the deposit at the desired dip and azimuth. All hammer and core drilling progress was monitored by in-hole surveying at 30-m (100-foot) intervals using a single-shot magnetic camera.

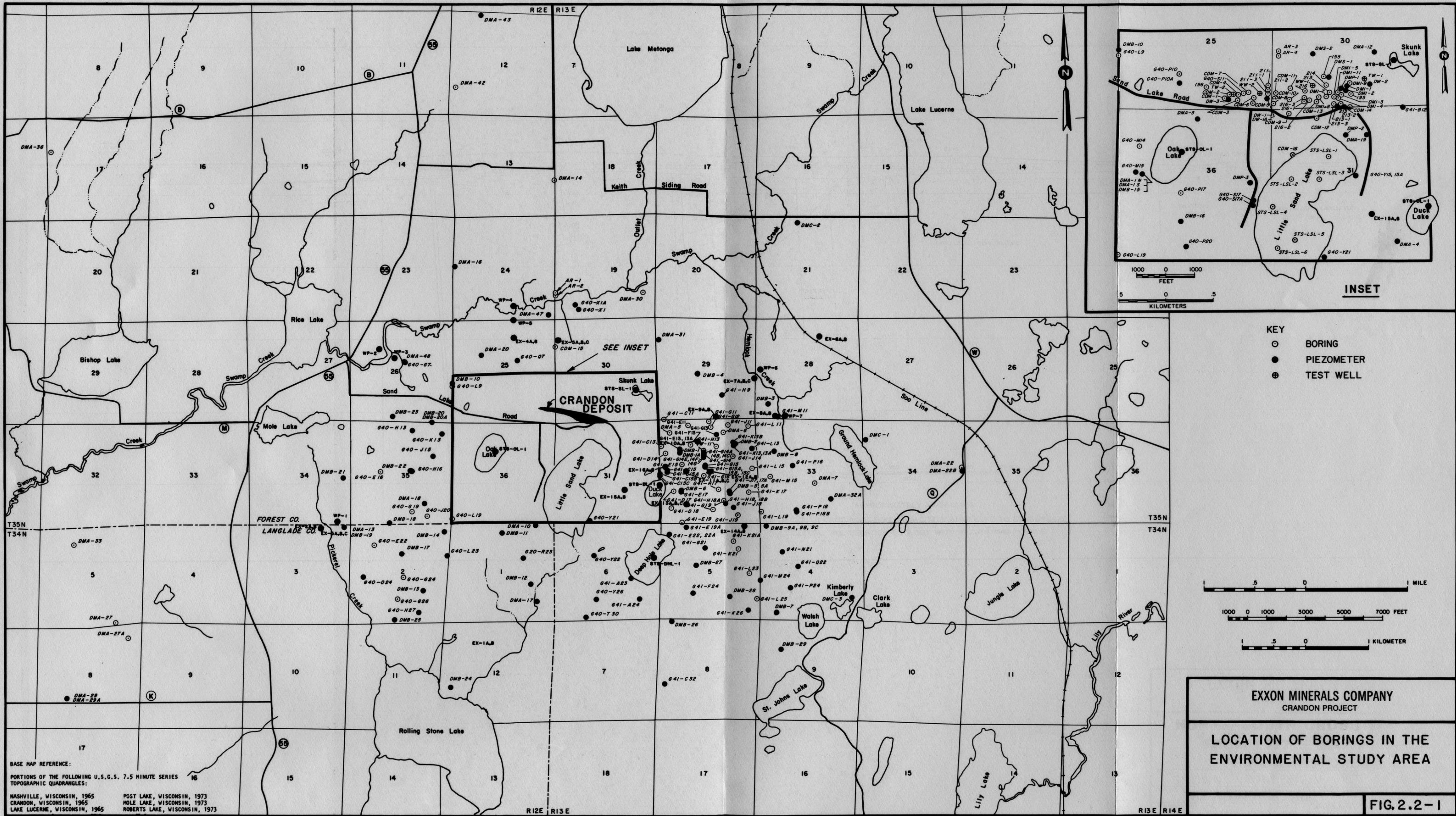
Figure 2.2-1 shows the location of all test wells and soil borings in the environmental study area. Borings in which piezometers have been installed are marked by solid black circles. All others have been abandoned, as per proper regulations. Figure 2.2-2 shows the location of bedrock core holes in the deposit vicinity. Bedrock holes have also been officially abandoned according to procedures dictated by law, and abandonment reports have been submitted to the state. The following description from a drilling contract outlines abandonment methodology:

Grouting of Boreholes

Upon satisfactory completion of each boring that does not contain a ground water observation well, and acceptance thereof by Exxon, the contractor shall refill the borehole with grout.

All boreholes are to be grouted. The grout mix shall consist of seven (7) gallons of water and two (2) pounds of powdered bentonite per sack (94 pounds) of Type I Portland cement. The contractor, at his option, may use an accelerating agent in the grout to achieve a rapid set and hardening of the grout. Exxon reserves the right to adjust the grout mix proportions in order to provide a grout consistency that is, in Exxon's judgment, better suited to the project needs.

The grout shall be pumped into the borehole through a pipe or hose. Pumping shall be initiated with the pipe or hose extended to the bottom of the borehole. The grout pipe or hose shall then be withdrawn in a tremie fashion until the casing or hole is full. Casing, where used, shall then be removed from the borehole in no more than 10-foot increments with the grout level in the remaining casing reestablished to the top of the hole after each increment of casing is removed. The grout added after the initial



LOCATION OF BORINGS IN THE ENVIRONMENTAL STUDY AREA

FIG. 2.2-1

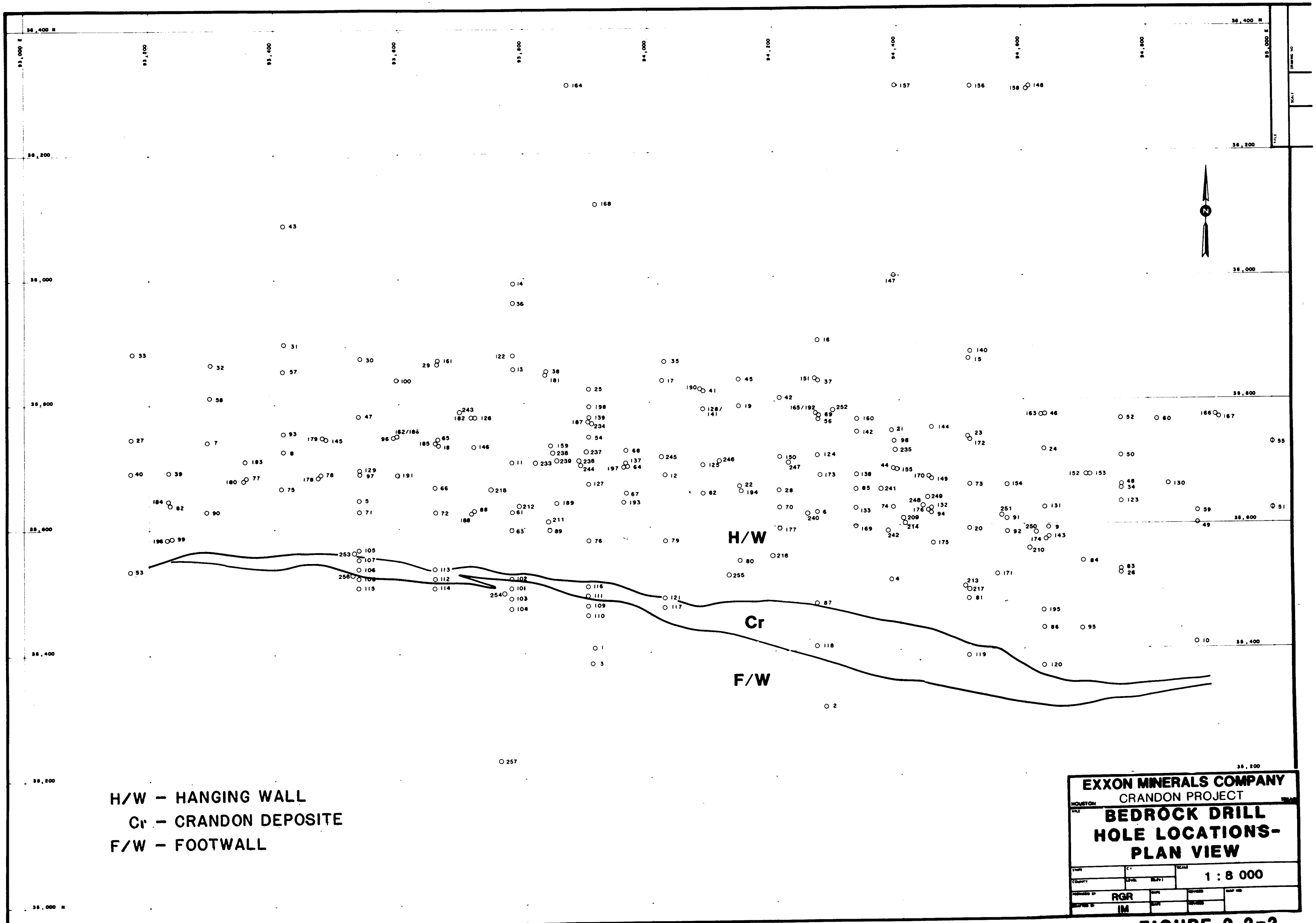

H/W
Cr
F/W
H/W - HANGING WALL
Cr - CRANDON DEPOSITE
F/W - FOOTWALL
EXXON MINERALS COMPANY
CRANDON PROJECT
BEDROCK DRILL HOLE LOCATIONS-PLAN VIEW
1 : 8 000
RGR
IM

FIGURE 2.2-2

pumping may be poured down the casing rather than being pumped. It is estimated that the grout mix specified herein, without an accelerating agent, will require 12 to 24 hours to achieve its initial set. If at any time prior to completion of the refilling operation the borehole is left unattended, it shall be suitably capped and protected.

All glacial borings or bedrock core holes were located by certified surveyors to obtain elevations and horizontal coordinates. The coordinates were based on the Wisconsin Coordinate System North Zone.

2.2.1.3 Soil Sampling Procedures

Samples of the glacial materials were generally obtained using a split spoon sampler at the selected sampling depth. The split spoon sampler was attached to the end of the drill string and lowered to hole bottom. By hammering on the drill rods, the sampler was driven into the undisturbed glacial soil material for approximately 457 mm (18 inches). The split spoon sampler was opened after removal from the hole. Generally, only the upper 25 to 51 mm (1 to 2 inches) of the sample have been disturbed by the rotary bit and drilling fluids. That portion of the sample was discarded. To further insure an undisturbed sample and a sample free of contamination by drilling fluids, only the lowermost 152 mm (6 inches) were logged and saved in a plastic container for laboratory testing.

A discussion of the procedures used to obtain the boring samples is presented in section 2.3, Ground Water. The drilling fluids that were used are described in Golder Associates (1981).

Two types of drilling fluid were used, depending upon the depth of the hole. For borings drilled to depths of approximately 50 to 75 m (164 to 246 feet), Revert, a biodegradable viscosity-increasing agent, was the most common drilling fluid. Revert, however, decomposes with time and is difficult to use when borings require more than a few days and/or remain open for the weekend.

More satisfactory product combinations for deeper holes are the Baroid products Quickgel, Quicktrol, and Barafos. All of these products are nontoxic. Quicktrol is a polymer that coats the walls of the hole and prevents the Quickgel, a high yield bentonite, from penetrating the formation. Upon completion, the Quickgel is broken down with Barafos, a dispersing agent. No evidence of well contamination from any of these drilling agents was found.

2.2.1.4 Soil and Bedrock Testing

All glacial borings are shown on Figure 2.2-1, and all bedrock holes are shown on Figure 2.2-2. A variety of tests were conducted on material from glacial and bedrock holes. Table 2.2-1 lists the tests that were performed on glacial and bedrock materials and the primary reasons for conducting the tests. Table 2.2-2 lists all the glacial borings and bedrock holes in the environmental study area and the tests that were conducted in materials from each hole. Table 2.2-3 contains a list of summary documents within the EIR and other reports that summarize the results of glacial and bedrock testing.

Samples of the various glacial soil materials encountered were selected for testing in the soils laboratory of the various geotechnical consulting firms. In the field, these samples were placed in glass jars or in plastic bags and enclosed in containers. The containers were labeled with pertinent sample history information and shipped to the laboratory. Laboratory tests to be performed were assigned to each sample. Tests were performed to determine various physical properties of the soil materials

TABLE 2.2-1

TESTS PERFORMED ON GLACIAL AND BEDROCK MATERIALS

TESTS	REASONS FOR TESTING
Sieve Analysis	- Determine soil classification. - Grain size analysis for Hazen's Approximation.
Permeability	- Investigation of aquifer characteristics. - Mine water inflow. - Soil characteristics.
Carbonate Pebble Analysis	- Soil attenuation. - Aid in glacial history interpretation.
pH	- Soil attenuation. - Aid in glacial history interpretation.
Clay Analysis	- Soil attenuation. - Aid in glacial history interpretation.
Compaction	- Soil rock mechanics.
Triaxial	- Soil rock mechanics.
Chemical Analysis	- Water quality.
Bedrock Rock Mechanics Testing (Uniaxial, Triaxial, P.L. Brazilian)	- Stope span calculations. - Pillar strength dimensions and sequencing. - Stope and pillar blasting procedures. - Distribution of rock strengths.
Assays	- Economic evaluation.
Radiological	- Characterize radioactivity.
Specific Gravity	- Criteria needed for determining ore reserves.

TESTS CONDUCTED IN GLACIAL AND BEDROCK BORINGS

2.2.9

GLACIAL BORINGS

WELLNUM	CNORTH	CEAST	TOTALD	SIEVE ANALYSIS	PERMEABILITY TESTS	CARBONATE PEBBLE ANALYSIS	pH	COMPACTION TESTS	TRIAXIAL TESTS	CLAY ANALYSIS	CHEMICAL ANALYSIS	
AR-1	37251.89	693867.81	9.27	X								
AR-1A	37254.39	693870.81	13.05									
AR-2	37226.89	693880.81	6.55	X								
AR-2A	37228.39	693878.31	9.60									
AR-3	35722.99	693880.69	9.30	X								
AR-4	35662.03	693880.69	9.27	X								
BE-211-1	35520.00	693820.00	60.96	X	R							
BE-211-2L	35495.00	693897.00	57.30	X	R							
BE-211-2U	35495.00	693897.00	57.30	X								
BE-211-3L	35502.00	693818.00	67.36	X	R							
BE-211-3U	35502.00	693818.00	67.36	X	R							
BE-213-1	35365.00	694469.00	28.35	X	R							
BE-213-2	35376.00	694538.00	28.97	X	R							
BE-213-3L	35391.00	694478.00	35.05	X	R							
BE-213-3U	35391.00	694478.00	35.05	X								
BE-216-1	35434.00	694193.00	46.33	X	R							
BE-216-2	35457.00	694258.00	42.98	X	R							
BE-216-3L	35460.00	694200.00	54.41	X	R							
BE-216-3U	35460.00	694200.00	54.41	X	R							
CDM-1	35437.27	393370.00	57.00									
CDM-10	35469.18	694031.31	68.58	X								
CDM-11	35574.79	694030.88	57.61									
CDM-12	35243.75	694362.25	43.59									
CDM-13	35430.96	694340.13	40.23	X								
CDM-14	35369.08	694644.44	34.14	X								
CDM-15	36450.77	693898.75	55.17									
CDM-16	34857.38	694060.50	56.39	X								
CDM-17	34865.85	694048.50	12.19									
CDM-18	34852.90	694061.75	00									
CDM-19	34852.90	694080.00	00									
CDM-2	35525.88	693414.63	49.68	X								
CDM-20	34845.19	694080.00	00									
CDM-3	35415.41	693534.88	62.18									
CDM-4	35519.78	693544.88	56.08	X								
CDM-5	35447.27	693673.25	67.67									
CDM-6	35512.83	693664.19	68.58	X								
CDM-7	35627.74	693665.56	61.57									
CDM-8	35386.73	693837.56	68.58									
CDM-9	35352.47	694031.19	66.45									
DMA-1	34644.00	692516.00	16.76									
DMA-10	33684.00	693543.00	14.02			X					X	
DMA-12	35932.00	694935.00	13.72	X								
DMA-13	33665.00	690617.00	12.34		H						X	
DMA-14	39142.89	693830.69	10.67		H							
DMA-16	37732.00	692280.00	18.38		H						X	
DMA-17	32481.00	693588.00	10.97		H						X	
DMA-18	34064.00	691862.00	21.49	X	C H		X			X		
DMA-19	35053.00	694860.00	9.14	X	H	X					X	
DMA-1N	34645.00	692516.00	16.76	X	F	X				X		
DMA-1S	34644.00	692516.00	16.76		F H							
DMA-20	36332.00	692697.00	16.46		F H	X						
DMA-22	34686.66	700240.75	10.82		H							
DMA-22R	34686.00	700234.00	30.60	X							X	
DMA-27	32050.11	687033.56	26.06									

TESTS CONDUCTED

GLACIAL BORINGS

WELLNUM	CNORTH	CEAST	TOTALD	SIEVE ANALYSIS	PERMEABILITY TESTS	CARBONATE PEBBLE ANALYSIS	pH	COMPACTION TESTS	TRIAXIAL TESTS	CLAY ANALYSIS	CHEMICAL ANALYSIS	
DMA-27A	31830.65	687268.25	11.95		C H							
DMA-29	30855.00	686222.00	12.19		C H							
DMA-29A	30861.37	686228.88	16.15									
DMA-29AL	30861.00	686222.00	16.15									
DMA-29AU	30861.00	686222.00	16.15									
DMA-3	35203.00	693098.00	13.72		F							
DMA-30	37393.32	695260.25	13.87		C H	X						
DMA-31	36625.00	695424.00	7.62	X								
DMA-32A	34153.00	698170.00	53.34								X	
DMA-33	33383.62	686347.75	15.24									
DMA-34	34747.00	685207.00	9.30		C H							
DMA-35	33888.00	684527.00	8.99									
DMA-36	39472.07	685863.13	8.84									
DMA-37	38204.09	685024.94	11.89									
DMA-38	43023.00	685765.00	9.14									
DMA-39	43757.62	686107.00	9.14		H							
DMA-4	33962.00	695204.00	9.14	X	F H	X	X			X	X	
DMA-42	40551.08	692215.25	7.92									
DMA-43	41758.00	692726.00	12.19		F							
DMA-44	26908.07	688606.38	9.45		H							
DMA-45	30672.00	704150.00	15.00		H							
DMA-46	35790.00	706955.00	22.10									
DMA-47	37001.00	693744.00	9.45	X								
DMA-48	36266.00	691504.00	8.99		H						X	
DMA-5	35168.25	695680.88	15.24		H							
DMA-6	35189.59	696564.81	9.14	X	H	X	X					
DMA-7	34406.24	697969.94	13.56									
DMB-1	34871.00	695826.00	18.07	X	F H		X			X		
DMB-10	35881.00	692254.00	30.33	X	FRH	X	X			X		
DMB-11	33516.00	693062.00	30.48			X				X		
DMB-12	32733.00	693484.00	24.96	X	R H	X	X					
DMB-13	32647.00	691891.00	18.29	X	F H	X	X					
DMB-14	33551.00	692198.00	30.75	X	F	X	X			X		
DMB-15	34644.00	692515.00	24.23	X	F H	X	X					
DMB-16	34101.00	692957.00	30.24	X	H	X	X			X		
DMB-17	33211.00	691518.00	24.54	X	H	X	X					
DMB-18	33699.00	691306.00	24.66	X	FRH	X	X			X	X	
DMB-19	33665.00	690622.00	48.98	X	FRH	X	X			X		
DMB-1A	34871.00	695829.00	24.20		F					X	X	
DMB-2	35051.00	696713.00	30.57	X	F H	X	X			X		
DMB-20	35273.00	692059.00	12.19	X	FRH	X				X	X	
DMB-20A	35272.00	692063.00	25.85		F						X	
DMB-21	34388.00	690610.00	15.09	X	F H						X	
DMB-22	34516.00	691620.00	24.08	X	F	X	X			X		
DMB-23	35326.00	691350.00	30.24		F R						X	
DMB-24	31108.00	692316.00	14.94		F						X	
DMB-25	32225.00	691448.00	39.47		F						X	
DMB-26	32163.00	695631.00	40.87		F							
DMB-27	33124.00	696072.00	25.57		F						X	
DMB-28	32565.00	696599.00	21.34		F						X	
DMB-29	31817.00	697417.00	21.12		F						X	
DMB-3	35630.00	697221.00	18.75	X	FRH	X	X					
DMB-4	36090.00	696099.00	24.48	X	F H	X	X				X	
DMB-5	34179.00	696634.00	30.02	X	F	X	X			X		
DMB-5A	34177.00	696635.00	36.64		F						X	
DMB-6	34255.00	695864.00	26.21	X	F H	X				X		

GLACIAL BORINGS

TESTS CONDUCTED

WELLNUM	CNORTH	CEAST	TOTALD	SIEVE ANALYSIS	PERMEABILITY TESTS	CARBONATE PEBBLE ANALYSIS	pH	COMPACTION TESTS	TRIAXIAL TESTS	CLAY ANALYSIS	CHEMICAL ANALYSIS	
DMB-7	32355.00	697337.00	24.14	X	FH	X					X	
DMB-8	34929.00	697335.00	15.45		F						X	
DMB-9A	33697.00	697151.00	79.40		F	X				X		
DMB-9B	33697.00	697151.00	79.40		F							
DMB-9C	33697.00	697151.00	79.40		F							
DMC-1	35089.00	698704.00	14.48	X	F						X	
DMC-2	38560.00	697609.00	15.70	X	H						X	
DMC-3	32595.00	698516.00	14.17	X	F						X	
DMI-1	35584.00	694584.00	33.22		H							
DMI-11	35523.04	694525.50	120.40									
DMI-2	35542.82	694571.38	42.37	X	H							
DMI-2L	35542.00	694564.00	42.37		F							
DMI-2U	35542.00	694564.00	42.37		H							
DMI-3	35510.97	694553.75	32.00									
DMI-4	35471.44	694532.31	61.11	X	H							
DMI-5	35476.71	694487.13	26.52									
DMI-7	35483.18	694426.69	77.05	X	H							
DMI-8	35488.36	694380.94	80.47	X	H							
DMI-9	35634.26	694618.00	31.70	X	H							
DMP-1	35563.00	694482.00	21.55	X	H							
DMP-2	35093.00	694545.00	11.13	X	H							
DMP-3	34645.00	693612.00	19.99	X	H							
DMS-1	35693.00	694403.00	39.01	X	FR							
DMS-2	35944.00	694302.00	56.08	X	FR							
DW-1A	35459.00	693807.00	21.64		FR							
DW-1L	35455.00	693806.00	65.53		RP							
DW-1U	35455.00	693806.00	65.53		R							
DW-2L	35594.00	694883.00	28.96									
DW-2U	35594.00	694883.00	28.96		P							
DW-3L	35434.00	693373.00	51.51		R							
DW-3U	35434.00	693373.00	51.51		F							
EX-10AL	35086.00	696237.00	78.03	X	FR							
EX-10AU	35086.00	696237.00	78.03	X	F							
EX-10BL	35085.00	696230.00	44.81	X	FR							
EX-10BU	35085.00	696230.00	44.81	X								
EX-11AL	34520.00	696073.00	86.87	X	FR							
EX-11AU	34520.00	696073.00	86.87	X	FR							
EX-11BL	34522.00	696077.00	53.04	X	FR							
EX-11BU	34522.00	696077.00	53.04	X	FR							
EX-11CL	34521.00	696068.00	31.09	X								
EX-12AL	34490.00	696380.00	92.96	X	FR							
EX-12AU	34490.00	696380.00	92.96	X	FR							
EX-12BL	34492.00	696375.00	56.69	X	FR							
EX-12BU	34492.00	696375.00	56.69	X								
EX-13AL	34002.00	696012.00	71.63	X	FR							
EX-13BL	33998.00	696015.00	58.83	X	FR							
EX-13BU	33998.00	696015.00	58.83	X	FR							
EX-13CL	33997.00	696012.00	32.92	X	FR							
EX-13DL	33996.00	696015.00	22.86	X								
EX-14AL	33605.00	696867.00	86.26	X	FR							
EX-14AU	33605.00	696867.00	86.26	X	FR							
EX-14BL	33606.00	696860.00	49.38	X	FR							
EX-14BU	33606.00	696860.00	49.38	X								
EX-15AL	34273.00	694947.00	71.63	X	FR							
EX-15AU	34273.00	694947.00	71.63	X	FR							
EX-15BL	34274.00	694948.00	15.85	X								

TESTS CONDUCTED

GLACIAL BORINGS

WELLNUM	CNORTH	CEAST	TOTALD	SIEVE ANALYSIS	PERMEABILITY TESTS	CARBONATE PEBBLE ANALYSIS	pH	COMPACTION TESTS	TRIAXIAL TESTS	CLAY ANALYSIS	CHEMICAL ANALYSIS	
EX-16AL	34539.00	695568.00	44.20	X	FR							
EX-16AU	34539.00	695568.00	44.20	X	FR							
EX-16BL	34541.00	695567.00	21.94	X	FR							
EX-1AL	31745.00	693029.00	40.48	X	FR							
EX-1AU	31745.00	693029.00	40.48	X	FR							
EX-1BL	31743.00	693028.00	14.33	X	FR							
EX-1BU	31743.00	693028.00	14.32	X								
EX-2AL	33632.00	689532.00	58.52	X	FR							
EX-2AU	33632.00	689532.00	58.52	X	FR							
EX-2BL	33634.00	689533.00	11.28	X								
EX-3AL	33615.00	690051.00	49.38	X	FR							
EX-3AU	33615.00	690051.00	49.38	X	FR							
EX-3BL	33616.00	690048.00	22.86	X	FR							
EX-3BU	33616.00	690048.00	22.86	X	FR							
EX-3CL	33613.00	690044.00	3.66	X								
EX-4AL	36549.00	693204.00	36.27	X	FR							
EX-4AU	36549.00	693204.00	36.27	X	F							
EX-4BL	36551.00	693201.00	35.66	X	FR							
EX-4BU	36551.00	693201.00	35.66	X	FR							
EX-4CL	36544.00	693203.00	8.84	X								
EX-5AL	36532.00	693967.00	57.61	X	F							
EX-5AU	36532.00	693967.00	57.61	X	F							
EX-5BL	36533.00	693964.00	34.14	X	F							
EX-5BU	36533.00	693964.00	34.14	X								
EX-5CL	36531.00	693964.00	22.86	X								
EX-6AL	36680.00	697971.00	59.74	X	FR							
EX-6AU	36680.00	697971.00	59.74	X	FR							
EX-6BL	36680.00	697969.00	26.52	X	FR							
EX-6BU	36680.00	697969.00	26.52	X								
EX-7AL	35924.00	697015.00	51.51	X	FR							
EX-7BL	35923.00	697013.00	34.14	X	FR							
EX-7BU	35923.00	697013.00	34.14	X	FR							
EX-7C	35922.00	697012.00	3.50	X								
EX-8AL	35467.00	697279.00	53.16	X	FR							
EX-8AU	35467.00	697279.00	53.16	X	FR							
EX-8BL	35470.00	697277.00	23.47	X	FR							
EX-8BU	35470.00	697277.00	23.47	X	F							
EX-9AL	35497.00	696386.00	85.34	X	F							
EX-9AU	35497.00	696386.00	85.34	X	FR							
EX-9BL	35501.00	696387.00	58.52	X	FR							
EX-9BU	35086.00	696237.00	58.52	X								
G40-D24	32937.00	690965.00	57.45	X	H							
G40-E16	34520.54	691148.44	15.70									
G40-E22	33421.72	691131.68	15.70									
G40-G19	33936.84	691706.25	19.96									
G40-G24	32866.98	691553.81	30.72		H							
G40-G26	32519.50	691495.88	30.78	X	H							
G40-G7	36257.92	691508.13	36.27									
G40-H13	35136.24	691700.13	59.53	X	H							
G40-H16	34522.00	691626.00	81.69	X	H							
G40-H27	32288.00	691791.00	76.20	X	H							
G40-J15	34689.00	691943.00	15.70	X							X	
G40-J20	33875.88	691875.38	23.16	X	H							
G40-K13	35092.00	692167.00	15.32	X	H						X	
G40-L19	33851.50	692216.75	36.73	X								
G40-L23	33199.00	692222.00	27.68	X	H						X	

TESTS CONDUCTED

GLACIAL BORINGS

WELLNUM	CNORTH	CEAST	TOTALD	SIEVE ANALYSIS	PERMEABILITY TESTS	CARBONATE PEBBLE ANALYSIS	pH	COMPACTION TESTS	TRIAXIAL TESTS	CLAY ANALYSIS	CHEMICAL ANALYSIS	
G40-L9	35889.11	692265.56	64.01									
G40-M14	34928.98	692459.06	28.96									
G40-M15	34644.00	692426.00	94.49	X	FRH							
G40-P10	35706.23	692830.94	21.58	X	H							
G40-P10A	35584.00	692780.00	48.77									
G40-P17	34354.42	692968.13	30.63	X	H							
G40-P20	33854.00	692969.00	24.69	X	H							
G40-Q7	36287.00	693223.00	21.49								X	
G40-R23	33153.00	693362.00	24.69	X	H						X	
G40-S11	35430.38	693539.63	24.63	X	H							
G40-S17	34228.00	693656.00	45.93		F R							
G40-S17A	34240.00	693662.00	9.14									
G40-T30	32237.00	694461.00	49.38									
G40-X1	37038.00	694333.00	43.59									
G40-X1A	37164.00	694284.00	22.86									
G40-Y15	34642.00	694695.00	53.34									
G40-Y15A	34645.00	694692.00	6.10									
G40-Y21	33751.00	694348.00	6.10									
G40-Y22	33187.00	694430.00	59.74									
G40-Y26	32516.00	694580.00	39.01									
G41-A23	32940.00	695033.00	14.63									
G41-A24	32632.00	695098.00	54.86									
G41-B12	35393.00	695131.00	38.40									
G41-C11	35386.19	695467.50	15.51	X								
G41-C13	34983.84	695530.00	15.39									
G41-C15	34549.00	695578.00	66.23	X	H						X	
G41-C15A	34554.07	695586.38	66.23		F							
G41-C15B	34523.00	695509.00	8.08	X								
G41-C15C	34491.00	695491.00	6.71									
G41-C32	31242.00	695590.00	79.86									
G41-D14	34770.48	695653.44	16.15									
G41-D17	34205.07	695722.00	15.48									
G41-D18	33924.65	695604.69	19.87	X	H							
G41-E11	35316.08	695828.69	15.09									
G41-E13	34868.00	695826.00	76.35	X	H						X	
G41-E13A	34864.97	695834.81	76.35		F H							
G41-E15	34558.64	695847.00	15.24	X	H							
G41-E17	34255.00	695861.00	79.25	X	FRH							
G41-E19	33757.01	695892.69	15.33	X								
G41-E19A	33607.00	695948.00	84.12	X	FRH							
G41-E22	33519.00	695729.00	68.28									
G41-E22A	33514.00	695735.00	12.83		FR							
G41-F13	35005.18	696067.94	17.01									
G41-F24	32691.00	696002.00	74.06	X	H							
G41-G11	35386.18	696276.75	24.84	X	H							
G41-G12	35304.00	696296.00	6.40	X	H							
G41-G13	35131.00	696386.00	97.23									
G41-G14	34726.28	696267.63	29.41	X								
G41-G14A	34772.00	696261.00	73.46	X	H						X	
G41-G14B	34764.00	696261.00	109.76	X	H						X	
G41-G14C	34756.00	696261.00	48.77								X	
G41-G14D	34703.00	696261.00	78.33									
G41-G14E	34695.00	696261.00	50.29									
G41-G14F	34688.00	696261.00	101.19									
G41-G15	34569.00	696293.00	118.26	X	H	X						
G41-G15A	34589.00	696283.00	34.44	X	FH	X					X	

TESTS CONDUCTED

GLACIAL BORINGS

WELLNUM	CNORTH	CEAST	TOTALD	SIEVE ANALYSIS	PERMEABILITY TESTS	CARBONATE PEBBLE ANALYSIS	pH	COMPACTION TESTS	TRIAXIAL TESTS	CLAY ANALYSIS	CHEMICAL ANALYSIS	
G41-G15B	34577.00	696282.00	51.82	X	H						X	
G41-G15C	34576.93	696295.06	103.02		FH							
G41-G16	34378.81	696290.44	22.98									
G41-G19	33796.63	696256.94	27.58	X	H							
G41-G21	33374.00	696245.00	30.63	X	H							
G41-H13	34960.98	696468.75	31.94	X	H							
G41-H17	34182.00	696457.00	22.65	X	H							
G41-H18	33964.00	696507.00	22.95	X	H							
G41-H18A	34013.00	696489.00	6.55	X	H							
G41-H18B	33972.00	696500.00	87.78									
G41-H9	35762.00	696469.00	96.01									
G41-J11	35360.27	696653.19	30.39									
G41-J14	34781.15	696747.69	24.45									
G41-J17	34165.45	696634.88	12.19	X	H							
G41-J17A	34171.54	696637.94	12.19		F							
G41-J18	33898.00	696620.00	21.49	X	H							
G41-J19	33766.15	696683.69	23.03									
G41-K13	34977.00	696764.00	86.87	X	H							
G41-K13A	34982.00	696760.00	37.24	X	FH							
G41-K13B	35006.00	696795.00	6.10	X	FH							
G41-K17	34185.26	696880.25	24.17									
G41-K21	33340.95	696846.75	23.10	X	H							
G41-K21A	33446.11	696747.69	90.83									
G41-K26	32388.00	696910.00	100.58	X	H							
G41-L11	35325.22	696991.50	27.58	X	H							
G41-L13	34950.31	697023.50	26.37									
G41-L15	34618.08	697011.31	22.65	X	H							
G41-L19	33851.50	697031.13	21.06	X	H							
G41-L23	33002.62	696958.00	24.66	X	H							
G41-L25	32504.26	697078.38	26.06	X	H							
G41-M11	35439.00	697300.00	48.92	X	FRH							
G41-M15	34477.87	697282.63	77.42		FR							
G41-M24	32888.00	697133.00	9.39	X	H							
G41-N21	33275.00	697509.00	45.87	X	H							
G41-P16	34673.00	697615.00	55.17	X	FRH							
G41-P18	34029.00	697635.00	39.62	X	FH							
G41-P18B	33952.00	697634.00	13.56	X	F						X	
G41-P24	32781.00	697585.00	105.16	X	H						X	
G41-Q22	33059.00	697746.00	96.47									
RP-1	35236.00	695111.00	8.38									
RP-1	35236.00	695111.00	8.38									
RP-10	35019.00	695353.00	3.51									
RP-11	35062.00	695664.00	3.51									
RP-12	35052.00	695820.00	8.05									
RP-13	34902.00	695655.00	2.29									
RP-14	35315.00	695550.00	7.25									
RP-15	35193.00	695642.00	7.16									
RP-2	35251.00	695286.00	10.36									
RP-3	35269.00	695439.00	10.21									
RP-4	35327.00	695718.00	10.27									
RP-5	35088.00	695220.00	12.19									
RP-6	35158.00	695366.00	8.38									
RP-7	35177.00	695489.00	6.55									
RP-8	35223.00	695759.00	9.30									
RP-9	34976.00	695166.00	10.36									
RR-1	37931.48	695656.06	12.50	X								

GLACIAL BORINGS

TESTS CONDUCTED

WELLNUM	CNORTH	CEAST	TOTALD	SIEVE ANALYSIS	PERMEABILITY TESTS	CARBONATE PEBBLE ANALYSIS	pH	COMPACTION TESTS	TRIAXIAL TESTS	CLAY ANALYSIS	CHEMICAL ANALYSIS	
RR-2	37907.98	695653.25	12.65	X								
STP-1	00	00	00									
STP-10	00	00	00									
STP-11	00	00	00									
STP-12	00	00	00									
STP-13	00	00	00									
STP-2	00	00	00									
STP-3	00	00	00									
STP-4	00	00	00									
STP-5	00	00	00									
STP-6	00	00	00									
STP-7	00	00	00									
STP-8	00	00	00									
STP-9	00	00	00									
STS-B1	35598.66	694385.69	33.62									
STS-B10	35509.17	694435.25	6.55									
STS-B11	35514.17	694460.25	6.55									
STS-B2	35552.73	694386.38	13.78									
STS-B3	35534.25	694342.31	6.40									
STS-B4	35594.18	694349.25	6.40									
STS-B5	35448.15	694323.25	12.50									
STS-B6	35434.16	694372.25	6.22									
STS-B7	35434.16	694430.25	6.55									
STS-B8	35490.15	694372.25	6.10									
STS-B9	35526.15	694401.31	6.37									
STS-DHL-1	33218.00	695385.00	13.11									
STS-DL-1	34315.00	695482.00	18.28									
STS-LSL-1	34832.97	694417.44	15.85									
STS-LSL-2	34618.08	694062.38	12.34									
STS-LSL-3	34598.27	694339.75	13.72									
STS-LSL-4	34243.17	693864.25	14.33									
STS-LSL-5	33927.70	694156.81	10.97									
STS-LSL-6	33817.97	693913.00	10.97									
STS-OL-1	34889.00	692871.00	16.15									
STS-SL-1	35839.00	695103.00	5.30									
TP-1	33802.73	696628.81	4.88	X	CH			X	X			
TP-10	35381.61	696220.38	3.05									
TP-11	35271.88	696141.13	3.66	X								
TP-12	35302.36	696110.63	2.59									
TP-13	34149.96	696147.19	3.05									
TP-14	34893.93	695879.00	3.05									
TP-15	35009.75	695818.00	3.05									
TP-16	35332.84	696199.00	2.44									
TP-17	34704.95	695830.19	3.05									
TP-18	34564.74	695824.13	3.05									
TP-19	34278.22	695885.06	2.13									
TP-2	35357.23	696659.25	4.57	X	CH			X	X			
TP-20	34198.97	696628.81	3.66									
TP-21	33296.75	697488.38	3.35	X								
TP-22	32796.88	697604.19	3.66	X	H							
TP-3	34808.58	695836.31	5.18									
TP-4	34656.18	693672.19	3.66	X	CH			X	X			
TP-41	34793.34	696247.81	4.88	X	C			X				
TP-5	34320.90	693032.13	3.35	X	CH				X			
TP-6	33863.69	691934.81	3.96									
TP-7	35351.13	696558.69	3.05									

TESTS CONDUCTED

GLACIAL BORINGS

WELLNUM	CNORTH	CEAST	TOTALD	SIEVE ANALYSIS	PERMEABILITY TESTS	CARBONATE PEBBLE ANALYSIS	pH	COMPACTION TESTS	TRIAXIAL TESTS	CLAY ANALYSIS	CHEMICAL ANALYSIS	
TP-8	35387.71	696650.13	3.66									
TP-9	35345.04	696452.00	1.52									
TW-1	35626.00	694861.00	16.76		P						X	
TW-2	35443.33	693404.94	29.30									
TW-41	34787.00	696261.00	101.90	X	H			X				
WP-1L	33695.00	690497.00	10.52		FR							
WP-1U	33693.00	690497.00	1.83									
WP-2L	36483.00	691029.00	9.94		FR							
WP-2U	36484.00	691029.00	1.83									
WP-3L	36353.00	691301.00	10.06		FR							
WP-3U	36346.00	691295.00	3.35									
WP-4L	37124.00	693190.00	9.75		F							
WP-4U	37132.00	693189.00	3.11									
WP-5L	36842.00	693225.00	10.06									
WP-5U	36840.00	693224.00	1.52									
WP-6L	36044.00	697202.00	10.06		F							
WP-6U	36042.00	697203.00	1.98									
WP-7L	35505.00	697371.00	10.06									
WP-7U	35507.00	697371.00	1.83		FR							
WW-1	35632.53	694290.50	39.60								X	
WW-2	35492.00	693774.00	47.20		P							
WW-4	35409.34	694462.25	00		P							

PERMEABILITY LEGEND:

F – FALLING HEAD
H – HAZEN APPROXIMATION
C – CONSTANT HEAD
P – PUMP TEST
R – RISING HEAD

TESTS CONDUCTED

BEDROCK BORINGS

HOLE	CNORTH	CEAST	TOTALD	ASSAYS	UNIAXIAL COMPRESSIVE TESTS	TRIAXIAL COMPRESSIVE TESTS	POINT LOAD COMPRESSIVE TESTS	BRAZILIAN TESTS	CHEMICAL ANALYSIS	RADIOLOGICAL TESTING	PERMEABILITY TESTS	SPECIFIC GRAVITY
1	35406.52	693910.50	124.05	X								
2	35309.81	694279.83	294.74	X								X
3	35381.81	693907.03	271.88	X						X		X
4	35512.51	694385.89	323.09	X								X
5	35644.55	693535.86	259.30	X						X		X
6	35621.39	694268.14	401.12	X								X
7	35739.21	693293.14	422.70	X						X		X
8	35723.29	693414.77	353.87	X						X		X
9	35594.01	694639.32	384.66	X								X
10	35408.87	694875.45	197.51	X								X
11	35704.10	693780.15	442.26	X						X		X
12	35682.88	694024.19	428.85	X						X		X
13	35853.59	693782.04	667.21	X								X
14	35990.88	693783.02	932.08									X
15	35866.39	694511.07	882.40	X								X
16	35896.90	694269.44	1080.52	X						X		X
17	35833.96	694019.78	702.26	X						X		X
18	35733.56	693661.20	471.53	X						X		X
19	35792.31	694143.59	612.34	X								X
20	35593.36	694511.74	382.83	X								X
21	35751.88	694387.27	648.00	X								
22	35664.16	694144.31	428.85	X								X
23	35741.01	694510.15	577.29	X						X		X
24	35719.47	694632.37	632.76	X								
25	35821.29	693902.87	758.65	X						X		
26	35521.67	694754.09	369.11	X								X
27	35745.29	693171.02	492.30	X								
28	35657.29	694207.02	544.07	X	X			X		X		
29	35862.29	693660.08	683.97	X								
30	35872.05	693538.18	694.94	X								
31	35895.42	693416.03	742.19	X								
32	35863.33	693298.22	733.70	X								
33	35880.95	693173.03	58.22									
34	35656.48	694755.49	201.50	X								
35	35864.79	694023.37	808.94	X						X		
36	35959.87	693782.30	845.52	X								
37	35833.33	694269.01	860.76	X						X		
38	35849.60	693834.85	665.68	X								
39	35690.78	693231.56	486.50	X								
40	35689.59	693170.54	53.04									
41	35818.27	694085.00	637.03	X								
42	35805.00	694208.29	885.14	X								
43	36085.84	693415.34	1154.60	X								
44	35690.85	694390.06	473.66	X								
45	35835.20	694143.33	730.61	X								
46	35776.16	694634.11	845.52	X								
47	35779.31	693535.57	540.72	X								
48	35662.06	694755.49	674.83	X								
49	35600.08	694877.07	489.51	X								
50	35708.61	694755.60	289.56	X								
51	35623.44	694999.09	543.76	X								
52	35768.68	694755.71	437.10									
53	35532.74	693169.78	382.52	X								
54	35744.64	693902.69	552.60	X	X			X				
55	35728.31	695000.09	808.94	X								
56	35773.47	694269.23	179.53									

TESTS CONDUCTED

BEDROCK BORINGS

HOLE	CNORTH	CEAST	TOTALD	ASSAYS	UNIAXIAL COMPRESSIVE TESTS	TRIAXIAL COMPRESSIVE TESTS	POINT LOAD COMPRESSIVE TESTS	BRAZILIAN TESTS	CHEMICAL ANALYSIS	RADIOLOGICAL TESTING	PERMEABILITY TESTS	SPECIFIC GRAVITY
57	35852.22	693413.90	601.98	X								
58	35810.59	693297.25	495.91	X								
59	35619.37	694877.43	854.66	X								
60	35766.80	694813.32	1089.66	X								
61	35624.36	693780.66	392.30	X								
62	35652.82	694085.47	316.08	X					X			
63	35596.06	693779.61	213.06	X								
64	35697.47	693961.33	566.01	X					X			
65	35741.67	693661.71	593.14	X					X			
66	35664.67	693657.34	328.57	X				X		X	R	
67	35653.74	693962.15	389.53	X								
68	35722.63	693961.64	799.80	X								
69	35776.14	694269.45	591.31	X					X			
70	35629.72	694207.56	406.60	X				X		X	R	
71	35626.76	693536.46	202.39	X								
72	35625.19	693658.13	242.01	X								
73	35664.22	694512.69	690.37	X								
74	35628.87	694389.56	406.60	X								
75	35664.10	693411.73	260.91	X					X			
76	35578.45	693901.55	222.50	X								
77	35679.86	693353.93	319.74	X				X		X	R	
78	35686.06	693474.72	354.79	X					X			
79	35577.08	694024.21	244.14	X								
80	35544.88	694144.12	214.27	X								
81	35480.92	694510.46	181.97	X								
82	35638.11	693233.30	315.16	X								
83	35525.43	694754.27	546.81	X								
84	35540.12	694694.85	287.73	X								
85	35657.90	694329.81	402.03	X								
86	35433.31	694631.97	238.35	X					X			
87	35475.31	694266.49	157.28	X								
88	35625.58	693718.29	443.18	X								
89	35594.01	693840.28	434.04	X								
90	35628.19	693292.13	239.57	X								
91	35608.80	694572.24	434.34	X				X		X	R	
92	35587.88	694573.26	355.09	X								
93	35751.75	693415.17	522.43	X								
94	35619.38	694450.15	406.91	X								
95	35431.94	694692.70	327.05	X					X			
96	35745.70	693591.94	399.59	X								
97	35687.73	693536.85	110.95									
98	35734.83	694391.05	522.43	X								
99	35585.15	693236.44	261.21	X								
100	35837.54	693596.01	571.20	X								
101	35502.48	693778.88	144.78	X								
102	35517.72	693779.05	162.46	X								
103	35486.36	693778.69	123.75	X								
104	35471.22	693778.74	124.66	X								
105	35565.55	693535.73	158.50	X								
106	35534.92	693535.18	120.70	X								
107	35550.13	693535.39	149.35	X								
108	35519.74	693534.98	101.80	X								
109	35473.91	693900.28	128.93	X								
110	35458.83	693900.28	108.20	X								
111	35489.85	693900.13	163.07	X								
112	35518.76	693656.75	135.33	X								

TESTS CONDUCTED

BEDROCK BORINGS

HOLE	CNORTH	CEAST	TOTALD	ASSAYS	UNIAXIAL COMPRESSIVE TESTS	TRIAXIAL COMPRESSIVE TESTS	POINT LOAD COMPRESSIVE TESTS	BRAZILIAN TESTS	CHEMICAL ANALYSIS	RADIOLOGICAL TESTING	PERMEABILITY TESTS	SPECIFIC GRAVITY
113	35533.77	693656.77	175.87	X								
114	35503.60	693656.61	129.84	X								
115	35504.58	693534.85	92.96	X								
116	35504.88	693900.32	158.50	X								
117	35470.33	694022.69	124.97	X								
118	35407.01	694266.08	91.44	X								
119	35390.01	694509.70	99.06	X								
120	35372.49	694631.42	76.50	X								
121	35485.65	694022.95	121.92	X								
122	35875.59	693781.91	967.44	X						X		
123	35635.49	694754.94	601.68	X						X		
124	35712.42	694268.39	687.02	X						X		
125	35698.33	694085.82	467.56	X								
126	35776.80	693720.30	528.52	X								
127	35668.88	693901.99	574.24	X								
128	35787.89	694085.89	811.99	X								
129	35691.14	693536.87	443.18	X								
130	35663.44	694830.44	711.40									
131	35626.48	694633.43	930.55	X						X		
132	35626.77	694450.16	513.28	X								
133	35627.50	694329.54	851.61	X								
134	36315.00	692838.60	274.32	X								
135	37970.80	692619.00	306.63	X								
136	35559.21	691914.26	609.60	X								
137	35700.25	693961.55	1046.99	X								
138	35681.53	694330.41	731.22	X								
139	35775.68	693902.79	1076.25	X								
140	35877.78	694514.23	1053.08	X								
141	35787.89	694085.89	397.46									
142	35749.68	694331.42	255.73	X								
143	35577.77	694637.96	578.82	X			X					
144	35756.53	694450.77	242.62									
145	35743.92	693480.71	641.60	X						X		
146	35729.42	693719.50	739.14	X								
147	35999.55	694392.11	354.79	X								
148	36301.69	694609.99	103.02									
149	35675.32	694449.69	733.04	X						X		
150	35710.29	694208.47	654.70	X								
151	35834.87	694265.77	1179.88	X			X					
152	35679.33	694699.38	689.80	X						X		
153	35679.06	694704.17	843.08	X								
154	35662.80	694572.75	662.94	X								
155	35690.18	694394.77	913.76		X		X		X		R	
156	36303.31	694516.61	417.58									
157	36304.62	694395.43	391.36									
158	36299.91	694608.29	365.76	X								
159	35730.80	693841.36	790.96	X						X		
160	35769.71	694331.26	936.96	X			X			X		
161	35866.73	693661.81	822.96	X								
162	35746.91	693595.98	672.08	X								
163	35775.84	694630.05	1162.81	X								
164	36308.48	693870.22	397.46									
165	35778.53	694266.50	905.56	X					X		R	
166	35773.64	694908.03	848.87									
167	35770.04	694912.88	323.09									
168	36117.21	693914.57	359.66	X								

TESTS CONDUCTED

BEDROCK BORINGS

HOLE	CNORTH	CEAST	TOTALD	ASSAYS	UNIAXIAL COMPRESSIVE TESTS	TRIAXIAL COMPRESSIVE TESTS	POINT LOAD COMPRESSIVE TESTS	BRAZILIAN TESTS	CHEMICAL ANALYSIS	RADIOLOGICAL TESTING	PERMEABILITY TESTS	SPECIFIC GRAVITY
169	35598.35	694329.13	351.74	X			X			X		
170	35675.83	694447.92	568.45	X			X					
171	35519.87	694556.64	249.33	X	X							
172	35737.38	694512.13	527.61									
173	35680.83	694272.39	623.01	X	X		X					
174	35577.12	694636.45	406.60	X	X		X	X				
175	35570.74	694452.88	272.80	X			X					
176	35624.00	694447.44	416.97	X	X		X	X		X		
177	35595.80	694207.68	306.02	X			X					
178	35681.76	693470.46	224.94	X			X					
179	35744.46	693479.45	415.75	X	X	X	X	X				
180	35678.28	693351.51	244.14	X			X					
181	35845.51	693833.12	1037.84	X	X		X		X			
182	35776.77	693717.48	967.44	X			X					
183	35708.19	693353.27	376.10	X	X		X	X				
184	35644.98	693231.02	263.35	X	X		X	X				
185	35735.35	693658.64	528.83	X	X		X					
186	35746.91	693595.98	575.77	X								
187	35768.81	693900.98	146.30									
188	35624.22	693716.37	308.46	X	X	X	X	X		X		
189	35638.52	693851.03	295.05	X	X		X	X				
190	35819.08	694083.68	683.97	X			X					
191	35684.89	693597.99	288.34	X	X		X	X				
192	35778.53	694266.50	981.15	X	X		X		X			
193	35639.62	693957.85	290.47	X	X		X					
194	35656.67	694146.68	482.80	X			X					
195	35461.03	694631.29	137.77		X		X					
196	35583.55	693228.61	167.64		X		X					
197	35696.27	693959.48	483.41	X	X		X					
198	35793.31	693902.99	656.54	X			X			X		
199	34567.83	696896.97	594.66									
200	34367.08	695969.74	606.86									
201	35172.55	692029.47	619.96									
202	34772.59	691896.09	115.82									
203	33677.11	697130.39	611.12									
204	34356.23	696853.14	626.36									
205	34008.12	696989.36	610.82									
206	34671.34	696743.50	606.86									
207	34668.59	698006.56	85.80									
208	34785.18	691898.56	604.72									
209	35605.19	694406.32	325.53		X		X			X		X
210	35546.21	694610.91	277.83							X		X
211	35612.03	693839.82	298.86						X	X	P	X
212	35625.00	693798.00	214.58				X			X		X
213	35500.52	694499.63	268.07						X	X	P	X
214	35602.96	694408.83	382.52									X
216	35542.75	694199.75	356.31									X
217	35487.94	694520.66	254.20									X
218	35674.97	693747.90	366.06		X		X					X
219	35596.84	693840.02	200.25									
220	35577.20	693821.09	167.64									
221	35515.94	694449.70	213.36									
222	35501.83	694465.98	205.43									
223	35472.13	694495.70	165.81									
224	35476.22	694540.54	140.51									
225	35600.78	693758.93	68.27									

BEDROCK BORINGS				TESTS CONDUCTED								
HOLE	CNORTH	CEAST	TOTALD	ASSAYS	UNIAXIAL COMPRESSIVE TESTS	TRIAXIAL COMPRESSIVE TESTS	POINT LOAD COMPRESSIVE TESTS	BRAZILIAN TESTS	CHEMICAL ANALYSIS	RADIOLOGICAL TESTING	PERMEABILITY TESTS	SPECIFIC GRAVITY
226	35571.30	694217.96	242.31									
227	35544.17	694238.73	192.02									
228	35563.83	694166.90	230.12									
229	35522.66	694200.04	152.09									
230	35584.10	693856.56	202.38									
231	35584.95	693783.77	148.43									
232	35525.54	694362.59	226.46									
233	35701.00	693826.77	390.80	X	X		X	X				X
234	35778.00	693906.02	534.01	X	X		X	X				X
235	35735.00	694393.70	450.49	X	X			X				X
236	35705.00	693872.49	409.04	X			X					X
237	35735.00	693909.07	489.81	X	X		X	X				X
238	35756.00	693840.49	512.67	X	X		X	X				X
239	35704.00	693863.35	443.48	X		X	X	X				X
240	35624.00	694258.06	351.13	X	X	X	X	X				X
241	35666.00	694372.36	370.03	X								X
242	35597.00	694384.56	312.12	X								X
243	35788.00	693684.49	541.02	X	X		X	X				X
244	35706.00	693881.64	403.25	X	X		X	X				X
245	35726.40	694037.94	548.64	X	X		X	X				X
246	35709.98	694119.79	547.73	X	X		X	X				X
247	35708.61	694240.99	383.74	X		X	X	X				X
248	35655.71	694480.16	384.96	X	X		X	X				X
249	35683.08	694480.42	464.21	X	X		X	X				X
250	35594.89	694645.18	408.74	X	X		X	X				X
251	35633.41	694572.21	428.24	X			X	X				X
252	35787.14	694296.18	463.30	X	X	X	X	X				X
253	35568.60	693535.70	114.30								F	
254	35489.40	693778.70	132.59								F	
255	35534.00	694144.10	129.00								F	
256	35547.00	693534.30	120.09								F	
257	35253.20	693767.50	120.70								F	

PERMEABILITY LEGEND:

F – FALLING HEAD
R – RISING HEAD
P – PUMP TEST

TABLE 2.2-3

SUMMARY DOCUMENTS CONTAINING THE RESULTS OF GLACIAL AND BEDROCK TESTING

GEOTECHNICAL REPORT/ VOLUME	SECTION/ TABLE/ FIGURE	NAME OF SUMMARY DOCUMENT
Report 1[a]		
Vol. 1	Fig. 4.2	Grain Size Distribution Summary: Site 40 Till
Vol. 1	Fig. 4.3	Grain Size Distribution Summary: Site 41 Till
Vol. 1	Fig. 4.4	Grain Site Distribution Summary: Site 40 Cse Strat. Drift
Vol. 1	Fig. 4.5	Grain Size Distribution Summary: Site 41 Cse Strat. Drift
Vol. 1	Fig. 4.6	Grain Size Distribution Summary: Site 40/41 Fn Strat. Drift
Vol. 1	Fig. 4.7	Grain Size Distribution Summary: Outwash
Vol. 1	Fig. 4.8	Grain Size Distribution Summary: Site 40/41 Lacustrine
Vol. 1	Table 4.1	Summary of Glacial Material Properties
Vol. 1	Table 4.2	Summary of Bulk Sample Test Results
Vol. 1	Table 4.3	Carbonate Content Test Results
Vol. 1	Table A-1	List of Test Borings by Phase
Vol. 1	Table C-2	Permeability Estimates by Hazen's Approximation
Vol. 2	Fig. V2-12	Permeability Test Results - TP Series
Report 2[b]		
Vol. 2	Sec. 2.2.2 Table 2.2-2	Results of Soil pH Analyses

[a]Geotechnical Review, Crandon Project Waste Disposal System, October 1981, Golder Associates.

[b]Environmental Impact Report, Crandon Project, December 1982, Exxon Minerals Company.

[c]Geohydrologic Characterization, Crandon Project, May 1982, Golder Associates.

[d]Results of Geologic, Geotechnical and Hydrologic Investigations of a Portion of the Proposed Exploration Ramp, August 1977, Dames & Moore.

TABLE 2.2-3 (continued)

GEOTECHNICAL REPORT/ VOLUME	SECTION/ TABLE/ FIGURE	NAME OF SUMMARY DOCUMENT
Report 2[b] (cont'd)		
Vol. 2	Sec. 2.2.2 Table 2.2-3	The Color of Soil Samples Based on Munsell Classification
Vol. 2	Sec. 2.2.2 Table 2.2-4	Results of Carbonate Pebble Content Analysis
Vol. 2	Sec. 2.2.2 Table 2.2-5	Results of Clay Mineralogy Analysis
Vol. 2	Sec. 2.3.1.4 Table 2.3-6	Summary of Permeability Tests
Vol. 2	Sec. 2.3.3.5 Page 2.3-28	Summary of Range of Permeabilities for Glacial Drift in Site Area
Vol. 2	Sec. 2.3.3.6 Page 2.3-29	Summary of Aquifer Characteristics
Vol. 2	Sec. 2.3.3.7 Table 2.3-7	Summary of Bedrock Permeabilities
Vol. 2	Sec. 2.3.4.1 Table 2.3-8	Summary of Ground Water Quality for Principal Aquifers
Vol. 2	Sec. 2.3.4.1 Table 2.3-9	Summary of USGS Ground Water Quality Data
Vol. 2	Sec. 2.3.4.2 Table 2.3-11	Results of Chemical Analysis of Bedrock Ground Water Samples
Vol. 7	Appendix 2.3E	Results of Field Permeability Tests
Vol. 7	Appendix 2.3F	Results of Laboratory Permeability Tests and Hazen Permeability Approximations
Report 3[c]	Table 4.1	Hydrologic Parameter of Overburden and Orebody
Report 4[d]	Table 1	Results of Laboratory Permeability Tests

including particle size by both sieve and hydrometer analysis, carbonate pebble content, Atterberg limits, moisture content, pH, color, and clay mineral species. American Society for Testing and Materials (ASTM) procedures were used to perform these tests of the soil material samples. Additional information on soil testing methodologies is presented in EIR subsection 2.3.1 as well as in Golder Associates (1981).

Particle Size - Particle size, or sieve analysis, is a quantitative determination of the distribution of particle sizes in a soil mass. The procedure used consisted of separating the samples into a series of fractions using a 75-mm (3-inch), 50-mm (2-inch), 37.5-mm (1.5-inch), 25.0-mm (1-inch), 19.0-mm (0.75-inch), 9.5-mm (0.38-inch), 4.75-mm (0.19-inch [No. 4]) and 2.00-mm (0.08-inch [No. 10]) sieves, or as many as may be needed depending on the sample or upon the specifications for the soil material under test. The mass of each fraction was then determined to 0.1 percent, and a percent weight was calculated. This procedure is in accordance with ASTM Standard Method for Particle Size Analysis of Soils (American Society for Testing and Materials, 1977) with the following exceptions:

- o The test was extended to and included the No. 200 U.S. Standard sieve 0.075-mm (0.003-inch); and
- o There was no further testing unless specifically requested, if the results indicated that less than 25 percent of the soil materials were finer than the No. 200 U.S. Standard sieve.

For a more complete description of the procedure, the reader is referred to ASTM Part 19 Standard Method D-422, Particle Size Analysis of Soils.

Hydrometer - Hydrometer analysis is a continuation of the particle size distribution analysis. Soil particles finer than 0.075 mm (0.003 inch) are too fine for the sieving process. Their distribution was determined by the sedimentation method measured by a hydrometer. The procedure used consisted of dispersing 50 to 100 g (1.75 to 3.5 oz.) of air dried sample with sodium-hexametaphosphate solution. After dispersion the sodium-hexametaphosphate solution was replaced with distilled or demineralized water, placed in a glass sedimentation cylinder, and agitated. Hydrometer readings (a density measure of the suspension) were then taken at intervals of 2, 5, 15, 30, 60, 250 and 1,440 minutes after sedimentation began, or as needed depending on the sample. The percentages of silt, clay, and colloid content were then calculated from these readings. This procedure is in accordance with the ASTM Standard Method for Particle Size Analysis of Soils. For a more complete description of this procedure, the reader is referred to ASTM Part 19, Standard Method D-422, Particle Size Analysis of Soil.

Carbonate Pebble Content - The particle size analyses (discussed above) were also used to obtain quantitative estimates of the amount of carbonate fragments in the gravel from the DM-series borings and from the G41-G15 series borings. For the DM-series borings, each portion of the tested sample retained on the No. 4 U.S. Standard sieve was examined and the number of carbonate pebbles was identified by their reaction to acid. The results of the analyses were expressed as a percentage (by weight) of the total pebble content of the sample. For the G41-G15 series borings, the entire grain size range of each sample was included in tests performed in accordance with ASTM procedure D3042-72.

Atterberg Limits - Atterberg limits are the water content boundaries of various states of a soil mass in terms of liquid limit (the boundary between liquid and plastic states), plastic limit (the boundary between plastic and semisolid states), and plasticity index (the difference between the liquid and plastic limits). These boundaries are expressed as a percentage of water in the amount of dry soil by weight.

The liquid limit is defined by convention as the water content at which two halves of a soil cake will flow together for a distance of 2.7 mm (0.5 inch) along the bottom of a groove separating the two halves when the cup, or container is dropped 25 times from a distance of 1 cm (0.3937 inch) at a rate of 2 drops/s. Tests were performed in a 1.8-cm (4.5-inch) porcelain evaporation dish-drop utilizing a mechanical liquid limit device. The plastic limit is defined by convention as the lowest water content at which the soil can be rolled into threads 3.2 mm (0.125 inch) in diameter without the thread breaking into pieces. Tests were performed by rolling a test sample into an ellipsoidal-shaped mass and dividing it into pieces. Each of these pieces in turn was formed into an ellipsoidal shape and then rolled at a rate of between 80 and 90 strokes/minute until a diameter of 3.2 mm (0.125 inch) was reached. This process was continued until the sample crumbled under the pressure required to roll. The moisture content was then determined by weighing, drying, and reweighing. These procedures are in accordance with ASTM Standard Methods. For a more complete description of the procedures, the reader is referred to ASTM Standard Method D-423, Standard Test Method for Liquid Limits of Soil and D-424, Standard Test Method for Plastic Limit and Plastic Index of Soil.

Moisture Content - Moisture content is expressed as a ratio of the weight of water and dry weight of solid in a given soil mass. It is used to determine dry density, degree of saturation, various indices, and for correlation with other soil parameters. The procedure used consisted of weighing the moist soil sample in a container of known weight, drying the sample to a constant weight in a 110°C ± 5°C (230°F ± 9°F) drying oven, and reweighing the sample. The percent moisture was then calculated. A more complete procedure is given in ASTM Standard Method D-2216, Moisture Content Determination of Soil.

Hydrogen Ion Activity - The hydrogen ion activity (pH) was measured with a pH meter. The procedure used is in accordance with the ASTM suggested method for hydrogen ion activity of peat material with the following exceptions:

- 25 g of soil sample and 100 ml of distilled water were used; and
- 24 hours were allowed for soaking.

The deviation from the ASTM methodology was considered necessary because ASTM methods for pH are for peat materials, not for the soil types encountered in the borings, and, therefore, were considered inappropriate. The soil pH method employed by Dames & Moore, in the absence of an ASTM standard method, has been widely used throughout the industry.

Color Test - The color test was performed during the particle size analyses. The color of the suspended silt/clay fraction was determined by comparison using a Munsell soil color chart (Munsell Color, 1975).

Clay Mineralogy - Eighteen samples of the glacial materials encountered were selected for clay mineral analyses. Samples were selected from different borings that exhibited measurable traces of clay and silt size particles in the opinion of the investigator and represented samples with the relatively highest fractions of clay and silt. All determinations were based on X-ray diffraction analysis performed by Dr. F. Michael Wahl, Department of Geology, of the University of Florida, Gainesville.

Asbestiform Materials - During the logging and relogging of the Crandon bedrock core, special efforts were taken to examine the core for the presence of asbestiform minerals. A binocular microscope (7-30 X) was used to aid in mineral identification.

Fifty-four thin sections were prepared from core from 14 drill holes intersecting the 185 and 140 m levels at the Crandon deposit. A Leitz SM-LUXPOL polarizing petrographic microscope with objectives of 2.5/0.08, 10/0.25, 40/0.65, and 63/0.85 was used for the examination of core thin sections.

The location of samples was verified by Wisconsin Geologic and Natural History Survey geologists by selecting a core thin section that could easily be matched to the sample chip by some diagnostic geologic feature. The chip was then matched to the core interval. At least one sample was checked from each hole so that a minimum of 26 percent of the sample locations were verified.

All 54 thin sections were examined by geologists from the DNR. The geologists verified the absence of asbestiform minerals in thin sections and the core intervals examined during the verification process.

In consideration of air quality concerns, the following summary of the analyses indicates (1) no asbestiform minerals, such as chrysotile and the fibrous amphibole polymorphs of actinolite, tremolite, grunerite, cummingtonite, anthophyllite, and riebeckite, have been found in the samples; and (2) the bedrock at Crandon is low grade metamorphic rock. The temperature-pressure conditions during metamorphism have not been high enough to develop the amphibole polymorphs. Therefore, the metamorphic grade precludes an asbestiform mineral source and supports the conclusion.

Bedrock Testing - Testing of bedrock materials, or performing various tests in bedrock boreholes, began at project inception and has continued through 1984. The following list summarizes the type of testing work: assays, uniaxial compressive testing, triaxial compressive testing, point load compressive testing, tensile strength testing, chemical analysis, radiological testing, permeability testing, and specific gravity testing. The primary purposes of testing bedrock materials and boreholes are ore body definition, feasibility engineering, and preliminary mine and site engineering. Numerous Exxon and geotechnical contractor reports cover the various bedrock tests outlined above.

Testing of bedrock materials was also performed as part of the geological study of the deposit and surrounding rocks. Major geological studies on drill core included petrography, sulfide and silicate mineralogy, ore microscopy, major and trace element geochemistry, oxygen and sulfur isotopes, fluid inclusions, microprobe studies of sericite and chlorite, and age dating. The primary purposes of such geological studies were to define stratigraphy and understand the sulfide mineralogy. Reports covering bedrock testing and methodology, which have been provided to the DNR, include Dames & Moore (1978), Exxon Minerals Company (1980), and Hazleton Environmental Sciences (1981).

Specific gravity determinations were both calculated and measured. Several hundred calculations were made from the percentages of copper, zinc, lead, and sulfur. The sulfur was allocated to copper for chalcopyrite, to zinc for sphalerite, to lead for galena, and the remainder to percent pyrite. These calculations are based on typical specific gravity for the minerals as well as typical chemical compositions assuming the sphalerite has 2 percent iron replacing the zinc. Several hundred specific gravity measurements were also made by weighing the sample in water versus air.

2.2.1.5 Quality Control

Quality control procedures were utilized by field and office personnel, as well as by subcontracted laboratory personnel, during the glacial and bedrock drilling, sample acquisition, and laboratory testing as a means of assuring that the work was completed according to currently accepted standards and methods.

Exxon does not maintain contractor quality control data in our files. It is the responsibility of the contractor to maintain these data files. The remaining paragraphs in this quality control subsection explain the general procedures used by Exxon and contractor personnel to help assure quality control. Laboratory testing procedures are also described in Appendix B of the report by Golder Associates (1981).

Field Procedures - All drilling operations were supervised by qualified field representatives who classified the soils encountered in the test borings and were responsible for sample collection for laboratory testing.

All piezometer installations were supervised by an Exxon or geotechnical contractor field representative who maintained a record of piezometer construction details. In addition, the development of the piezometer after construction was monitored. Piezometer construction information and piezometer development data were reported on daily memos of field activities.

Recordings of ground water levels in piezometers, ground water sampling from piezometers, and in-situ permeability tests were conducted by trained Exxon or geotechnical contractor personnel. In addition to recording these activities on daily memos of field activities, the resulting data were recorded on special forms designed for each activity.

Analytical Quality Control - Monitoring of analytical performance was accomplished by the analysis of duplicate ("split") samples. Duplicates were handled as regular samples and were included in a specific sample analysis sequence.

Approximately every tenth sample submitted to the laboratory was split into duplicate samples with the same designated sample number. The second portion of the sample was designated "QA." The analysis of the "QA" sample was used to document that reproducible data were being generated by comparison of the data with the known precision of the analytical method. Precision specifies the upper and lower control limits for test results as compared to a standard deviation. The standard deviation accepted for the various parameters can be found in publications of the U.S. EPA (1974) or APHA et al. (1976), or it can be derived from the data.

Approximately every twentieth sample submitted to the laboratory was split into triplicate subsamples. Each of these subsamples retained the same designated sample number. The second subsample was additionally designated "QA" and the third "spike." The "QA" subsample was analyzed as described in the preceding paragraph. The "spike" portion was spiked with known concentrations of the parameters being analyzed. The analysis of the percent recovery of the known quantities was used to assess whether the procedure was reliable and was measuring within an acceptable range of accuracy. The lower control limit for recovery is based on the standard deviation accepted for the various parameters by the U.S. EPA (1974) and APHA et al. (1976), or it can be derived from the data.

As part of the quality control program for the present study, samples were split at intervals specified by the DNR or as part of in-house QA/QC. These splits were conducted in the field for separate analysis by Aqualab, Inc., and the DNR. The Aqualab laboratory facilities were also audited by Dames & Moore, DNR, and Exxon personnel regarding laboratory analysis records and compliance with procedures outlined in the Quality Assurance Manual.

Constant head and falling head laboratory tests were performed using a constant head permeameter in accordance with ASTM methods. All laboratory equipment was calibrated in accordance with the geotechnical contractors' standard soils laboratory procedures.

Laboratory Procedures - Pertinent sample history and analytical data for soil samples were recorded on standard laboratory sheets. All test procedures were in accordance with ASTM methods. All laboratory equipment was calibrated in accordance with the testing firms' standard soils laboratory procedures.

Data Analysis - All data were rechecked by an Exxon or geotechnical contractor employee other than the original investigator. This review included checking of all calculations, tables, graphs, maps, and figures a minimum of two times before incorporating them into a report.

Procedures for Handling and Assay Analysis of Geological Samples - The following quality control procedures were followed by Exxon in preparation of assay pulps:

1) Assay intervals were marked on the drill core by the geologist. The core boxes were transported from the warehouse to the sample preparation laboratory.

   a) Bags were prepared for samples.

   b) Tags were prepared for identifying the assay intervals, usually 1.5 m (4.9 feet), in the core boxes.

   c) Assay intervals were then recorded in numerical order.

2) The laboratory and equipment were cleaned.

3) The core was split in half using a hydraulic splitter.

   a) Half of the core was returned to the core box.

   b) The other half of the core fell into a clean collection bucket.

   c) The splitter station was cleaned.

4) The split interval was then crushed to minus 3/4 inch using a jaw crusher.

5) The crushed material was then put through a Jones splitter to obtain a representative sample. A 1/8 split was collected in a clean tray. The reject was stored in the warehouse. The entire unit was cleaned.

6) The 1/8 split was then put through a gyro crusher, where it was reduced to minus 1/8 inch. The crusher station was cleaned.

7) The sample material was then pulverized to minus 200 mesh. The pulverizer was cleaned.

8) The pulp was then rolled 50 times on a clean rubber mat to ensure a proper sample mixing. The area was cleaned.

9) One hundred grams of rolled pulp were then put into a pulp envelope and mailed to the assay laboratory. The remainder of the pulp was stored in the warehouse.

10) The assay pulp was shipped to Skyline Assay Laboratory of Tucson, Arizona. A duplicate umpire sample was prepared from every tenth pulp and shipped to Union Assay Laboratory for analysis. If a significant discrepancy was found, the procedure was for the laboratories to rerun the pulps. If discrepancies still existed, the procedure was for the laboratories to switch pulps and rerun the analysis. It would then be apparent whether the problem was with the laboratory or with Exxon's sample pulp preparation.

When the samples first arrived at the Skyline Assay Laboratory, they were checked against the transmittal form to determine that the sample numbers and the total number of samples were identical. Each group of samples was assigned a job number. Assignment of job numbers was based on the "California License Tag" system. On the Crandon Project, the first job number was TBQ-001, and subsequent jobs followed as TBQ-002, etc. All of the samples, laboratory work sheets, final reports, and invoicing were marked and coded to this system. A second review of the samples and corresponding paperwork was completed before they were given to a laboratory supervisor.

The supervisor assigned the job to various laboratory personnel to perform the analysis for copper, lead, and zinc. A portion of the samples was carefully weighed into 200-ml volumetric flasks. The first and every tenth sample were resampled at the end of each job, along with known standard samples and a blank for control purposes. The samples were then subjected to vigorous hot mineral acid dissolution, cooled, diluted to a known volume, and analyzed by standard atomic absorption techniques. The corresponding values were reported in percentages.

Gold and silver were determined by a standard fire assay procedure with check assays on the higher values in each job. Values were reported in ounces per ton.

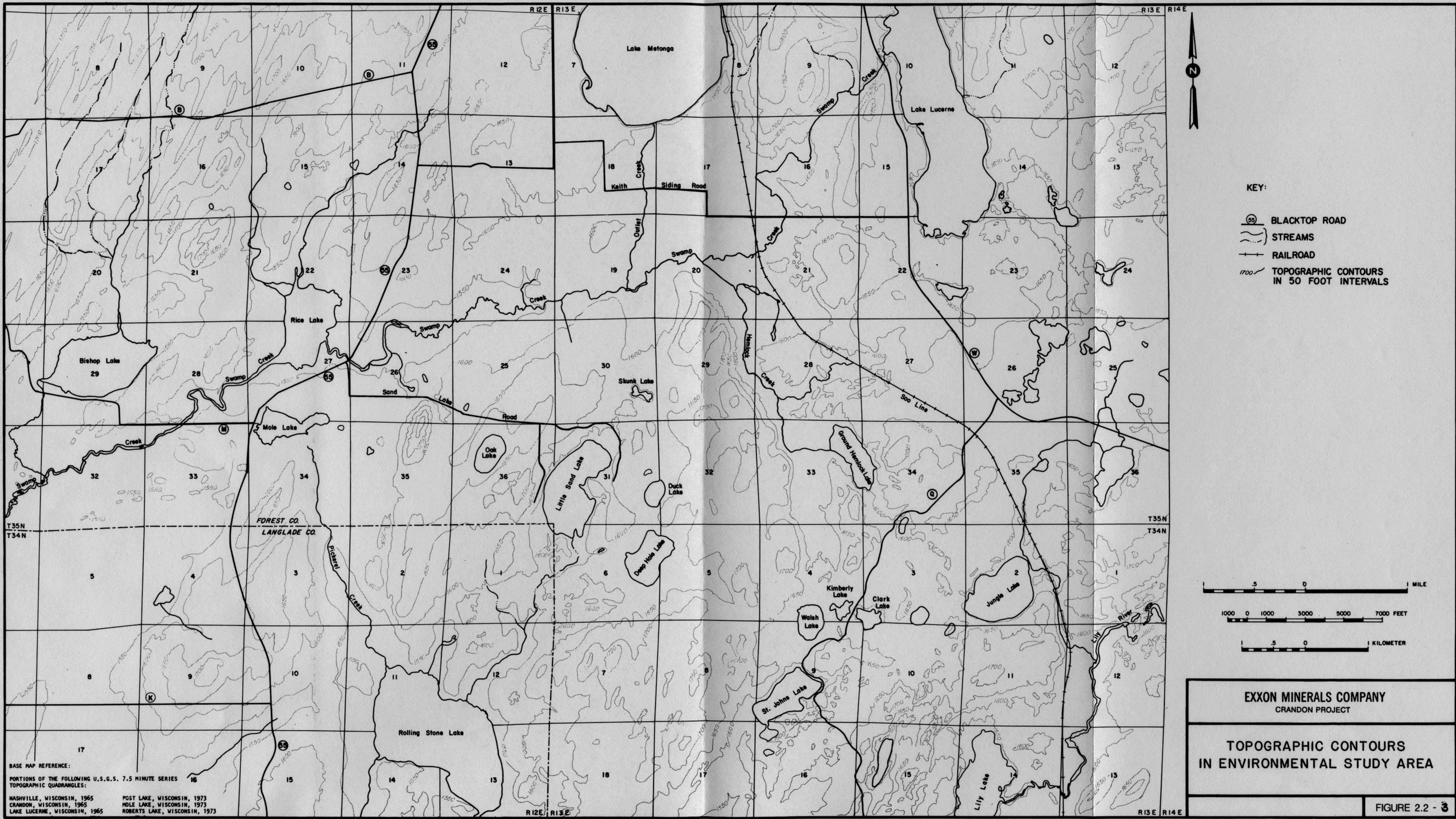
Upon completion of the laboratory work, the supervisor checked the control samples and calculations, after which the job was submitted to be printed in final report form. The reports were reviewed for typographical errors and a final check of the laboratory analysis before mailing to Exxon. The remaining pulp was also returned to Exxon.

2.2.2 Environmental Study Area Geology

2.2.2.1 Physiography

The environmental study area is located within the Northern Highlands physiographic province (Martin, 1965), a region of rolling terrain that reflects its glacial origins. Figure 2.2-3 illustrates the topographic features of the area. Ground surface elevation in the environmental study area ranges from less than 472 m (1,550 feet) MSL near Rolling Stone Lake, approximately 5 km (3 miles) south of the ore deposit, to more than 533 m (1,750 feet) MSL, approximately 8 km (5 miles) northwest of the ore body.

The ground surface in the environmental study area is variable, from nearly flat in floodplain and basin areas to a grade of approximately 25 percent. Topography in the study region is characterized by a general southwest trend of the ridges and intervening valleys. This trend reflects the southwesterly advance of the most recent Woodfordian glacier, which reshaped the preexisting topography. Processes associated with the Woodfordian glacier deposited new material on the reshaped uplands and



EXXON MINERALS COMPANY
CRANDON PROJECT

TOPOGRAPHIC CONTOURS IN ENVIRONMENTAL STUDY AREA

FIGURE 2.2 - 3

valleys. This southwest trend is especially apparent in the upland areas of the regional study area 8 to 16 km (5 to 10 miles) northwest of the deposit where elongated elliptical ridges, or drumlins, have approximately 30 m (100 feet) of vertical elevation. The southwest trend is also apparent in the Swamp Creek valley and in the orientation of the prominent ridges south of Mole Lake and immediately to the east and west of the ore deposit (Figure 2.2-3).

2.2.2.2 Bedrock Geology

The bedrock in northern Wisconsin is similar to and is the southern extension of a province of the Canadian Shield, referred to as the Southern Province. This Province is one of seven Canadian Shield rock provinces consisting of rocks ranging in age from 960 to 3,200 million years (Table 2.2-4) (Van Schmus et al., 1975; Van Schmus, 1976).

Volcanic rocks are found within the Southern Province as irregularly shaped belts surrounded by granitic and gneissic rock (Figure 2.2-4). These belts are comprised of volcanic flows and pyroclastics with interbedded sedimentary rocks such as shale, sandstone and conglomerate. Locally, the volcanic belts are intruded by large masses of granite or granodiorite. It is within these volcanic belts that massive sulfide deposits may be found.

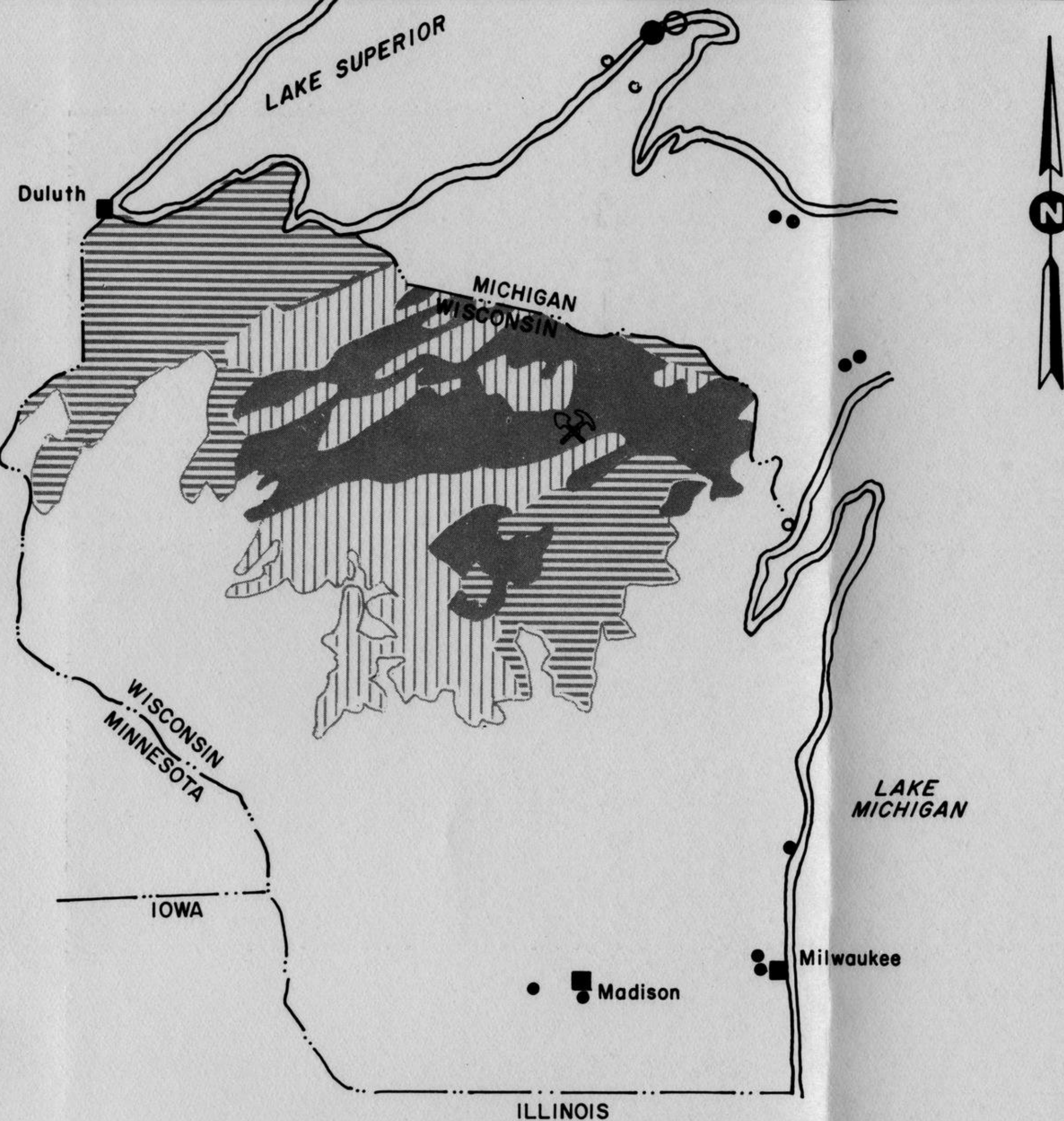
A massive sulfide deposit is generally defined as a tabular shaped body consisting of more than 50 percent sulfide by volume. The principal sulfide mineral found in these deposits is pyrite (iron sulfide) with lesser amounts of sphalerite (zinc sulfide), chalcopyrite (copper sulfide), galena (lead sulfide), and trace amounts of gold and silver. Many massive sulfide deposits are underlain by a stockwork of chalcopyrite veinlets that may contain quartz and pyrite.

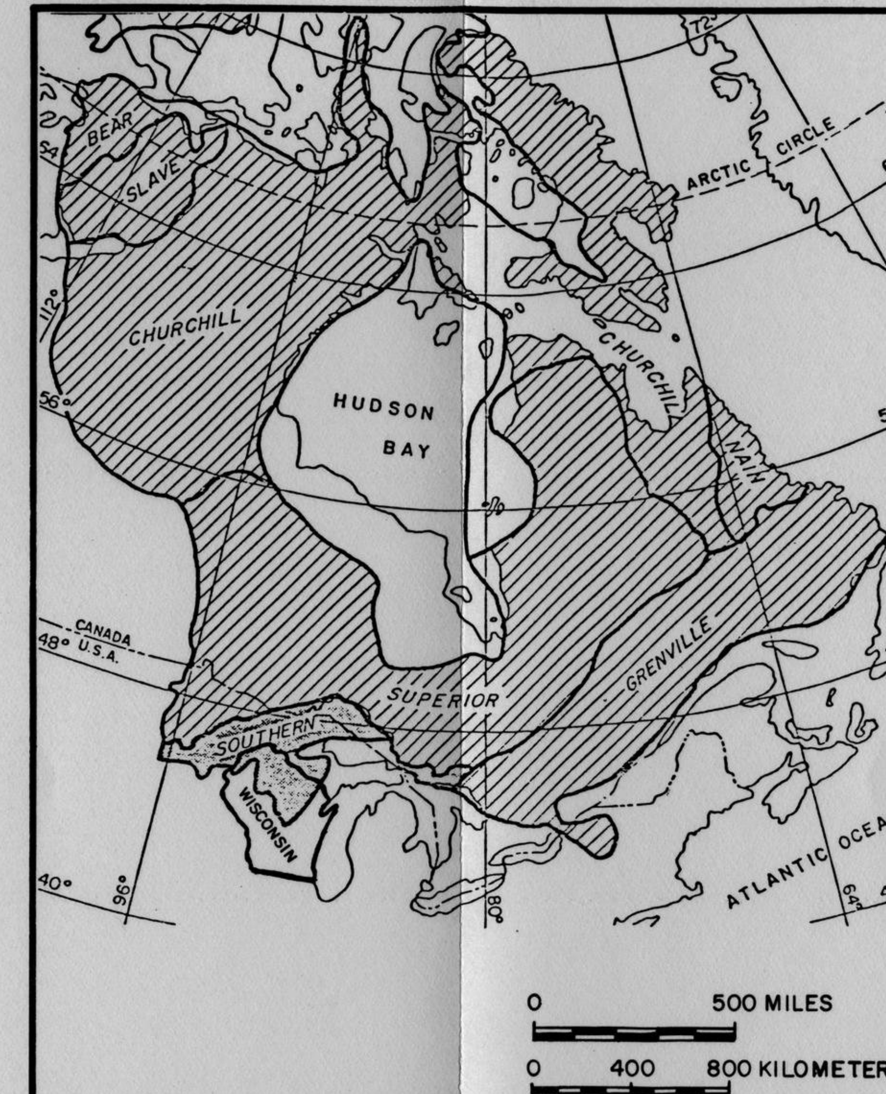
TABLE 2.2-4

THE GEOLOGIC TIME SCALE*

ERA	PERIOD	EPOCH	AGE	APPROXIMATE NUMBER OF MILLION YEARS AGO
	Quaternary	Recent		
		Pleistocene		0.007-2.0
			Wisconsinan	0.007-0.075
			Valderan	0.007-0.011
			Twocreekan	0.011-0.0125
			Woodfordian	0.0125-0.022
			Farmdalian	0.022-0.028
			Altonian	0.028-0.075
Cenozoic			Illinoian	
			Kansan	0.075-1.6
			Nebraskan	
		Pliocene		1.6-5.3
		Miocene		5.3-23.7
	Tertiary	Oligocene		23.7-36.6
		Eocene		36.6-57.8
		Paleocene		57.8-66.4
Mesozoic	Cretaceous			66.4-144
	Jurassic			144-208
	Triassic			208-245
Paleozoic	Permian			245-286
	Pennsylvanian			286-320
	Mississippian			320-360
	Devonian			360-408
	Silurian			408-438
	Ordovician			438-505
	Cambrian			505-570
Precambrian		Late		570-1600
		Middle		1600-2500
		Early		>2500

*Holmes, 1965; Hadley, 1976; Decade of North American Geology, Geology, 1983.





LOCATION OF THE SOUTHERN PROVINCE, CANADIAN SHIELD

EXPLANATION:

PALEOZOIC SEDIMENTARY ROCKS

LATE PRECAMBRIAN: 600-1600 M.Y.

MIDDLE PRECAMBRIAN: 1600-2500 M.Y.

EARLY PRECAMBRIAN: 2500 M.Y. AND OLDER

EPICENTER	MODIFIED MERCALLI INTENSITY
●	I - IV
∘	I - IV AND II - VI
○	VII
●	VIII

CRANDON DEPOSIT

REFERENCE:

1. U.S.G.S. AND AAPG, 1962.
2. SIMS, 1976.
3. DOCEKAL, 1970.
4. KING AND ZIETZ, 1971.

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REGIONAL GEOLOGY AND EARTHQUAKE EPICENTER MAP

FIGURE 2.2-4

In Wisconsin, three major ages of Precambrian rocks are exposed. Of these, the Middle Precambrian rocks are of interest in the study region and are described below.

1) Early Precambrian (older than 2,500 million years). Rocks in the Early Precambrian are among the oldest in North America. Most of the rock is granitic gneiss, about 3,200 million years old, containing minor amounts of volcanic rock that have been folded and intruded by granite (Sims, 1976; Sims and Peterman, 1976) (Figure 2.2-4).

2) Middle Precambrian (1,600 to 2,500 million years). Beginning about 2,100 million years ago, sediments began to accumulate in northeastern Wisconsin. Perhaps the most important sediments deposited were the iron formations which host the iron ore of the Gogebic and Florence areas (James et al., 1968). To the south, flows and volcanic sediments were deposited in a large trough extending across Wisconsin from Ladysmith to Marinette. It is within this volcanic belt that the massive sulfide ore deposits at Ladysmith (Flambeau and Thornapple), Rhinelander (Pelican) and Crandon are found. About 1,800 million years ago, during the Penokean Orogeny, this volcanic belt was faulted and folded and intruded by granite (Goldich, 1972; Maass et al., 1977). Erosion followed and quartz-rich sandstone was deposited to the south and west in the vicinity of Rusk and Barron counties.

3) Late Precambrian (600 to 1,600 million years). During this period quartz-rich sandstone continued to be deposited in western Wisconsin. About 1,500 million years ago, a large body of granite, the Wolf River batholith, was emplaced in east-central Wisconsin (Van Schmus et al., 1975).

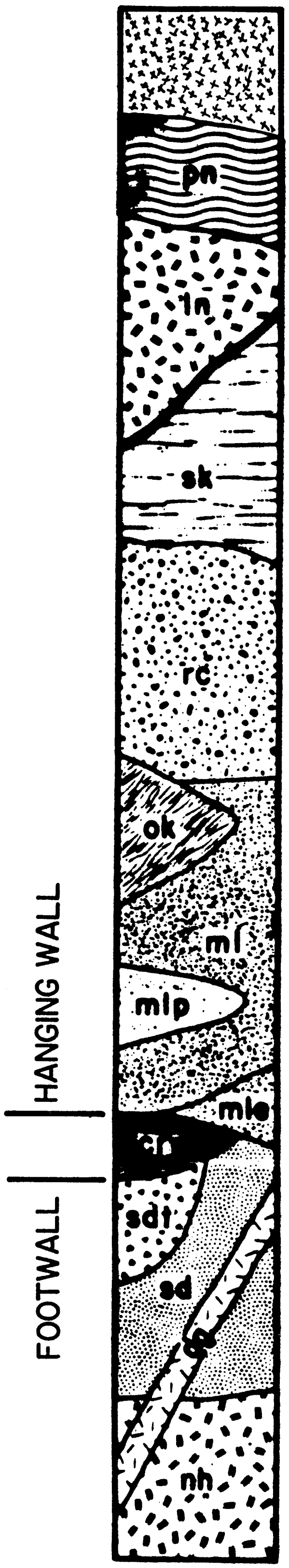
   The northernmost area of Precambrian rock in Wisconsin is composed of a sequence of basaltic flows with interbedded sedimentary rocks. These basalt flows accumulated in a large trough or rift, which formed about 1,100 million years ago and extended from Lake Superior into Kansas; a distance of over 1,600 km (1,000 miles) (Sims, 1976). Deposits of copper occurred in some of these rocks in the Upper Peninsula of Michigan. Near White Pine, Michigan, deposits of copper sulfide are found in a shale.

There has been no major folding, faulting, or igneous activity in the Southern Province of the Canadian Shield since the Precambrian era.

The bedrock geology of the site area is the result of the synthesis and interpretation of data from several sources. The data were gathered from 257 diamond core drilling holes in the ore deposit and in surrounding areas. Two seismic programs also provided data and included a refraction seismic survey conducted near the ore body by Exxon contractors and a seismic survey performed near Mole Lake by the U.S. Geological Survey (USGS) (Lidwin, 1980; Golder Associates, 1981).

The Crandon bedrock was formed during two volcanic cycles that deposited rock referred to as the Hemlock Creek and the Swamp Creek groups (Schmidt et al., 1978). Each group is subdivided into formations that are composed of rock of a similar lithologic character and depositional history. Frequently, members of distinct lithologic character have been identified in the formation. The Crandon stratigraphic section is summarized on Figure 2.2-5.

A plan view showing the subcrop geology of the site area is presented on Figure 2.2-6. In the vicinity of the mine/mill site, the geologic formations described in the stratigraphic section (Figure 2.2-5) are used. Outside the mine/mill site where formational names have not been assigned, descriptive geologic terminology was used. All of the diamond drill core holes outside the mine/mill site are located on the map and the trace of the drill hole plotted. Because of plotting density, all of the nearly 200 holes in the mine/mill site were not plotted. Four associated cross sections, A-A' through D-D', are presented on Figures 2.2-7 through 2.2-10, respectively. Stratigraphic and lithologic descriptions of the geology of the site area are presented in the following paragraphs. Figures 2.2-5 through 2.2-10 provide supporting documentation for these descriptions.



SWAMP CREEK GROUP

FOREST FORMATION (ft)
Muddy sandy sediments containing much terrigenous debris.

PINE FORMATION (pn)
Predominately a basinal sequence of cherty tuff , argillite and slump breccia.

LINCOLN FORMATION (ln)
Porphyritic flows with minor interflow tuff , chert and argillite.

HEMLOCK CREEK GROUP

SKUNK LAKE FORMATION (sk)
Predominately a basinal sequence of cherty tuff , chert , argillite , and slump breccia.

RICE LAKE FORMATION (rc)
A series of volcanic debris flows (blocky chloritic and minor siliceous lapilli and breccia size debris) and eutaxitic ash flows.

OAK LAKE FORMATION (ok)
A predominately basinal sequence of cherty tuff and sericitic tuff.

MOLE LAKE FORMATION (ml)
Predominately a homogenous , chloritic tuff.

PROSPECT MEMBER (mlp)
A volcanic debris flow consisting of siliceous , lapilli size debris.

EAGLE MEMBER (mle)
A volcanic greywacke.

CRANDON FORMATION (cr)
A basinal sequence comprised of massive sulfide , argillite , tuff , chert , and dolomite.

SAND LAKE FORMATION (sd)
A volcanic sequence of fine tuffs and minor debris flows.

TOWNSHIP MEMBER (sdt)
A volcanic vent breccia complex consisting of poorly sorted , anguler lithic debris.

DUCK LAKE GABBRO (dg)

NASHVILLE FORMATION (nh)
Porphyritic flows.

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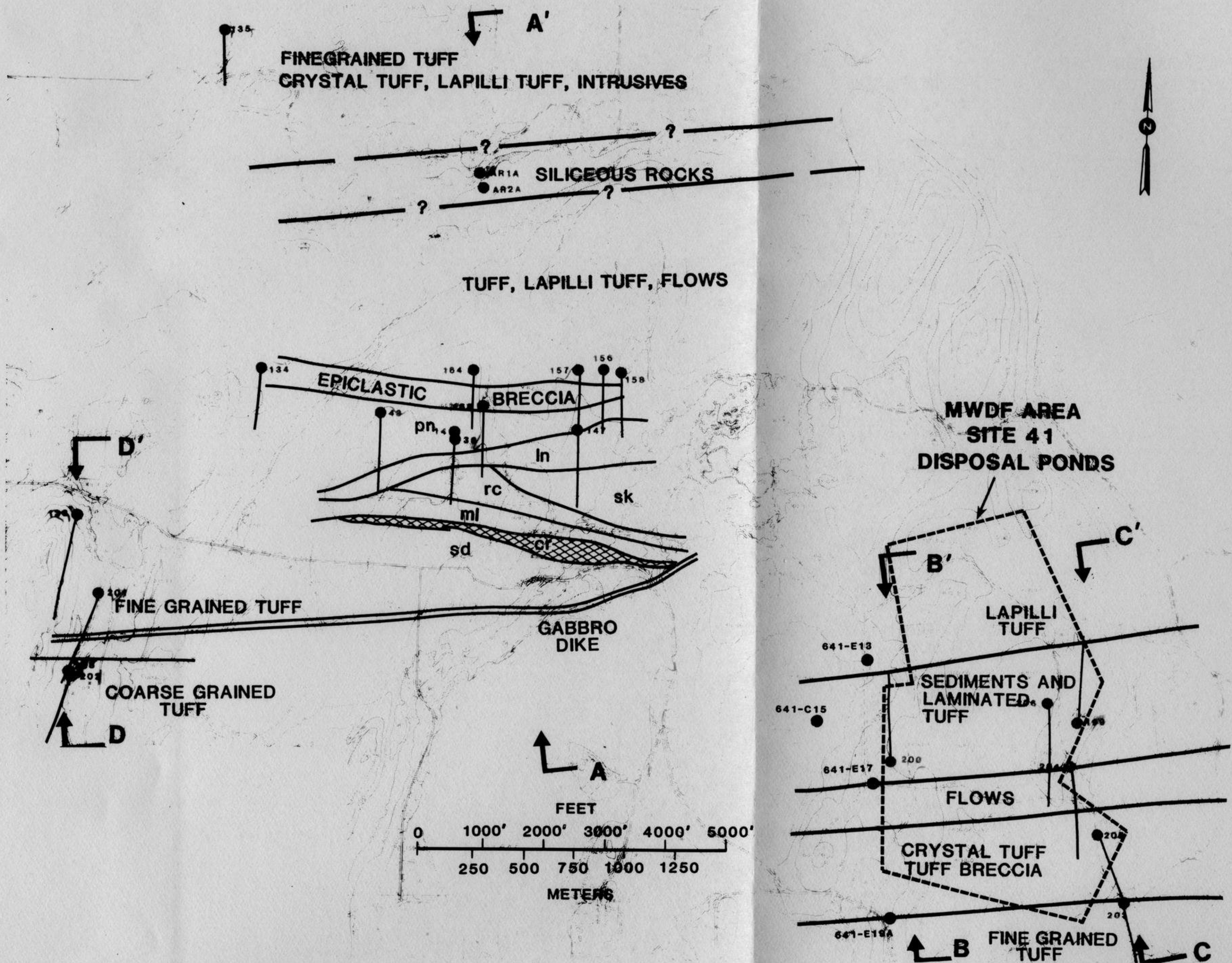
STRATIGRAPHIC COLUMN

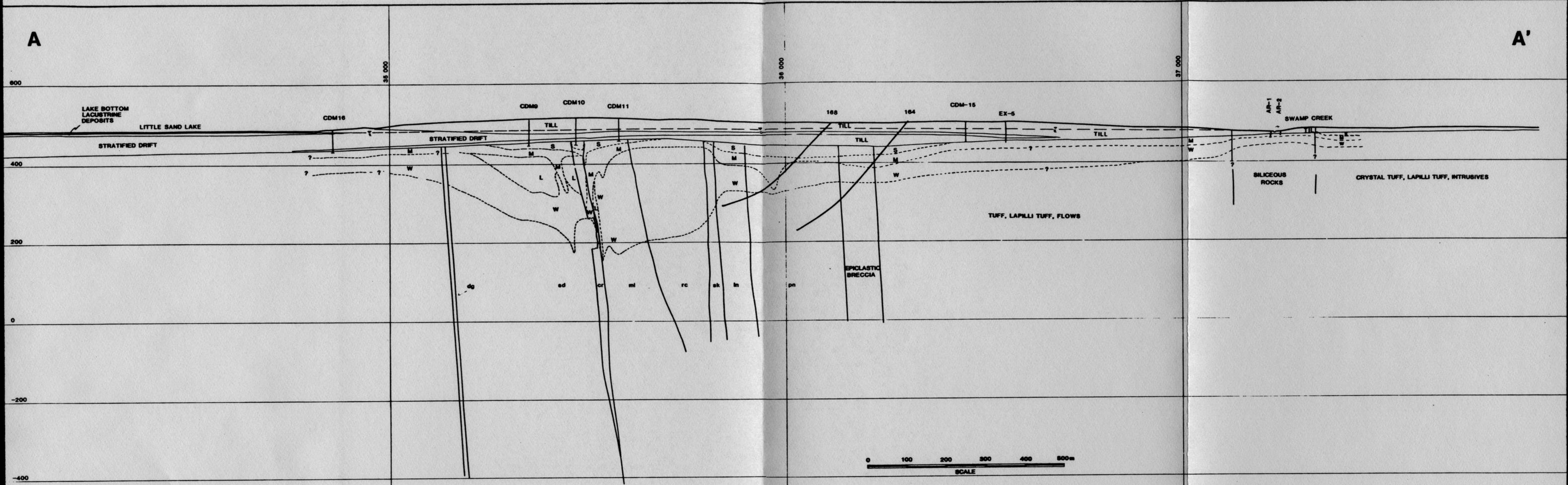
R. ROWE | FIGURE 2.2–5



EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
BEDROCK GEOLOGY OF THE SITE AREA

SCALE SHOWN	STATE WISCONSIN	COUNTY FOREST
DRAWN BY ROGER ROWE	DATE 2/84	CHECKED BY	DATE
APPROVED BY	DATE	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE
DRAWING NO **FIGURE 2.2-6**	SHEET ___ OF ___	REVISION NO



(APPROXIMATELY AT 94 000E)

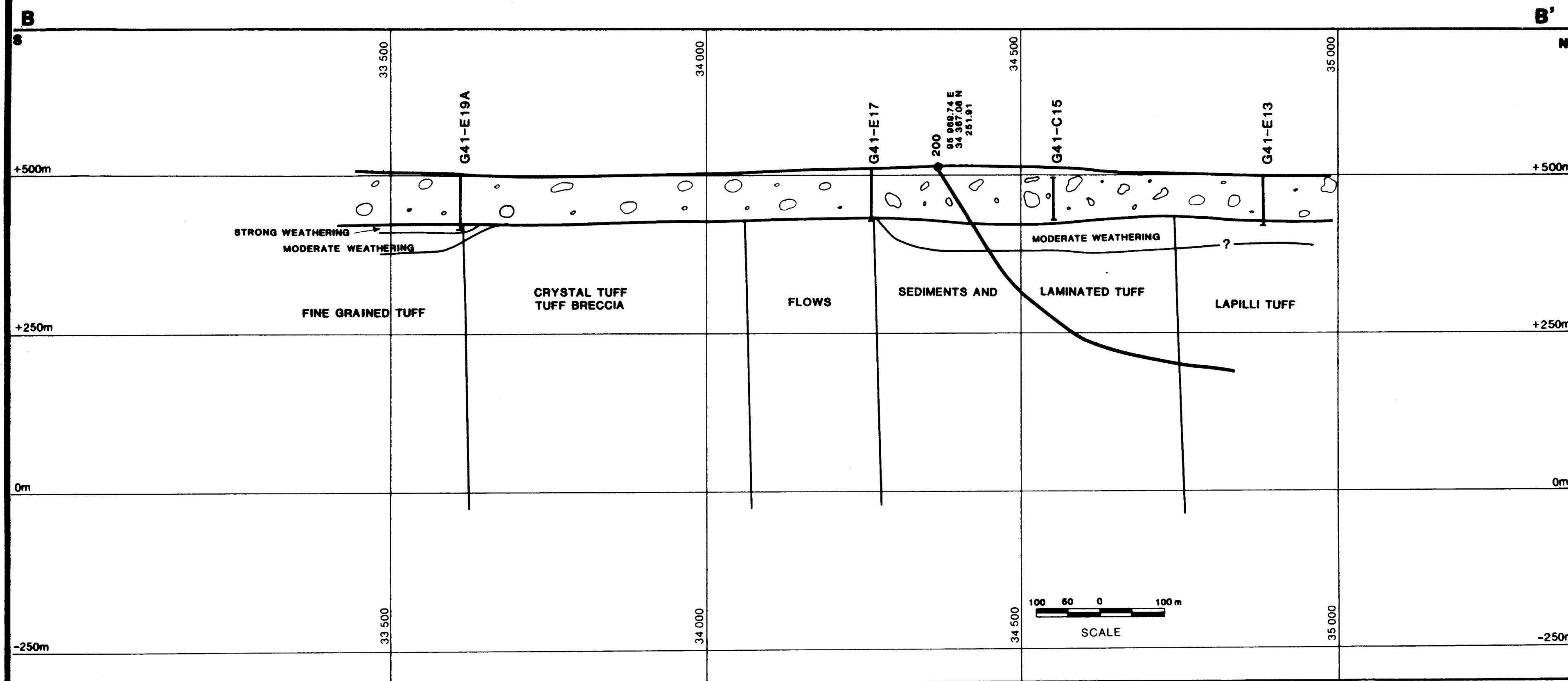
NORTH-SOUTH CROSS-SECTION FROM LITTLE SAND LAKE TO SWAMP CREEK

GLACIAL AND BEDROCK GEOLOGY WITH WEATHERING PROFILE

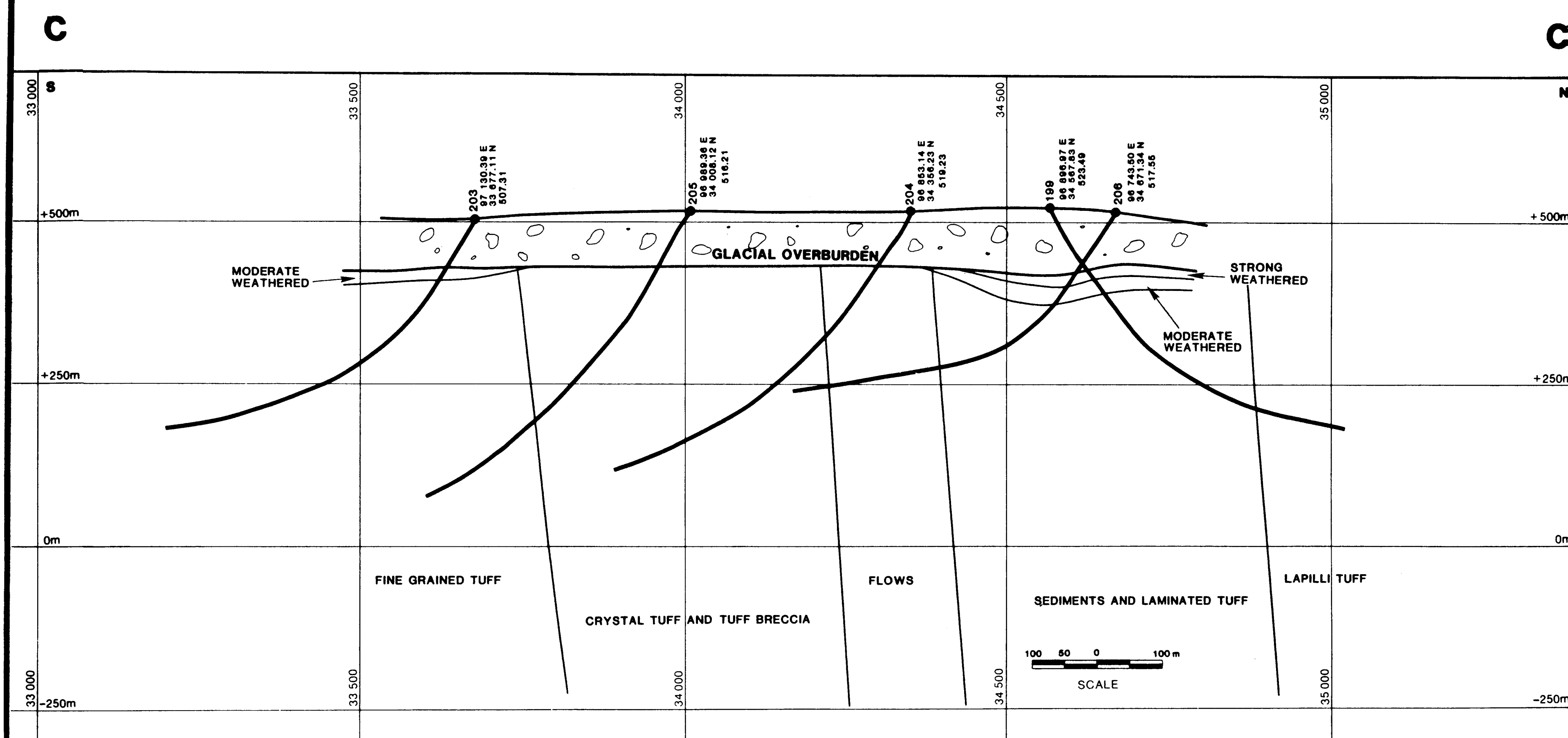
EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE **NORTH-SOUTH CROSS SECTION FROM LITTLE SAND LAKE TO SWAMP CREEK**					
SCALE SHOWN	STATE WISCONSIN		COUNTY FOREST		
DRAWN BY R. ROWE	DATE 8/84	CHECKED BY		DATE	
APPROVED BY	DATE	APPROVED BY		DATE	
APPROVED BY	DATE	EXXON		DATE	
DRAWING NO **FIGURE 2.2-7**		SHEET ____ OF ____		REVISION NO	

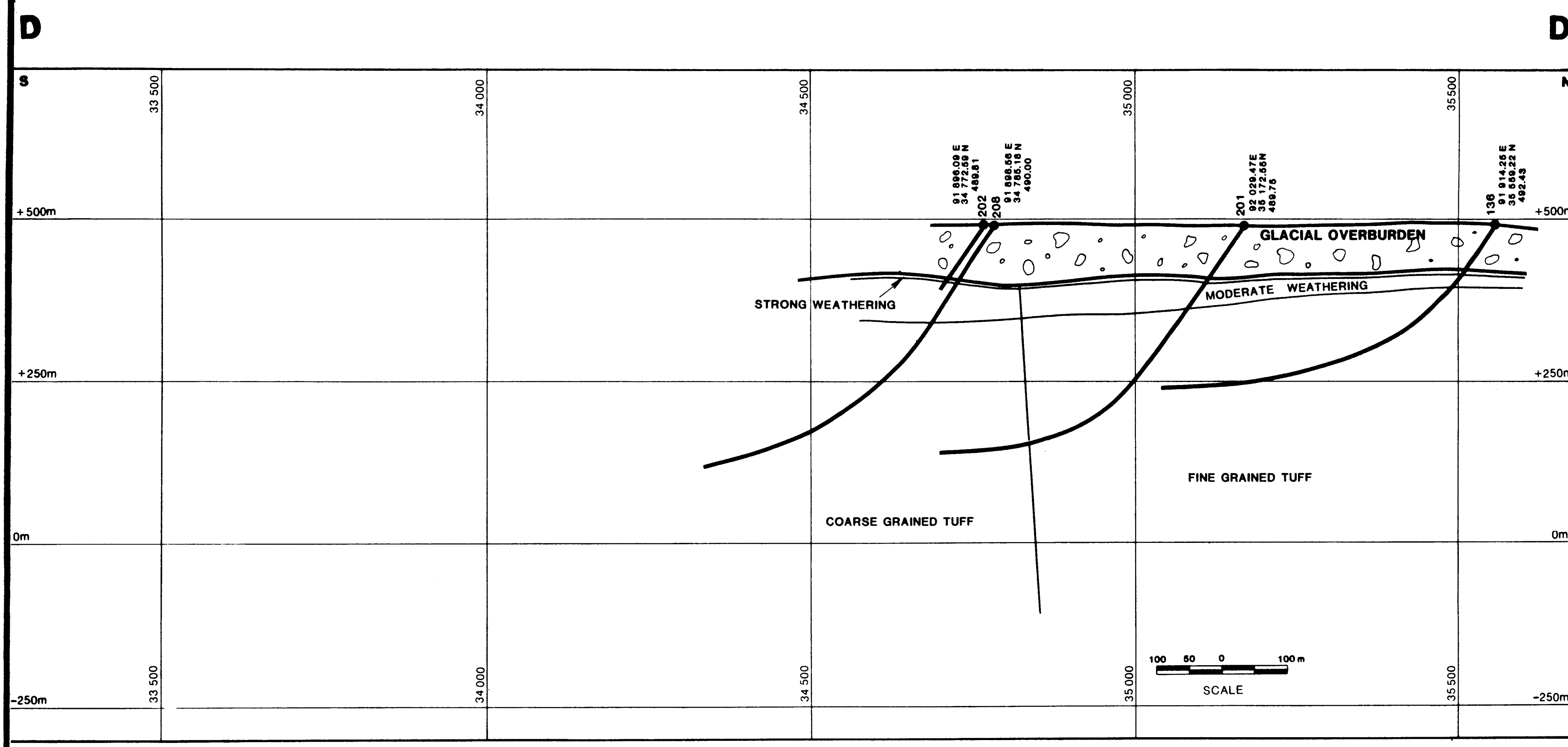


EXXON MINERALS COMPANY CRANDON PROJECT		
TITLE NORTH-SOUTH CROSS SECTION THROUGH MWDF SITE 41 AREA		
SCALE SHOWN	STATE WISCONSIN	COUNTY FOREST
DRAWN ROGER ROWE	DATE	CHECKED BY / DATE
APPROVED BY	DATE	APPROVED BY / DATE
APPROVED BY	DATE	EXXON / DATE
DRAWING NO FIGURE 2.2-8	SHEET OF	REVISION NO



EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE NORTH-SOUTH CROSS SECTION THROUGH MWDF SITE 41 AREA					
SCALE SHOWN	STATE WISCONSIN		COUNTY FOREST		
DRAWN ROGER ROWE	DATE	CHECKED BY		DATE	
APPROVED BY	DATE	APPROVED BY		DATE	
APPROVED BY	DATE	EXXON		DATE	
DRAWING NO FIGURE 2.2-9		SHEET ___ OF ___		REVISION NO	



EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE **NORTH-SOUTH CROSS SECTION THROUGH MWDF SITE 40 AREA**

SCALE SHOWN	STATE WISCONSIN		COUNTY FOREST		
DRAWN ROGER ROWE	DATE	CHECKED BY		DATE	
APPROVED BY	DATE	APPROVED BY		DATE	
APPROVED BY	DATE	EXXON		DATE	
DRAWING NO **FIGURE 2.2-10**		SHEET ___ OF ___		REVISION NO	

The rocks of the first volcanic cycle are referred to as the Hemlock Creek Group. The lower portion of the cycle is a series of basaltic flows of the Nashville Formation. The base of the flows has not been encountered in drilling. Overlying the flows is the Sand Lake Formation, a thick sequence of tuff with interbedded coarser volcanic debris. The upper portion of this formation consists of a sequence of volcanic breccias composed of angular, dark, chloritic altered fragments and less angular, light colored siliceous fragments. This sequence of breccias, referred to as the Township Member, formed when hot water and steam from a submarine volcanic system explosively erupted on the sea floor and shattered the preexisting rock. The silicified breccias and tuffs of the Sand Lake Formation were later refractured and locally flooded with quartz, chalcopyrite, and pyrite to make up the stringer sulfide ore.

The breccias are overlain by a sequence of volcano-sedimentary rocks (Crandon Formation) consisting of fine tuff, chert, argillite, and massive sulfide. The massive sulfide commonly contains economic amounts of sphalerite with lesser amounts of copper, lead, and silver and is called the massive sulfide ore. The rock is generally fine grained, thin bedded, and contains no coarse volcanic debris, indicating a period of relative quiescence.

All rocks beneath the Crandon Formation are referred to as the stratigraphic footwall environment, and all rocks above the Crandon Formation are referred to as the stratigraphic hanging wall environment.

The thick chloritic tuff of the Mole Lake Formation, which consists of several lithologic units, overlies the Crandon Formation. Locally, the Prospect Member, a thin unit composed of subrounded siliceous debris, is contained within the Mole Lake Formation near its base. A wedge of cherty tuff (Oak Lake Formation) interfingers with the chloritic tuff of the Mole Lake Formation at the western end of the deposit.

A thick series of volcanic debris and pumice flows, referred to as the Rice Lake Formation, overlies the chloritic tuff of the Mole Lake Formation. Typically, these debris and pumice flows are characterized by angular, somewhat flattened, dark chloritic fragments in a light colored matrix. Overlying the volcanic debris are the chert, cherty tuff, and tuff of the Skunk Lake Formation, representing the top of the Hemlock Creek Group.

The base of the Swamp Creek Group is marked by flows of the Lincoln Formation, which contains small amounts of tuff and argillite between the flows. The flows are rhyolitic in composition. Cherty tuff and tuff of the Pine Formation overlie the flows and form a wedge thickening to the west. Interbedded mafic flows are common, especially to the east. Epiclastic sediments of the Forest Formation lie to the north. These muddy, sandy sediments contain much terrigenous debris and are highly susceptible to weathering.

The geology between the epiclastic breccia and Swamp Creek Group is not well known. Core from the upper part of holes 164, 156, 157, and 158 indicate intermediate to mafic tuffs and flows. A bedrock core from hole EX-5 consists of relatively felsic fine grained tuff.

Two holes were drilled for bridge foundation studies at the proposed road crossing at Swamp Creek. Holes AR-1A and AR-2A both penetrated bedrock at a relatively shallow depth ($<$7 m [23 feet]), and cores recovered were a very siliceous material. A sequence of fine grained tuff, crystal tuff, lapilli tuff, and intrusive rocks is located north of the siliceous ridge. Figure 2.2-7 (A-A') represents a north-south geologic cross section from Little Sand Lake to Swamp Creek.

Six 300-m bedrock diamond drill core holes were placed in the proposed MWDF area (site 41). A few meters of bedrock core were also taken from the bottom of six Golder glacial overburden holes in order to further delineate bedrock geology. A plan view of the geology in the proposed MWDF area is presented on Figure 2.2-6, and north-south cross sections are presented on Figures 2.2-8 and 2.2-9. The rocks are predominantly a fine grained tuffaceous sequence, with crystal tuffs predominating. The unit labeled "flows" is a series of 3- to 15-m flows commonly with interflow tuff beds. The laminated tuff sequence to the north of the flows is very fine grained, indicating a distal volcanic source and quiet conditions. A crystal tuff sequence is located north of the laminated tuff.

Diamond core holes 136, 201, 202, and 208 penetrate the bedrock immediately to the southwest of the ore deposit (site 40) (Figure 2.2-6). Figure 2.2-10 (cross section D-D') represents an approximately north-south stratigraphic cross section through the area. The bedrock is a fairly monotonous sequence of fine and coarse grained tuffs. A gabbro dike is present in this vicinity and has been correlated with the gabbro dike (dg) underlying the ore body because of similar thickness and textural characteristics.

Bedrock Morphology - Within the environmental study area, the top of bedrock forms an irregular surface (Figure 2.2-11). The bedrock surface map was constructed from several sources:

1) Bedrock elevation data obtained from drilling. Logs for holes in Figure 2.2-11 are contained in Appendix 2.2B.

2) Geoterrex seismic survey. Survey lines indicated on bedrock surface map (Geoterrex Ltd., 1980).

3) Geoterrex vertical electrical sounding survey in vicinity of Swamp Creek (Geoterrex Ltd., 1981).

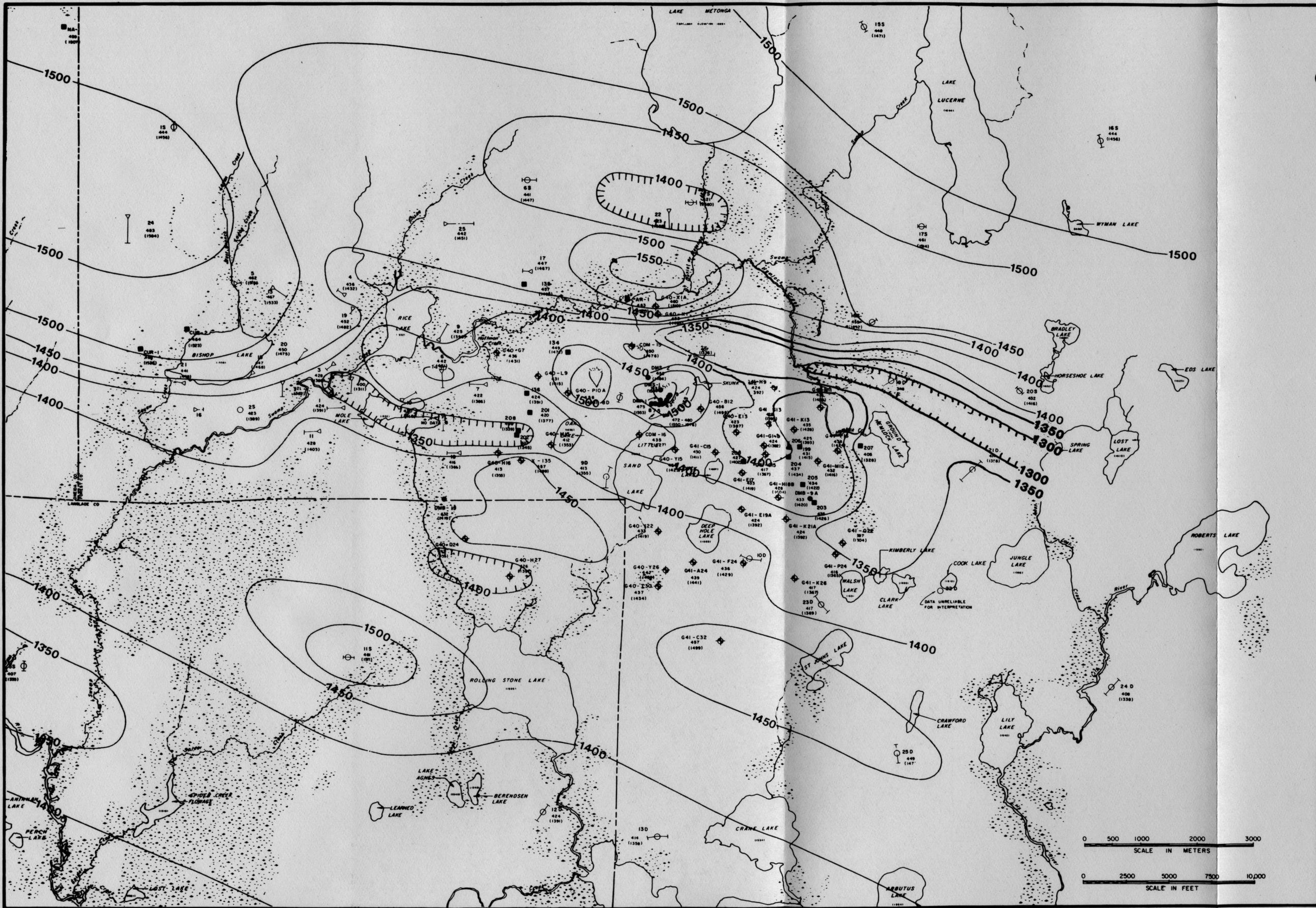
4) USGS seismic survey. Survey lines indicated on bedrock surface map. (Data supplied to DNR in the report by Golder Associates [1981].)

Higher bedrock elevations occur over the ore body for two reasons. Not only has the rock in the footwall been silicified by hydrothermal fluids, but much of the hanging wall rock also consists of siliceous volcanic units. Silica is generally resistant to weathering and erosion. The higher elevation east-west trending bedrock north of the mine/mill site and south of Swamp Creek is also attributable to siliceous rock, which was encountered in holes AR-1A and AR-2A (Figures 2.2-7 and 2.2-11).

Higher bedrock elevations may also be emphasized by structural trends (fault zones, fracture zones) or previous surface water drainage patterns. For example, the higher east-west trending bedrock elevation south of Swamp Creek is especially prominent because the preglacial surface water drainage eroded an east trending valley to the south, southeast of the high. This valley may have followed a structural trend, causing it to weather more rapidly than surrounding terrain.

Structure alone does not produce lower bedrock elevations. For example, in the proposed MWDF (site 41) area, the bedrock is relatively flat (Figure 2.2-11). From observation of drill core in holes 199, 206, 200, and G41-C15, it is apparent that an east/west structural zone trends through the sediments and laminated tuff unit, which is the least competent unit in the stratigraphic sequence.

The bedrock in northern Wisconsin, including the Crandon area, has undergone uninterrupted erosion since Precambrian time. The last major geologic change in the area occurred between 12,500 and 75,000 years ago, when much of northern and central Wisconsin was covered by continental glaciers. The glacial activity deposited from 30 to 70 m (100 to 230 feet) of Pleistocene overburden on top of the Crandon ore deposit.



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BEDROCK SURFACE IN ENVIRONMENTAL STUDY AREA

FIG. 2.2-11

2.2.2.3 Glacial Overburden Geology

Historical Glacial Stratigraphy

The surficial geology throughout the study region, and much of northern Wisconsin, consists of glacial drift deposited during the Pleistocene Epoch (2 million to 7,000 years ago). Drift from three of the four major glacial advances has been recognized in Wisconsin, but the majority of the surficial deposits resulted from the most recent advance, the Wisconsinan age (7,000 to 75,000 years ago).

The oldest surficial deposits in the study region may be from the Altonian substage (28,000 to 40,000 years ago) of the Wisconsinan stage. The relatively younger glacial material was deposited during the Woodfordian substage (12,500 to 22,000 years ago) (Hadley, 1976).

The glacial history of northeastern Wisconsin during the Woodfordian substage is rather complex. The Woodfordian ice advanced as a series of lobes and sublobes from several different directions during a relatively short period of time (Hadley, 1976). This type of glaciation produced an extremely complex set of surficial deposits, particularly in areas such as Forest and Langlade counties where two glacial lobes met. Numerous individuals, including Weidman (1907, 1913), Hole (1943), Thwaites (1943), LaBerge and Meyers (1971), and McCartney (1979), have studied glacial materials in northeastern Wisconsin and attempted to differentiate the various deposits. Mickelson et al., (1974) and Simpkins (1979) described the glacial history of the study region, including the genesis of land forms, the sequence of the various ice advances, and the resulting surficial deposits.

In the environmental study area, the surficial soil materials (glacial drift) were mapped during field examination of land exposures, by the interpretation of aerial photographs, and through data obtained from numerous shallow borings. The locations of these borings are shown on Figure 2.2-1. In addition, eight borings (DMA-34, DMA-35, DMA-37, DMA-38, DMA-39, DMA-44, DMA-45, and DMA-46) were drilled outside the study region. The logs of borings are included in Appendix 2.2B. The samples obtained from these borings were examined and analyzed in the field and laboratory. The results of the various laboratory tests are presented in Tables 2.2-5 through 2.2-8 and in Appendix 2.2A.

The surficial geology of the environmental study area was formed by the first recognized Woodfordian ice advance, the Green Bay lobe and by the subsequent Langlade glacial lobe (Mickelson et al., 1974). The surficial landforms are mainly the result of the final Langlade advance, but also reflect the slightly earlier Green Bay topography. The advance of the Green Bay ice from the southeast brought debris that was deposited when the ice retreated, creating a topography of gently rolling upland areas and intervening valleys. The subsequent advance by the Langlade Lobe from the north and northeast reshaped the preexisting topography and deposited the materials in the current landforms. These landforms and material descriptions are shown on the surficial geology map of the environmental study area (Figure 2.2-12) and cross sections (Figures 2.2-13 and 2.2-14).

Although the two drifts can be differentiated, information is insufficient to accurately define the details of the Green Bay topography and landforms. Therefore, the Green Bay material is described using the general term "drift" on the interpretive cross sections. The Langlade material,

TABLE 2.2-5

RESULTS OF SOIL pH ANALYSES

BORING	SAMPLE	DEPTH (FEET)	pH	BORING	SAMPLE	DEPTH (FEET)	pH
DMA-4	2	8.5	7.05	DMB-12	5	20.5	8.95
DMA-6	4	13.5	9.00	DMB-13	5	19.0	8.75
DMA-18	5	24.5	9.10	DMB-14	6	25.0	8.95
DMB-1	5	19.0	9.30	DMB-14	12	55.0	8.80
DMB-2	8	35.3	9.10	DMB-15	1	53.5	8.60
DMB-3	4	15.5	7.30	DMB-16	10	43.8	9.35
DMB-4	5	20.5	9.10	DMB-17	6	25.0	8.10
DMB-4	8	35.0	8.90	DMB-18	9	40.1	7.80
DMB-5	6	23.7	8.50	DMB-19	7	75.5	6.95
DMB-5	11	48.5	9.00	DMB-22	9	38.6	8.35
DMB-10	5	18.5	8.75				

TABLE 2.2-6

THE COLOR OF SOIL SAMPLES BASED ON MUNSELL CLASSIFICATION

BORING	SAMPLE*	DEPTH (FEET)	COLOR
DMA-4	2	8.5	7.5 YR 4/4
DMA-6	4	13.5	7.5 YR 4/4
DMA-18	5	24.5	7.5 YR 5/4
DMB-1	3	11.0	10 YR 5/6
DMB-1	5	19.0	7.5 YR 5/4
DMB-2	8	35.3	7.5 YR 5/4
DMB-4	2	6.5	5 YR 5/6
DMB-4	5	20.5	7.5 YR 5/4
DMB-4	8	35.0	7.5 YR 5/6
DMB-4	12	55.0	7.5 YR 6/6
DMB-5	6	23.7	10 YR 5/3
DMB-5	11	48.5	10 YR 5/4
DMB-6	2	5.5	5 YR 6/6
DMB-6	11	50.0	2.5 YR 5/6
DMB-7	2	5.5	7.5 YR 5/8
DMB-7	14	63.5	10 YR 6/6

BORING	SAMPLE*	DEPTH (FEET)	COLOR
DMB-10	5	18.5	10 YR 5/2
DMB-12	5	20.5	10 YR 6/4
DMB-13	5	19.0	7.5 YR 6/6
DMB-14	6	25.0	7.5 YR 6/8
DMB-15	1	53.5	10 YR 5/4
DMB-16	3	10.5	5 YR 5/6
DMB-16	10	43.8	7.5 YR 6/6
DMB-17	2	6.5	5 YR 5/6
DMB-17	6	25.0	7.5 YR 5/6
DMB-17	13	60.0	5 YR 5/6
DMB-18	9	40.1	10 YR 5/4
DMB-19	7	75.5	10 YR 5/4
DMB-20	8	34.0	5 YR 5/6
DMB-21	10	44.0	5 YR 5-6/6
DMB-22	9	38.6	10 YR 6/4

TABLE 2.2-7

RESULTS OF CARBONATE PEBBLE CONTENT ANALYSES

BORING	SAMPLE	CARBONATE	TOTAL > NO. 4	PERCENT CARBONATE
DMA-1	4	0	-	-
	5	0	-	-
	8	0	-	-
DMA-4	3	0	-	-
	4	0	-	-
	5	0	-	-
DMA-6	2	0	-	-
	4	0	-	-
	6	3	63	4.8
DMA-10	4	0	-	-
	6	0	-	-
	8	26	152	17.1
DMA-19	2	0	-	-
	3	8	59	13.6
	5	2	25	8.0
DMA-20	4	0	-	-
	5	2	59	3.4
	6	6	97	6.2
DMA-30	1	0	-	-
	9	18	162	11.1
DMB-2	2	0	-	-
	7	5	118	4.2
	12	0	-	-
	15	0	-	-
DMB-3	4	1	69	1.4
DMB-4	5	0	-	-
	7	0	-	-
	8	1	19	5.3
	11	3	28	10.7
	14	0	-	-
DMB-5	6	0	-	-
	11	0	-	-
DMB-6	2	0	-	-
DMB-7	3	0	-	-
	5	0	-	-
	8	0	-	-
	12	0	-	-
	15	2	49	4.1

BORING	SAMPLE	CARBONATE	TOTAL > NO. 4	PERCENT CARBONATE
DMB-9	3	0	-	-
	9	8	180	4.4
	23	0	-	-
DMB-10	3	0	-	-
	4	12	108	11.1
	5	0	-	-
		8	84	9.5
		1	120	0.8
DMB-11	15	4	82	4.9
	16	5	105	4.8
	19	2	56	3.6
DMB-12	5	10	28	35.7
DMB-13	5	8	81	9.9
DMB-14	6	0	-	-
DMB-15	1	0	-	-
DMB-16	10	0	-	-
DMB-17	4	0	-	-
	5	5	85	5.9
	6	0	-	-
DMB-18	9	0	-	-
DMB-19	7	2	45	4.4
DMB-20	2	0	-	-
	6	0	-	-
DMB-22	9	2	28	7.1
G41-G15	2	NA	NA	2.0
G41-G15A	2	NA	NA	3.3

NOTE: Samples from DMA- and DMB-series borings tested for particles retained on the No. 4 U.S. standard sieve. Samples from G-borings tested for the entire particle size range of each sample.

TABLE 2.2-8

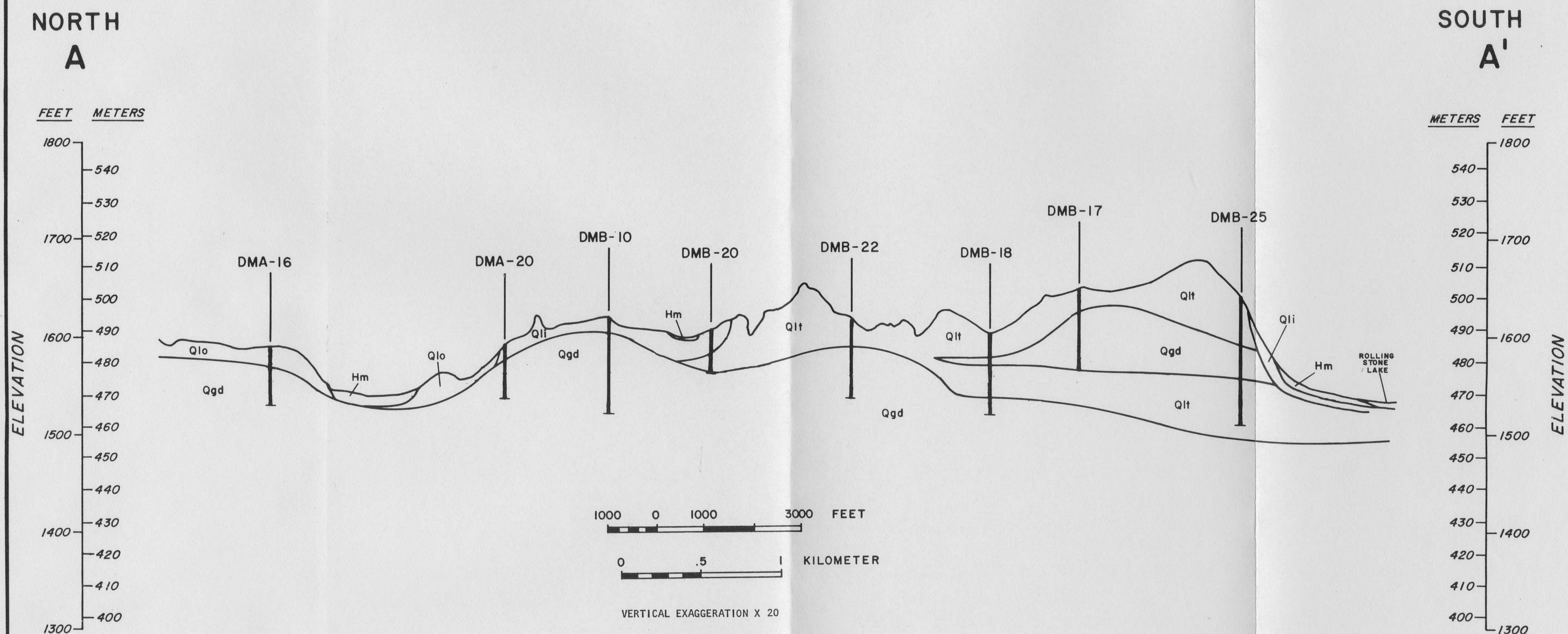
RESULTS OF CLAY MINERALOGY ANALYSES

BORING	SAMPLE	DEPTH (feet)	MINERALS							
			MONTMORILLONITE	ILLITE	CHLORITE	KAOLINITE	QUARTZ	FELDSPAR	DOLOMITE	CALCITE
DMA-1	3	9.1	9	43	39	9	V	Mo	--	--
DMA-4	1	4.0	74	4	14	8	V	Mi	--	--
DMA-18	1	3.5	62	22	12	4	V	Mi	--	Mi
DMB-1	5	19.0	28	32	34	6	V	Mi	Mo	--
DMB-1	10	44.0	44	26	22	8	V	Mi	A	--
DMB-2	4	15.5	13	29	58	--	V	Mo	--	--
DMB-5	2	5.5	45	40	12	3	V	A	--	--
DMB-5	19	88.5	36	28	27	9	V	Mo	--	--
DMB-6	1	2.0	71	6	18	5	V	Mo	--	--
DMB-9	3	6.0	30	47	17	6	A	Mi	--	--
DMB-10	7	29.0	15	40	39	6	V	Mi	Mo	--
DMB-11	7	29.0	15	36	40	9	V	Mo	Mi	--
DMB-14	12	55.0	83	17	Tr	--	V	Mi	--	--
DMB-16	11	48.7	43	24	28	5	V	A	--	--
DMB-18	6	25.5	37	37	21	5	V	Mo	Mo	--
DMB-19	4	55.5	51	21	24	4	V	Mo	Mi	--
DMB-20	6	24.0	71	13	10	6	V	A	--	--
DMB-22	3	9.0	16	48	36	--	V	A	Mi	--

NOTE: Clay mineral content expressed as percentage of all clay minerals. See Appendix 2.2C for description of analyses and results.

KEY: V = Very abundant
A = Abundant
Mo = Moderate
Mi = Minor
Tr = Trace
-- = None observed


EXXON MINERALS COMPANY
CRANDON PROJECT
SURFICIAL GEOLOGY IN ENVIRONMENTAL STUDY AREA
FIGURE 2.2-12
KEY:
A A' GEOLOGIC CROSS SECTION
1700 SURFACE CONTOUR, CONTOUR INTERVAL: 50 FEET
GEOLOGY:
Hm MARSH AND LACUSTRINE DEPOSITS: SILT, FINE SAND, ORGANICS (HOLOCENE)
Qlo LANGLADE OUTWASH: SAND, SOME GRAVEL, NONCALCAREOUS, MASSIVE BEDDING (PLEISTOCENE)
Qli LANGLADE ICE CONTACT DEPOSITS: INTERBEDDED SAND, GRAVEL, SOME SILT, NONCALCAREOUS (PLEISTOCENE)
Qlt LANGLADE TILL: SAND WITH GRAVEL, SOME SILT AND BOULDERS, NONCALCAREOUS, NONBEDDED (PLEISTOCENE)
1 MILE
1000 0 1000 3000 5000 7000 FEET
1 KILOMETER
BASE MAP REFERENCE:
PORTIONS OF THE FOLLOWING U.S.G.S. 7.5 MINUTE SERIES TOPOGRAPHIC QUADRANGLES:
NASHVILLE, WISCONSIN, 1965
CRANDON, WISCONSIN, 1965
LAKE LUCERNE, WISCONSIN, 1965
POST LAKE, WISCONSIN, 1973
MOLE LAKE, WISCONSIN, 1973
ROBERTS LAKE, WISCONSIN, 1973
R12E R13E R14E
T35N T34N
FOREST CO.
LANGLADE CO.
Lake Metonga
Lake Lucerne
Sherman Corners
Keith Siding Road
Rice Lake
Bishop Lake
Mole Lake
Sand Lake Road
Oak Lake
Little Sand Lake
Skunk Lake
Duck Lake
Deep Hole Lake
Ground Hemlock Lake
Bradley Lake
Horseshoe Lake
Wyme Lake
Tee Lake
Spring Lake
Lost Lake
Kimberly Lake
Clark Lake
Walsh Lake
Cook Lake
Jungle Lake
St. Johns Lake
Crawford Lake
Lily Lake
Rolling Stone Lake
Swamp Creek
Hemlock Creek
Outlet Creek
Gilisa Creek
Logan Creek
Pickerel Creek
Spider Creek
Lily River
Soo Line



LEGEND:

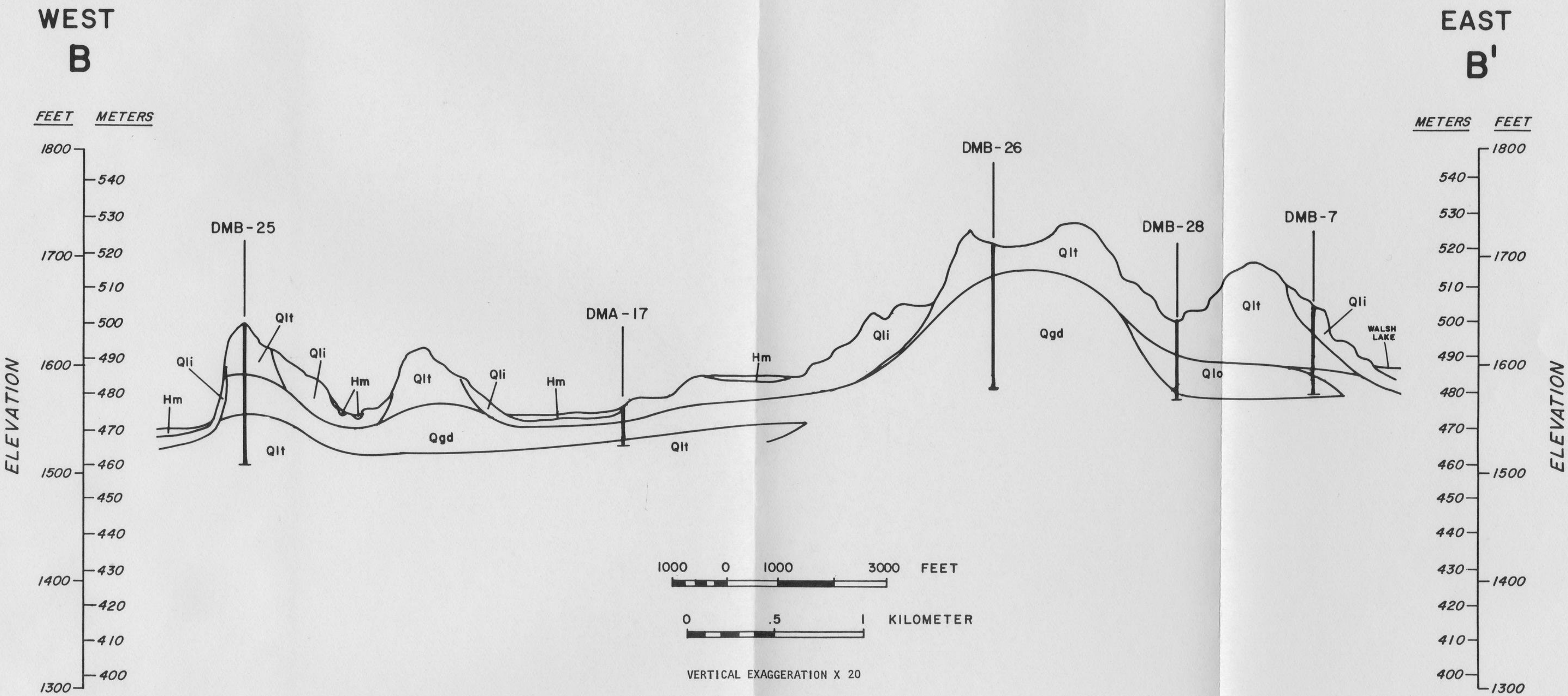
Holocene	Hm	Alluvial and Lacustrine Deposits: Silt, Fine Sand, Organics
Pleistocene	Qlo	Langlade Outwash: Sand, Some Gravel, Noncalcareous, Massive Bedding
	Qli	Langlade Ice Contact Deposits: Interbedded Sand, Gravel, Some Silt, Noncalcareous
	Qlt	Langlade Till: Sand with Gravel, Some Silt and Boulders, Non-calcareous, Nonbedded
	Qgd	Green Bay Drift: Undifferentiated Sand, Some Gravel, Trace Silt, Calcareous
Precambrian	p€	Undifferentiated Metasediments and Meta-volcanics

NOTE: SEE FIGURE 2.2-12 FOR LOCATION OF SECTION

EXXON MINERALS COMPANY
CRANDON PROJECT

CROSS SECTION A-A'
ENVIRONMENTAL STUDY AREA

FIGURE 2.2-13



LEGEND:

Holocene	Hm	**Alluvial and Lacustrine Deposits:** Silt, Fine Sand, Organics
Pleistocene	Qlo	Langlade Outwash: Sand, Some Gravel, Noncalcareous, Massive Bedding
	Qli	Langlade Ice Contact Deposits: Interbedded Sand, Gravel, Some Silt, Noncalcareous
	Qlt	Langlade Till: Sand with Gravel, Some Silt and Boulders, Noncalcareous, Nonbedded
	Qgd	Green Bay Drift: Undifferentiated Sand, Some Gravel, Trace Silt, Calcareous
Precambrian	p€	Undifferentiated Metasediments and Meta-volcanics

NOTE: SEE FIGURE 2.2-12 FOR LOCATION OF SECTION

EXXON MINERALS COMPANY
CRANDON PROJECT

CROSS SECTION B - B'
ENVIRONMENTAL STUDY AREA

FIGURE 2.2-14

however, can be more easily examined, and discrete landforms and materials may be identified. Surficial geology of portions of Langlade and Forest counties has been mapped by the USGS on unpublished 1:24000 blueline maps, including the study region (USGS, undated). General agreement exists between the map of the study region (Figure 2.2-12) and the USGS maps showing surficial geology of the study region.

The Green Bay lobe deposited a sandy, calcareous drift containing approximately 2 to 56 percent carbonate fragments in the gravel (Mickelson et al., 1974). The color of the suspended silt-clay fraction is generally brown (7.5YR4/6). The last advance of Woodfordian ice to affect the regional study area came from the north and northeast and is termed the Langlade Lobe (Mickelson et al., 1974). Deposits from the Langlade Lobe generally overlie the Green Bay Lobe drift and generally are reddish brown-brown, noncalcareous, nonbedded sand with gravel and some silt and boulders. The Langlade drift is difficult to distinguish from the Green Bay drift; however, it is noncalcareous, generally contains no carbonate gravel, and is reddish brown to brown (5-7.5YR4/6) (Mickelson et al., 1974).

The drift from the two lobes is mixed where the ice sheets merged or were in proximity to one another. The drifts stratigraphically truncate and interfinger one another from continued readvance and retreat of the ice fronts at a given location during Woodfordian time. In some areas, these deposits were overlain and/or separated by bedded sand and gravel and/or sand and silt deposits, termed outwash (Simpkins, 1979).

Within the environmental study area, the thickness of the surface materials varied from less than 8 m (25 feet) to more than 110 m (360 feet). The lowest glacial drift encountered in the environmental study area was a brown, noncalcareous silty sand containing weathered gravel. The age of this lowest noncalcareous drift is uncertain. Based on its stratigraphic position, noncalcareous composition, and the weathered condition of the gravel, it might represent the Merrill drift which was deposited during the Altonian substage approximately 40,000 years ago by ice advancing from the north-northwest (Mickelson et al., 1974; Simpkins, 1979). From samples overlying the bedrock in Borings DMB-19, DMB-24, and DMB-25 (near Rolling Stone Lake), the drift was found to be noncalcareous and contains an average of 60 percent sand, 30 percent silt, and 10 percent clay (Mickelson et al., 1974). The color is from dark red (Munsell classification 10R3/4) to reddish brown (5YR3/4). The color and overall condition of this oldest drift, however, were similar to the younger, Woodfordian-age Langlade drift. This questionable lower Langlade drift was overlain by characteristic Woodfordian drifts and was also encountered in many deep borings in the mine/mill and mine waste disposal areas.

Differentiation between the Green Bay and Langlade drifts in the environmental study area was made on the basis of the color of the silt/clay fraction and the calcareous composition and presence of carbonate pebbles in the Green Bay drift. The initial differentiation was made during the laboratory examination of the samples based on their reaction to dilute hydrochloric acid. The calcareous Green Bay drift yielded a reaction, but the Langlade drift did not. Particle size analyses and color determination of the suspended silt/clay fraction were performed concurrently. The results of the particle size analyses enabled the samples to be characterized as either ice-laid or water-deposited drift. The particle size analyses were also used to obtain quantitative estimates of the amount of carbonate fragments in the gravels. Samples with gravel-size fractions were treated with acid to identify carbonate pebble content, which was a criterion for indicating Green Bay drift. Samples characterized by this criterion had carbonate pebble contents between 0.8 and 35.7 percent, whereas samples with no carbonate pebbles were indicative of Langlade drift. The results of these color determinations and the particle size analyses are indicated in Tables 2.2-6 and 2.2-7 and Appendix 2.2A. Variations in carbonate content were also used to distinguish till sheets in northeastern Wisconsin by McCartney (1979).

In addition, selected samples were analyzed by X-ray diffraction to determine their clay mineralogy. The clay minerals montmorillonite and illite were consistently present in all samples. In addition, chlorite was also found in the clay-size fraction in all samples. Kaolinite was present in most samples but in small quantities. The most dominant non-clay mineral was quartz, which was abundant in all samples. The results of these tests are shown in Table 2.2-8 and Appendix 2.2A. No differentiation could be made between the Green Bay drift and Langlade drift based on clay mineralogy. However, the results of pH, carbonate content, and color tests were useful in distinguishing between drifts. The combined results of these tests were used as the basis for differentiating the two Woodfordian drifts and in preparing the interpretive cross sections (Figures 2.2-13 and 2.2-14).

Genetic Glacial Stratigraphy

To understand glacial stratigraphy from a hydrologic perspective, the glacial overburden must be defined on a genetic basis. This allows the glacial overburden to be divided according to hydrologic characteristics.

Five genetic types of glacial deposits found at the Crandon Project are described below based on supporting documentation presented in the report by STS Consultants, Ltd. (1984a). Each is distinguished by particle size distribution, shape of the gradation curve, percent passing the No. 200 sieve (P200), degree of sorting, and depositional features that can be seen in representative samples. The terminologies for these five genetic categories are: glacial till, basal till, coarse grained stratified drift, fine grained stratified drift, and lacustrine.

Glacial Till -- All glacial till samples were classified as either SM-SP or SM under the Unified Soil Classification System. Typically, the samples were described as slightly silty fine to medium sand to silty fine to coarse sand. Gradation curves from the glacial till samples have a characteristic shape. The till consists of a well graded mixture (poorly sorted) of silt, sand, gravel, and cobbles with only a trace of clay (less than 10 percent). The glacial till deposits are extensive across the site area and form many upland areas.

Basal Till -- A layer of glacial till was found on the bedrock surface under portions of the site. It was designated as basal till because it could be distinguished from the other till deposits generally by color and grain size distribution. The basal till generally had a reddish brown color and a high P200 content. The basal till layer was relatively thin, usually less than 10 m (30 feet) thick.

The 11 basal till samples that were analyzed for grain size had a range of 9 to 90 percent passing the No. 200 sieve with an average P200 of 36 percent (STS Consultants, Ltd., 1984a). They were described as silty fine to coarse sandy silt (ML). The composite gradation curve for the basal till is similar to the surficial till except that the samples had slightly higher P200 content. The basal till was often encountered above or below basal lacustrine deposits.

Coarse Grained Stratified Drift -- The term coarse grained stratified drift is used to describe glacial outwash deposits. Fifty-five samples of the coarse grained stratified drift were analyzed and had a range of 1 to 16 percent passing the No. 200 sieve with an average P200 of 7 percent (STS Consultants, Ltd., 1984a). The samples ranged from well sorted silty fine to medium sand to well graded sand and gravel. The majority of the coarse drift samples had a P200 of less than 10 percent. Besides the relatively low P200 content, the coarse grained stratified drift samples were distinguished by the presence of stratification, indicating fluvial deposition, which was absent in the till samples.

Fine Grained Stratified Drift -- The fine grained stratified drift is a relatively well sorted, uniformly graded, fine grained glacial outwash deposit. Samples of fine grained stratified drift had an average P200 of 11 percent within a range of 2 to 51 percent (STS Consultants, Ltd., 1984a). Under the Unified Soil Classification System, these samples were classified as SP, SM-SP, SM, or ML. They were generally described as fine sand, silty fine sand, and fine sandy silt. The fine grained stratified drift, together with the coarse grained stratified drift, form what is called the aquifer material at the Crandon Project. These are glacial outwash deposits, as opposed to the glacial till or fine grained lake deposits.

Lacustrine -- The lacustrine category includes relatively fine grained sediments deposited at the bottom of lakes during both glacial and more recent (post-glacial) deposits under Little Sand, Oak, Skunk, Duck, and Deep Hole lakes. Samples of the lacustrine sediments from glacial times had an average P200 of 66 percent within a range of 9 to 98 percent (STS Consultants, Ltd., 1984a). These lacustrine sediments were characterized by their fine grained nature and the presence of varves. The varves were generally very thin layers (less than 0.5 cm [0.20 inch]) of very fine sand, silt, and moderate to high plasticity clay reflecting the seasonal and annual fluctuations in deposition.

Samples of the lacustrine sediments from post-glacial lakes included massive deposits of fine silt and clay ranging in thickness from 1 m (3.3 feet) in Skunk Lake to 15 m (50 feet) in Duck Lake.

Thirteen geologic cross sections were prepared to illustrate the soil conditions (Figures 2.2-16 through 2.2-18). The index for the geologic cross sections is presented on Figure 2.2-15. The cross sections illustrate the interpreted stratigraphy of the Crandon Project using the five categories described previously: glacial till, basal till, coarse grained stratified drift, fine grained stratified drift, and lacustrine. The cross sections were based on results from the new EX borings as well as older G40, G41, CDM, and DM borings.

2.2.3 Mine/Mill Site Geology

The mine/mill area includes the surface facilities for the mine and mill and the ore body, generally including the area bounded by Skunk, Little Sand, and Oak lakes, as shown on Figure 2.2-19.

LEGEND

- TEST BORING LOCATION
- TEST BORING INCLUDING GROUNDWATER OBSERVATION WELL
- TEST BORING INCLUDING MULTIPLE GROUNDWATER OBSERVATION WELL
- WELL DATA PROVIDED BY U.S.G.S.
- GOLDER ASSOCIATES TEST PIT LOCATION
- GOLDER ASSOCIATES TEST WELL LOCATION
- DAMES & MOORE TEST WELL LOCATION
- CRANDON FORMATION
- EX BORINGS AND PIEZOMETER LOCATIONS
- WP WELL POINT LOCATIONS
- RECLAIM POND BORINGS

NOTE

SUPERVISION OF BORINGS AND GROUNDWATER OBSERVATION WELL INSTALLATION DETERMINED BY THE FOLLOWING DESIGNATION PREFIXES:

G	GOLDER ASSOCIATES
DM	DAMES & MOORE
DW	DAMES & MOORE
BE	BRAUN ENGINEERING TESTING
X	EXXON MINERALS COMPANY
STS	SOIL TESTING SERVICES OF WISCONSIN, INC.
AR,RR	SOIL TESTING SERVICES OF WISCONSIN, INC.
CDM	CAMP DRESSER & McKEE, INC.
EX	STS CONSULTANTS LTD.

NOTE: ELEVATIONS IN METERS MSL

250 0 250 500 750 1000

SCALE IN METERS

REVISED	DATE	BY	DESCRIPTION
	6-21-84	J.J.T.	EX, WP, RP LOCATIONS

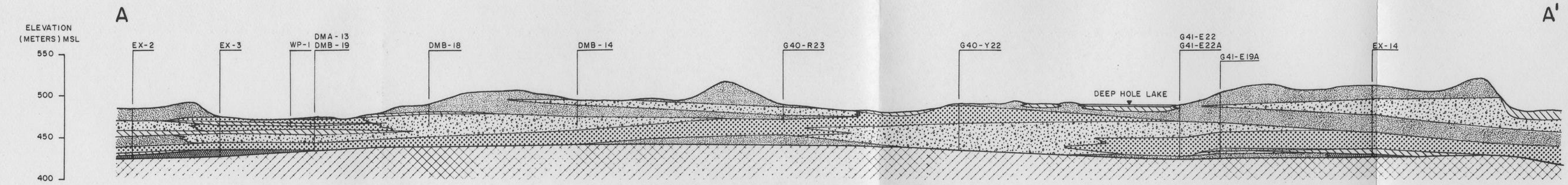
STS DRWG. 12959-2

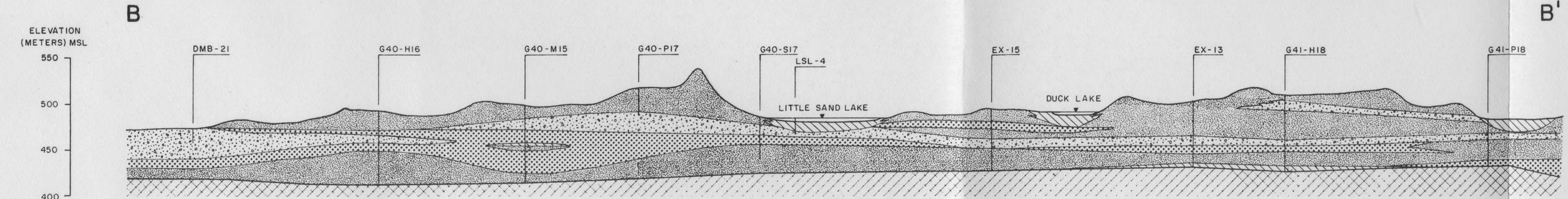
EXXON MINERALS COMPANY
CRANDON PROJECT

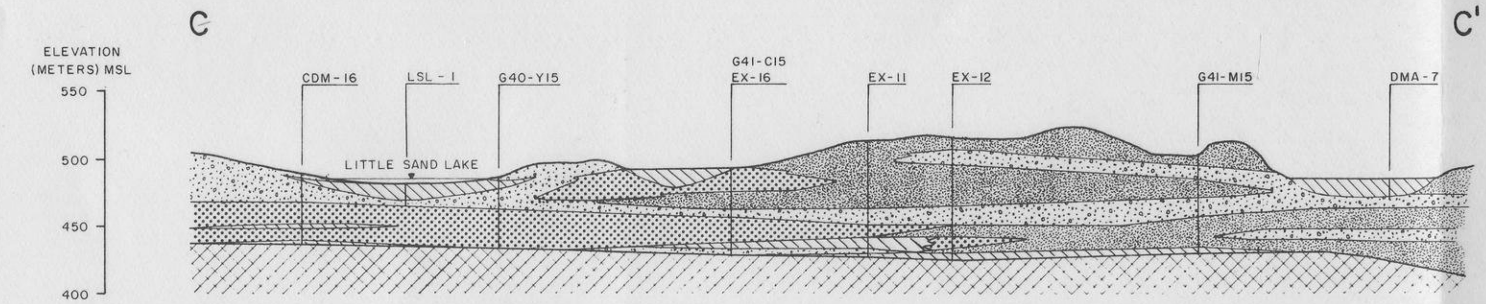
TITLE: **GEOLOGIC CROSS-SECTION INDEX**

SCALE: AS SHOWN	STATE: WISCONSIN	COUNTY: FOREST	
DRAWN BY: CAB	DATE: 4-12-82	CHECKED BY: DB	DATE: 4-12-82
APPROVED BY: [signature]	DATE: 4-12-82	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE

DRAWING NO: **FIGURE 2.2-15** SHEET ___ OF ___ REVISION NO

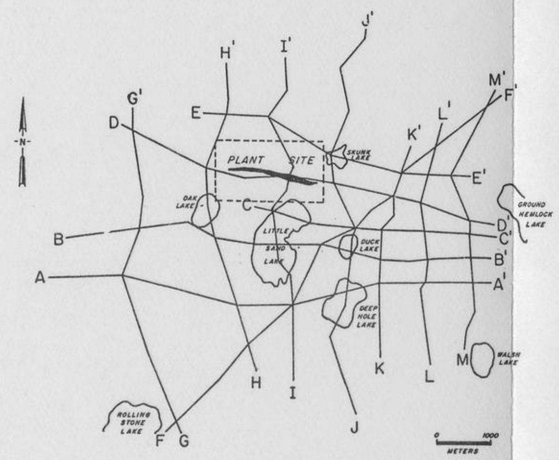






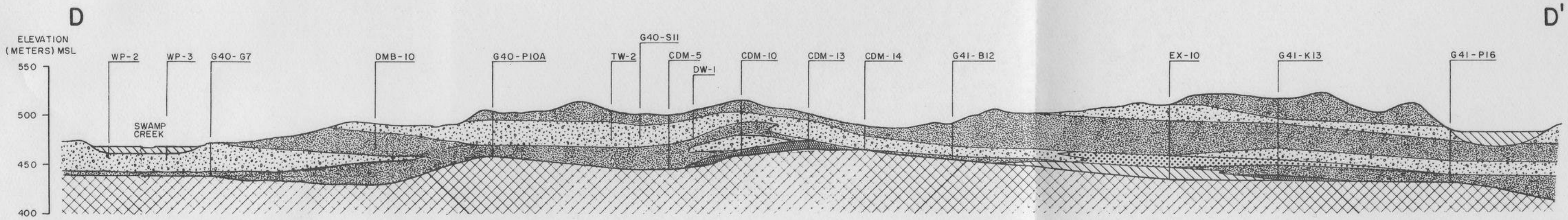
LEGEND

- LACUSTRINE
- TILL
- COARSE GRAINED STRATIFIED DRIFT
- FINE GRAINED STRATIFIED DRIFT
- BASAL TILL
- BEDROCK
- LAKE WATER LEVEL



CROSS-SECTION INDEX

NOTE: PROJECTIONS OF SOIL STRATA BASED ON DATA FROM BORING LOCATIONS. SOIL CONDITIONS BETWEEN BORINGS MAY VARY.



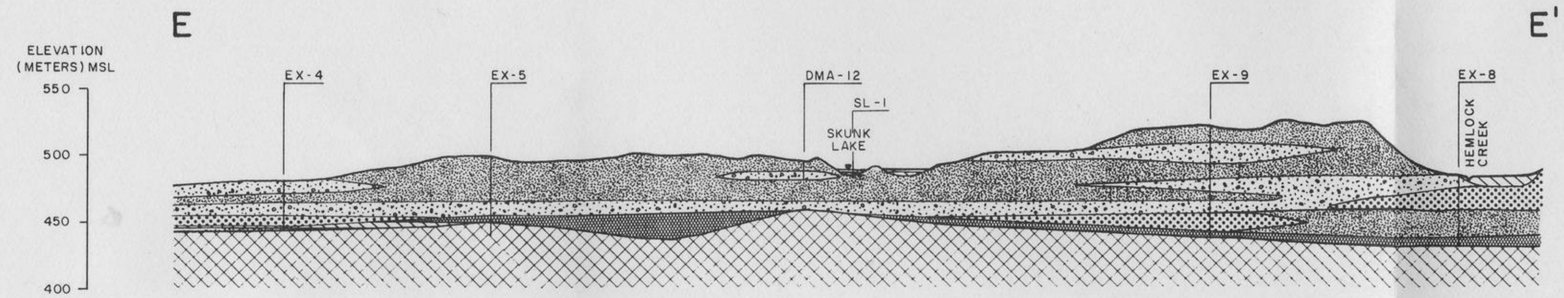
250 0 250 500 750 1000

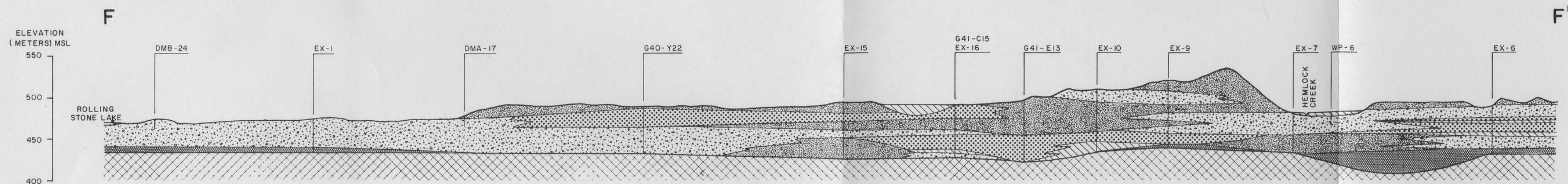
HORIZONTAL SCALE IN METERS
VERTICAL EXAGGERATION: 5X

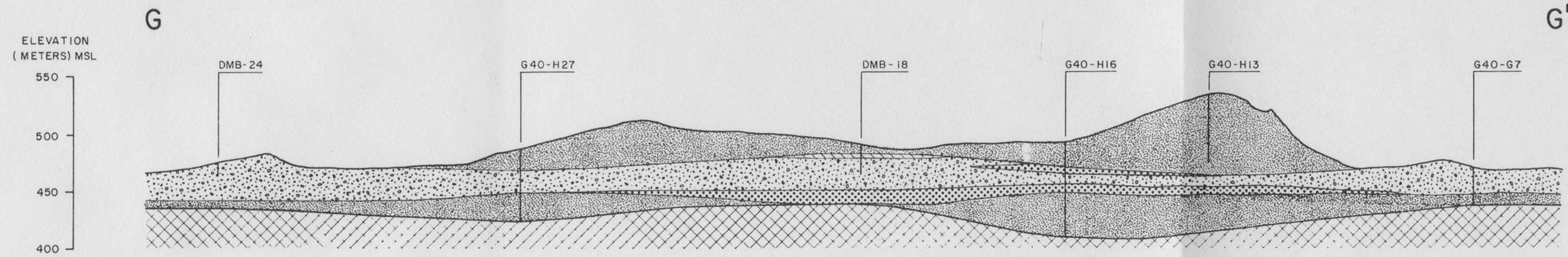
EXXON MINERALS COMPANY
CRANDON PROJECT

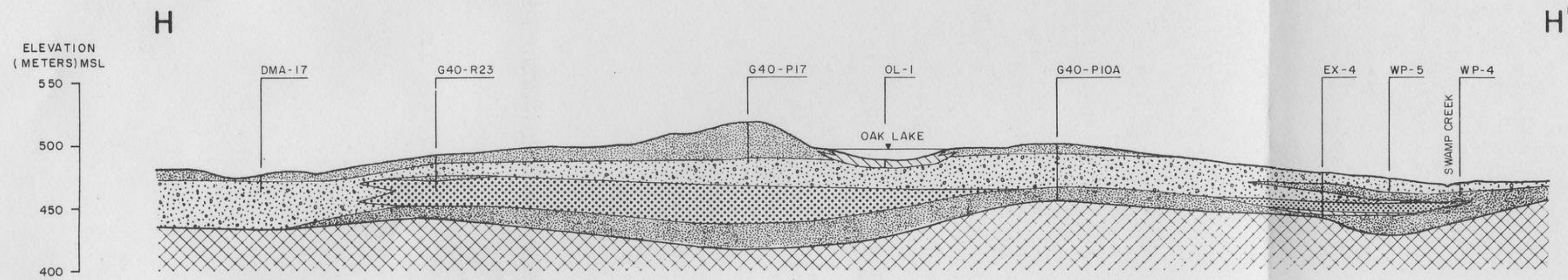
TITLE
GEOLOGIC CROSS SECTIONS A-A', B-B', C-C' & D-D'

SCALE SHOWN	STATE WISCONSIN	COUNTY FOREST	
DRAWN BY STS	DATE 6/84	CHECKED BY	DATE
APPROVED BY	DATE	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE
DRAWING NO **FIGURE 2.2-16**		SHEET OF	REVISION NO 1



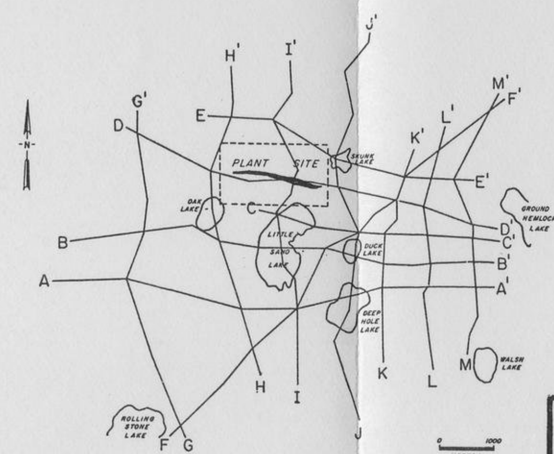






LEGEND

- LACUSTRINE
- TILL
- COARSE GRAINED STRATIFIED DRIFT
- FINE GRAINED STRATIFIED DRIFT
- BASAL TILL
- BEDROCK
- LAKE WATER LEVEL



CROSS-SECTION INDEX

NOTE: PROJECTIONS OF SOIL STRATA BASED ON DATA FROM BORING LOCATIONS. SOIL CONDITIONS BETWEEN BORINGS MAY VARY.

250 0 250 500 750 1000

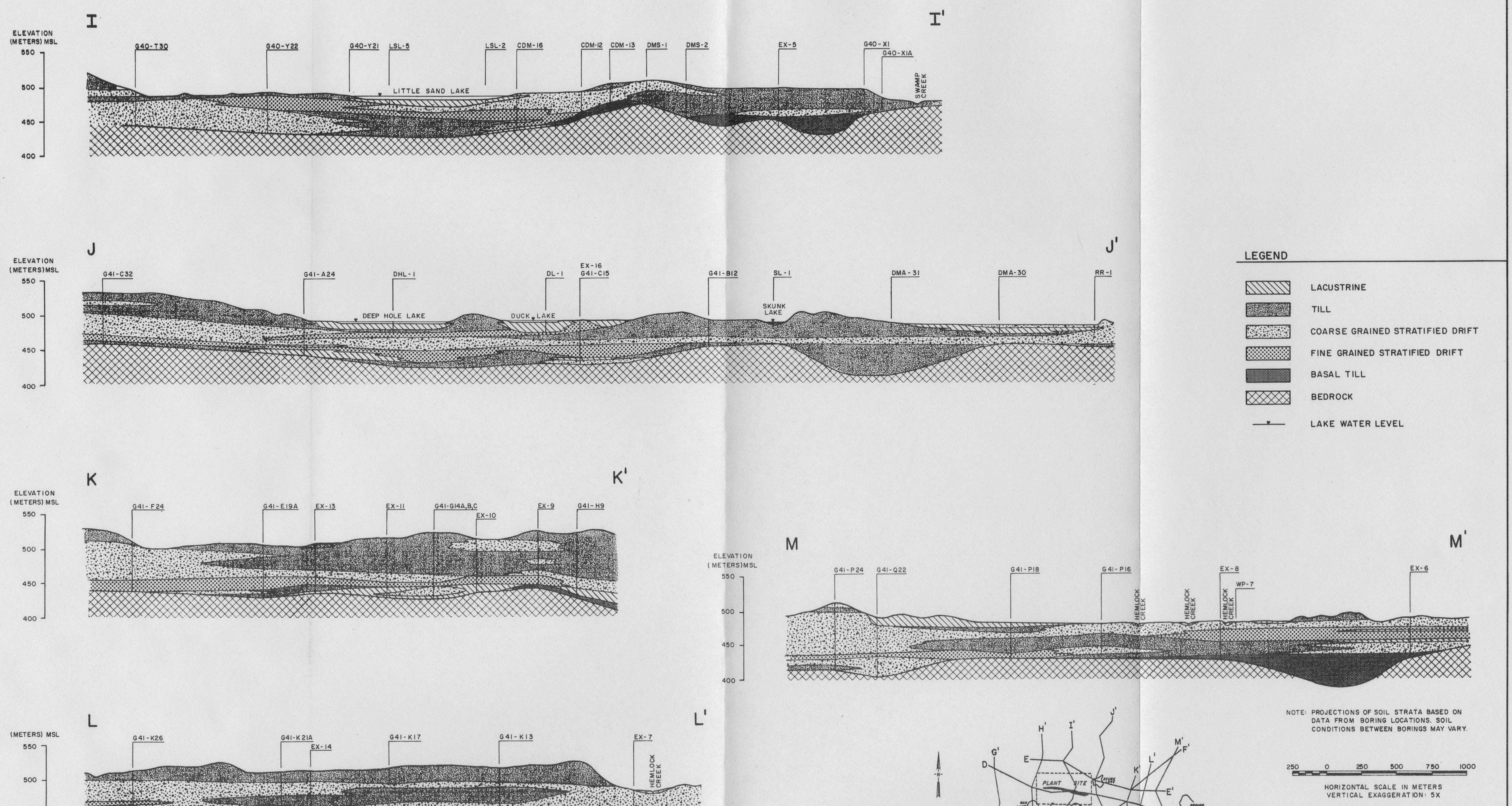
HORIZONTAL SCALE IN METERS
VERTICAL EXAGGERATION: 5X

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
GEOLOGIC CROSS SECTIONS E-E', F-F', G-G' & H-H'

SCALE SHOWN	STATE WISCONSIN		COUNTY FOREST		
DRAWN BY STS	DATE 6/84	CHECKED BY		DATE	
APPROVED BY	DATE	APPROVED BY		DATE	
APPROVED BY	DATE	EXXON		DATE	
DRAWING NO FIGURE 2.2-17			SHEET OF	REVISION NO 1	

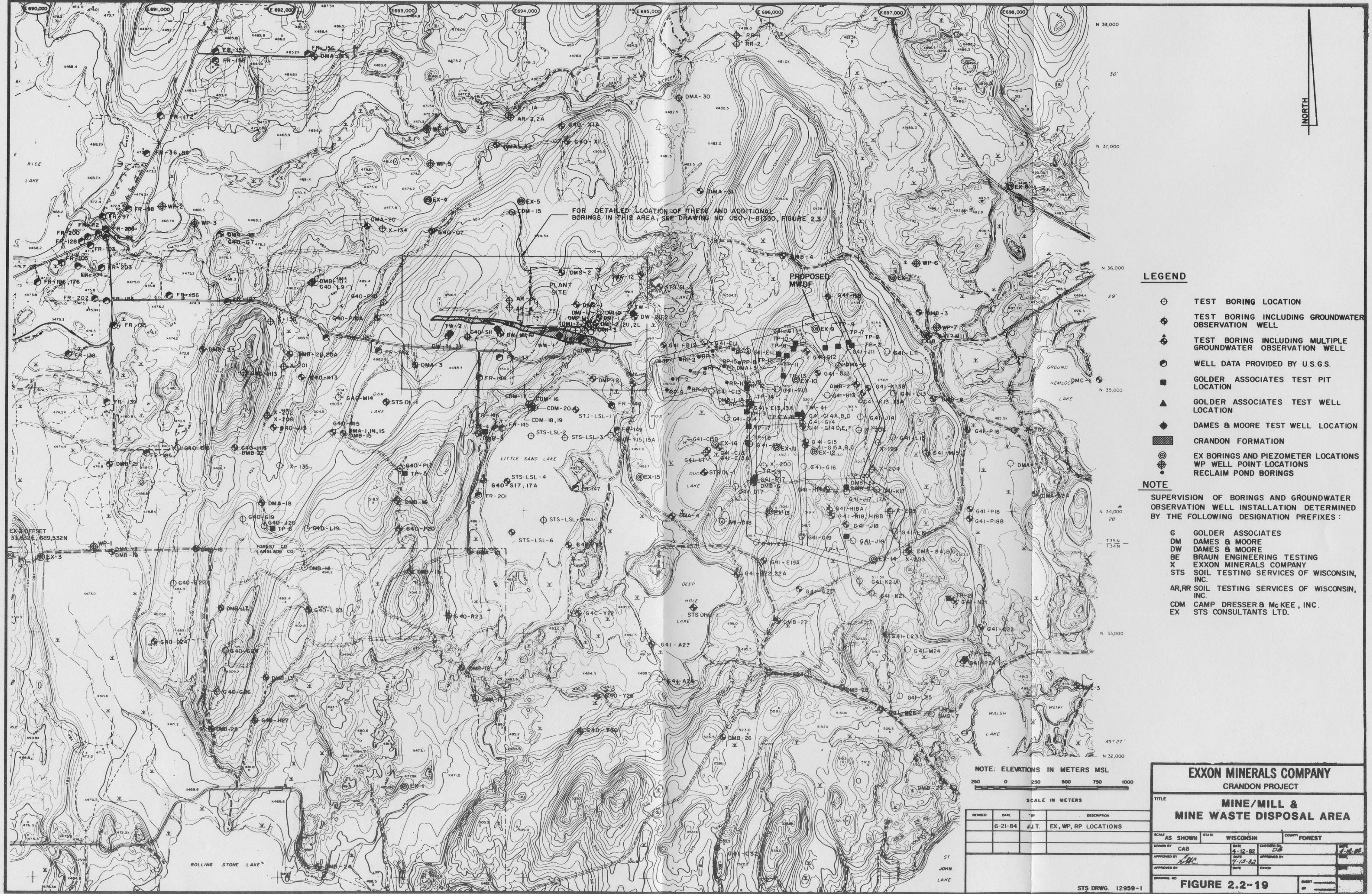
GGS INC.



EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE **GEOLOGIC CROSS SECTIONS I-I', J-J', K-K', L-L' & M-M'**

SCALE SHOWN	STATE WISCONSIN		COUNTY FOREST		
DRAWN BY STS	DATE 6/84	CHECKED BY		DATE	
APPROVED BY	DATE	APPROVED BY		DATE	
APPROVED BY	DATE	EXXON		DATE	
DRAWING NO	**FIGURE 2.2-18**		SHEET OF	REVISION NO 1	



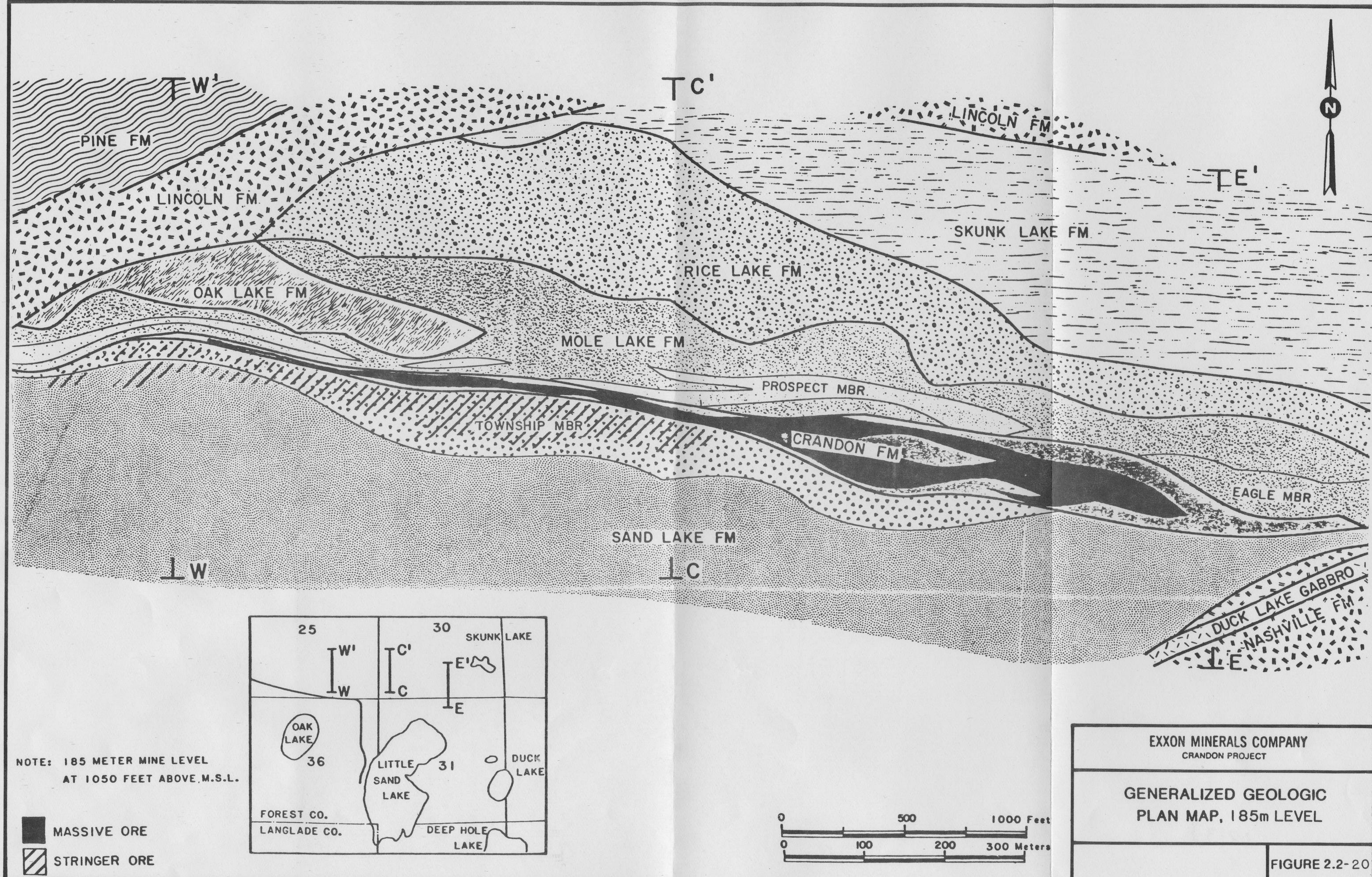
REVISED	DATE	BY	DESCRIPTION
	6-21-84	J.J.T.	EX, WP, RP LOCATIONS

STS DRWG. 12959-1

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: **MINE/MILL & MINE WASTE DISPOSAL AREA**

SCALE: AS SHOWN — STATE: WISCONSIN — COUNTY: FOREST
DRAWN BY: CAB — DATE: 4-12-82 — CHECKED BY: DB
APPROVED BY: [signature] — DATE: 4-12-82 — APPROVED BY:
APPROVED BY: — DATE: — EXXON:
DRAWING NO: **FIGURE 2.2-19**



NOTE: 185 METER MINE LEVEL AT 1050 FEET ABOVE M.S.L.

EXXON MINERALS COMPANY
CRANDON PROJECT

GENERALIZED GEOLOGIC PLAN MAP, 185m LEVEL

FIGURE 2.2-20

2.2.3.1 Physiography

Ground surface elevation in the mine/mill area is from less than 485 m (1,600 feet) MSL near Little Sand and Skunk lakes to more than 539 m (1,770 feet) MSL, between Oak Lake and Little Sand Lake. The area consists of a series of southwest-northeast trending drumlin ridges with flat and pitted outwash plains and lake beds forming the lowlands. These landforms reflect the southwesterly advance of the Langlade ice lobe, which deposited till and outwash on the uplands and valleys, respectively.

The ground surface in the mine/mill area is quite variable, from nearly flat in the outwash plains to a grade of approximately 15 percent and greater on the sides of ridges.

2.2.3.2 Bedrock Geology

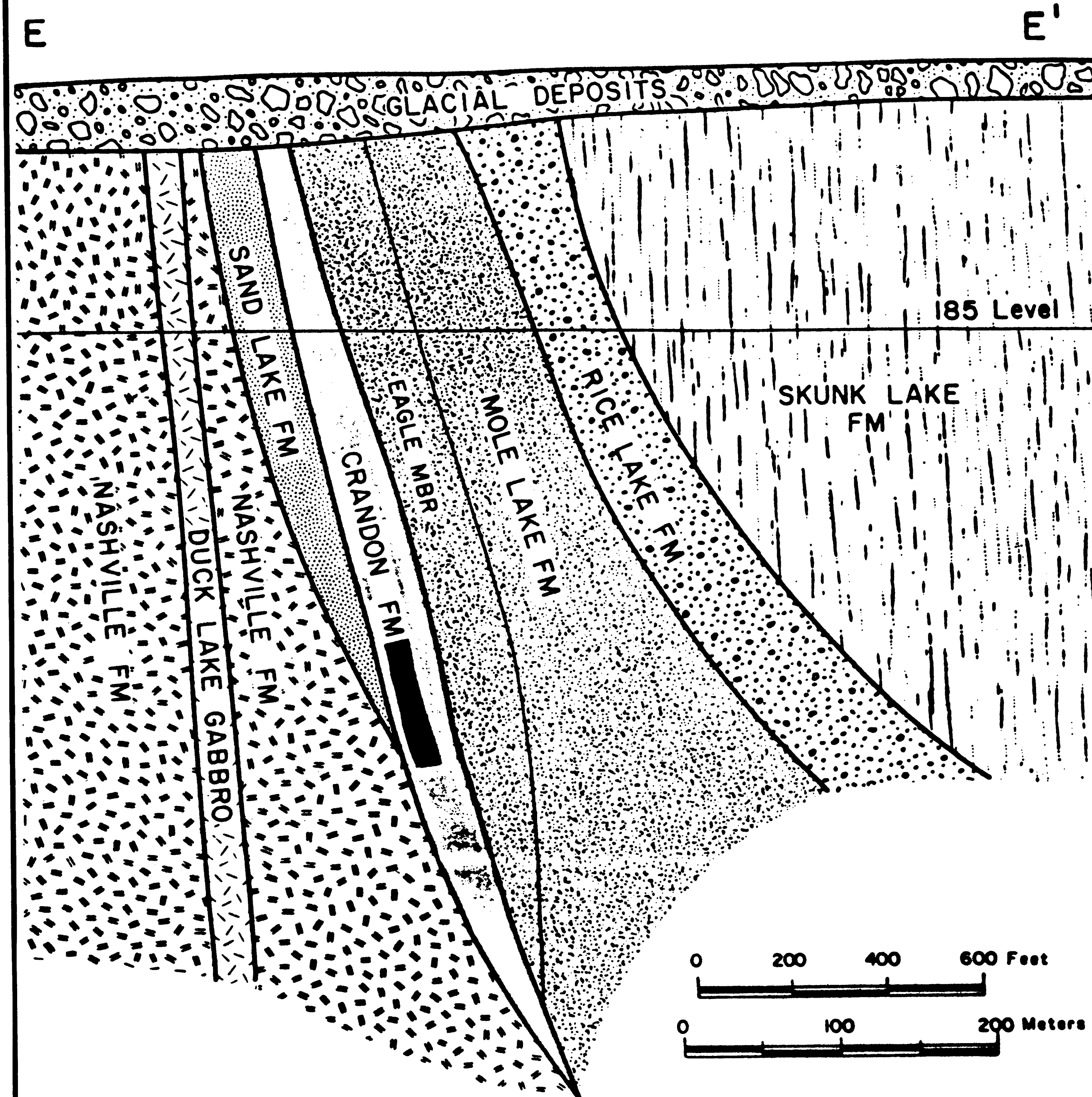
The Precambrian bedrock of the mine/mill area, including the ore body, were deposited during two volcanic cycles, referenced as the Hemlock Creek and the Swamp Creek groups. The formations and members that comprise these two groups are illustrated with descriptions on Figure 2.2-5. Detailed stratigraphic descriptions have been presented in subsection 2.2.2.1. The rock formations strike approximately north 80 degrees west and dip 70 to 90 degrees north, as illustrated on Figures 2.2-6 and 2.2-20 through 2.2-23.

The Crandon sulfide deposit is identifiable for a distance of approximately 1,524 m (5,000 feet) along strike and to a depth of approximately 732 m (2,400 feet) below the bedrock surface. Its thickness varies from less than 0.3 m (1 foot) on the west to 76 m (250 feet) near its center (Schmidt et al., 1978).

Within the Crandon deposit there are two distinct ore types, designated as massive ore and stringer ore. They occur in near equal amounts (Figures 2.2-20 through 2.2-23). Massive ore is zinc-rich and consists of layers of sulfide within the sediments of the Crandon Formation. Stringer ore consists of copper-rich quartz-chalcopyrite veins in the breccia and tuff of the underlying Sand Lake Formation. Current recoverable reserve estimates are 61.1 million metric tons (67.4 million short tons) with an approximate average grade of 5.6 percent zinc, 1.0 percent copper, 0.5 percent lead, 40 grams/ton silver, and 1 gram/ton gold.

Massive Ore - The massive sulfide ore forms a tabular body with a length of 1,300 m (4,260 feet) extending to a depth of 550 m (1,800 feet), and varying in thickness from 0 to 60 m (0 to 200 feet). The ore body strikes approximately north 80 degrees west and dips from vertical to 75 degrees northward (Figure 2.2-22). The ore consists primarily of bands of sphalerite with minor chalcopyrite and galena interbedded with pyrite. Total sulfide content of the ore averages 70 percent by volume. The remaining 30 percent is generally quartz or chlorite.

Stringer Ore - The stringer ore body consists of a network of quartz-chalcopyrite-pyrite veins that crosscut the breccias in the Sand Lake Formation approximately parallel to and beneath or to the south of the Crandon Formation massive ore (Figures 2.2-22 and 2.2-23). The stringer ore body is 1,400 m (4,590 feet) in length, extends to a depth of 700 m (2,300 feet), and ranges from 0 to 50 m (0 to 160 feet) in thickness. Chalcopyrite is the important ore mineral and occurs as stringy or patchy grains in the quartz veins. Sphalerite and galena are not common in this ore.



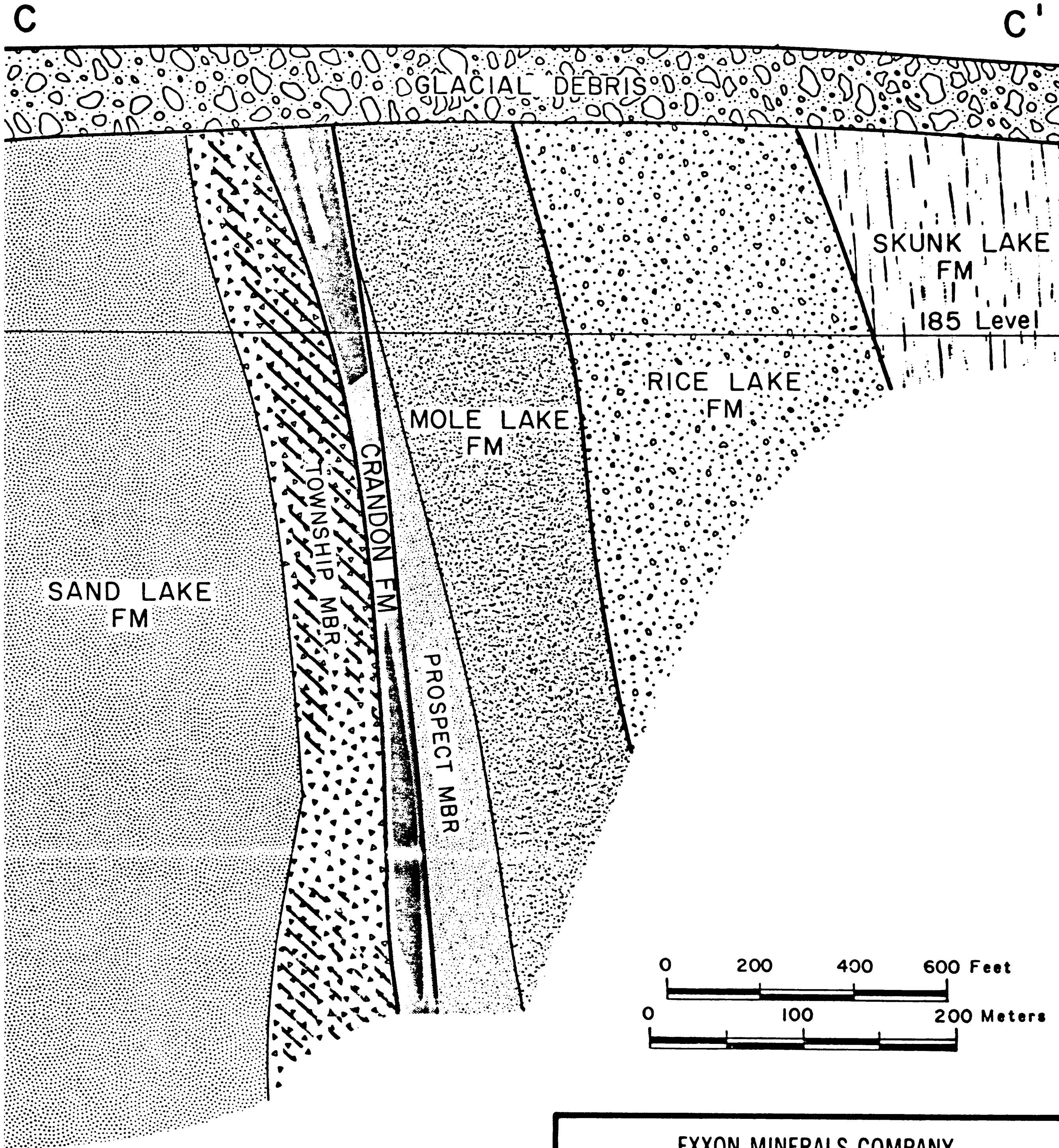
NOTE: 185 METER MINE LEVEL
AT 1050 FEET ABOVE M.S.L.

MASSIVE ORE

EXXON MINERALS COMPANY
CRANDON PROJECT

GENERALIZED GEOLOGIC
CROSS SECTION E - E'

FIGURE 2.2-21



NOTE: 185 METER MINE LEVEL AT 1050 FEET ABOVE M.S.L.

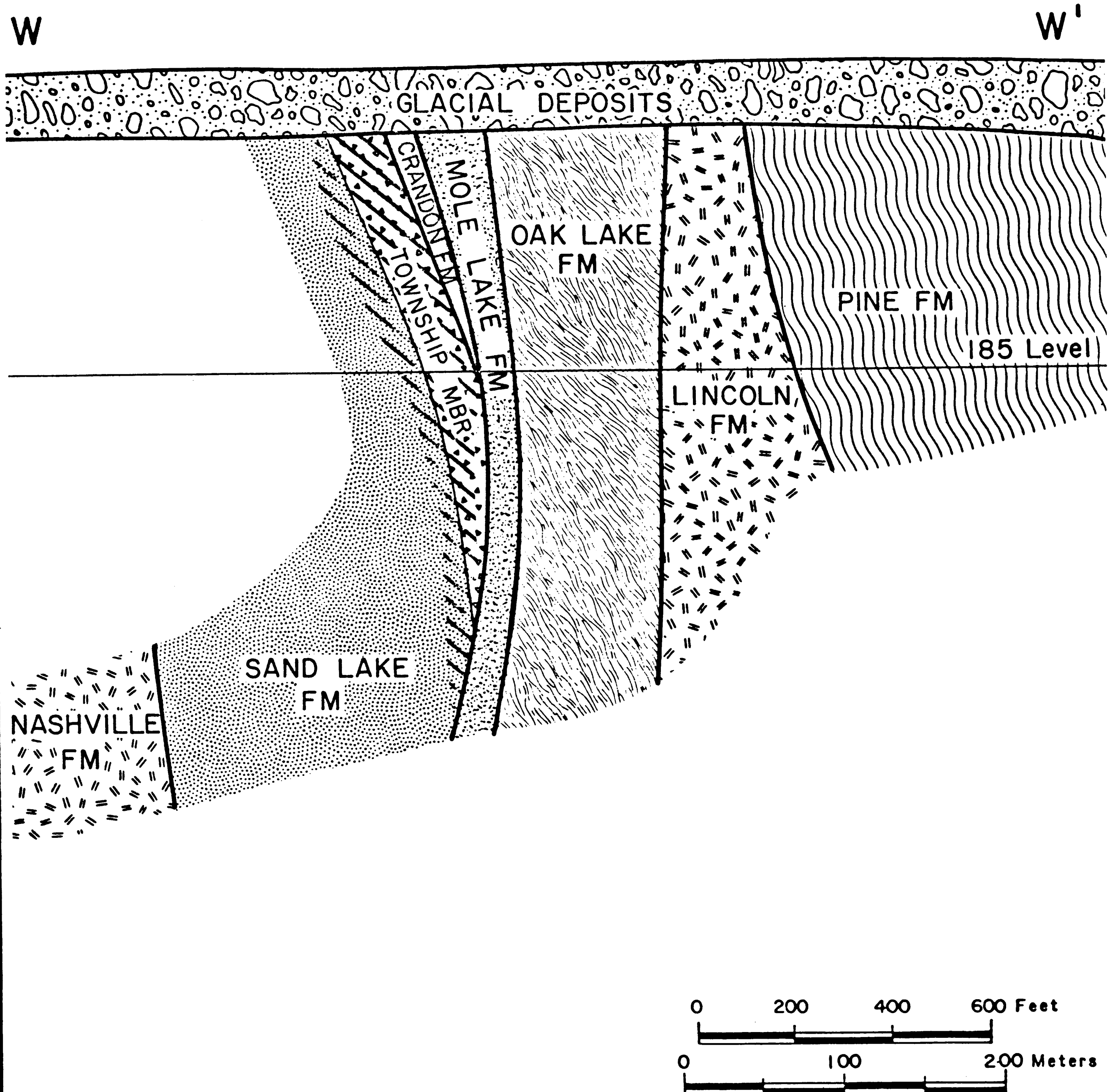
MASSIVE ORE

STRINGER ORE

EXXON MINERALS COMPANY
CRANDON PROJECT

GENERALIZED GEOLOGICAL CROSS SECTION C - C'

FIGURE 2.2-22



NOTE: 185 METER MINE LEVEL
AT 1050 FEET ABOVE M.S.L.

STRINGER ORE

EXXON MINERALS COMPANY
CRANDON PROJECT

GENERALIZED GEOLOGIC
CROSS SECTION W-W'

FIGURE 2.2-23

Near the surface, the ore body has been partially oxidized and leached. The oxidation of chalcopyrite and subsequent downward percolation of copper bearing water has resulted in the formation of supergene chalcocite (a copper sulfide), which is redeposited as thin films on the pyrite. Chalcocite occurs only in small amounts and is generally above the 140-m (455-foot) level.

Asbestiform mineralization in the Crandon sulfide deposit was investigated (Lambe, 1979). Asbestiform minerals consist of chrysotile, and the fibrous amphibole polymorphs of actinolite, tremolite, grunerite, cummingtonite, anthophyllite and reibeckite. Samples of massive and stringer ore and of the enclosing volcanic sedimentary rocks to be penetrated by the mine were examined by the preparation of thin sections and examination under an optical microscope. No asbestiform minerals were found in core and thin sections of waste rock to be disturbed by the underground workings. Three rock samples were noted to contain an amphibole mineral, but these samples came from volcanic rock that occurs outside of the area to be mined (May, 1979).

The Crandon deposit does not display any major folding or faulting. Minor faulting or shearing exists along the Crandon Formation-hanging wall contact. This minor faulting developed in thin, incompetent beds in response to stress release and promoted the weathering of the Crandon Formation rocks, which will be discussed below. Other small fault zones have been observed in drill core, but they can seldom be correlated from drill hole to drill hole.

Bedrock Weathering - The Crandon deposit has been subjected to uninterrupted weathering since Precambrian time, as the area has been one of positive relief since the Penokean orogeny 1.8 billion years ago.

Weathering is the destructive process or group of processes causing the physical disintegration and chemical decomposition of bedrock. The primary agent of destruction is ground water, commonly containing atmospheric oxygen. Over geologic time, the thickness and profile of the weathered bedrock would have varied considerably, depending upon environmental conditions. At present, the total thickness of weathered rock is relatively thin because of extensive stripping by glacial action.

In describing the weathered rock at Crandon, the drill core was evaluated with respect to the destructive processes of oxidation, leaching, argillization (pervasive clay development), and fracturing (Rowe, 1982). The extent to which each destructive process has affected the material sampled by the drill core was classified by relative intensity (Table 2.2-9).

After each of the destructive processes was evaluated and rated for a specified interval of core, an overall rating of weathering intensity was applied that reflects the severity of all the destructive processes combined. Figure 2.2-24 is a generalized cross section illustrating a typical north-south weathering profile of the Crandon ore deposit rock. The weathering profile and active destructive processes vary considerably between the stratigraphic footwall, Crandon Formation, and the stratigraphic hanging wall. This is in response to the primary chemistry of the rock and the physical-chemical conditions acting upon it.

TABLE 2.2-9

DESTRUCTIVE PROCESSES AND WEATHERING INTENSITY RATINGS

Destructive Processes

Oxidation	Total:	Total oxidation of all sulfides.
	Partial:	Partial oxidation of all sulfides.
	Trace:	Traces or small quantities of transported and/or indigenous limonite on fractures or bedding planes.
Leaching	Strong:	>5 volume percent secondary porosity.
	Moderate:	2-5 volume percent secondary porosity.
	Weak:	Trace-1 volume percent secondary porosity.
Argillization	Strong:	Pervasive strong development of clay. Rock soft and breaks easily. (Rock easily gouges with nail.)
	Weak:	Weak or partial clay development, but rock does not break easily.
Fracturing	Strong:	>20 fractures/foot.
	Moderate:	5-20 fractures/foot.
	Weak:	1-4 fractures/foot.

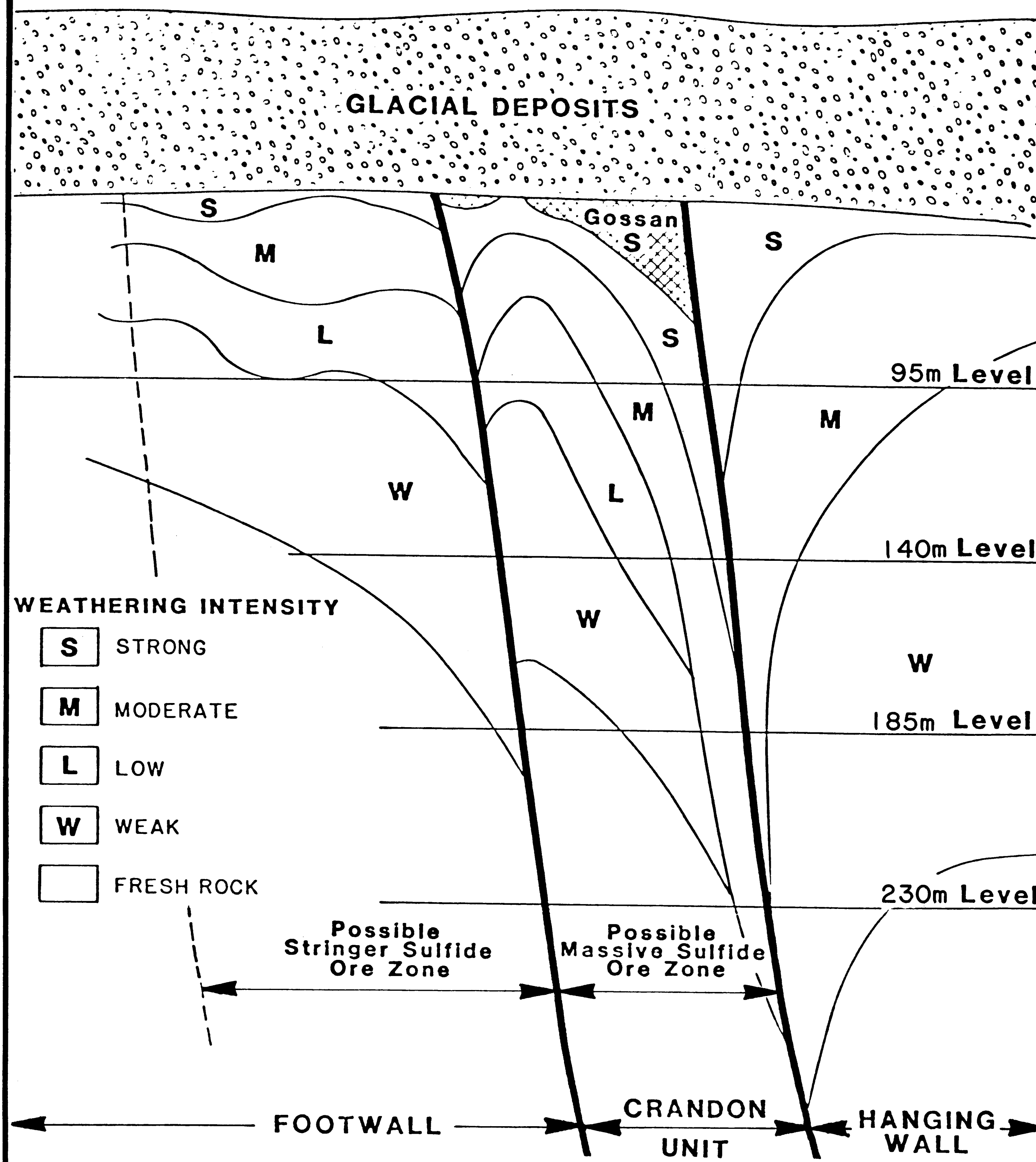
Weathering Intensity Rating

Strong: Strong development of two or more of the destructive processes. Rocks will have very low compressive strengths, and workings would have to be supported at all times.

Moderate: Strong development of one of the destructive processes (or moderate development of two) and weak to moderate development of at least one more. Rocks may or may not be strong enough to hold a back, depending upon which destructive processes have been active. Strong development of argillization or fracturing would make the rock very weak or unstable, whereas strong development of oxidation or leaching may not seriously affect its ability to hold a back.

Low: Moderate leaching with only minor other effects. The compressive strength of the rock is not seriously reduced.

Weak: Weak development of leaching and or oxidation. Rock strengths are not affected.



EXXON MINERALS COMPANY
CRANDON PROJECT

GENERALIZED WEATHERING PROFILE OF CRANDON ORE DEPOSIT ROCK

REFERENCE: ROWE, 1982.

FIGURE 2.2-24

Weathering in the Mine Site Area

Footwall - The footwall rock referred to in this discussion is primarily a 200-m (656-foot) zone south of the Crandon Formation (Figure 2.2-20). The rock is unique not only because it contains the stringer sulfide (copper-rich) ore zone, but also because it is strongly silicified and pyritized by the hydrothermal solutions that created the ore body. Because of their siliceous character, they react in a particular way to the destructive weathering processes.

The primary destructive weathering process is leaching. Leaching is generally in the moderate range for a few tens of meters beneath the subcrop, gradually reducing to the low and weak range (Figure 2.2-24). The base of the leached zones is somewhat irregular but is not as highly erratic as the Crandon Formation weathering profile discussed below.

Crandon Formation - The Crandon Formation is more deeply weathered than the footwall rock because of the presence of thin, interbedded tuffs, high sulfide content (50 to 90 percent), and minor faulting or shearing. The most prominent feature is a weathering "groove" along the hanging wall side of the Crandon Formation, which locally may penetrate below the proposed 230-m mine level. The groove actually runs the length of the Crandon Formation and is highly irregular.

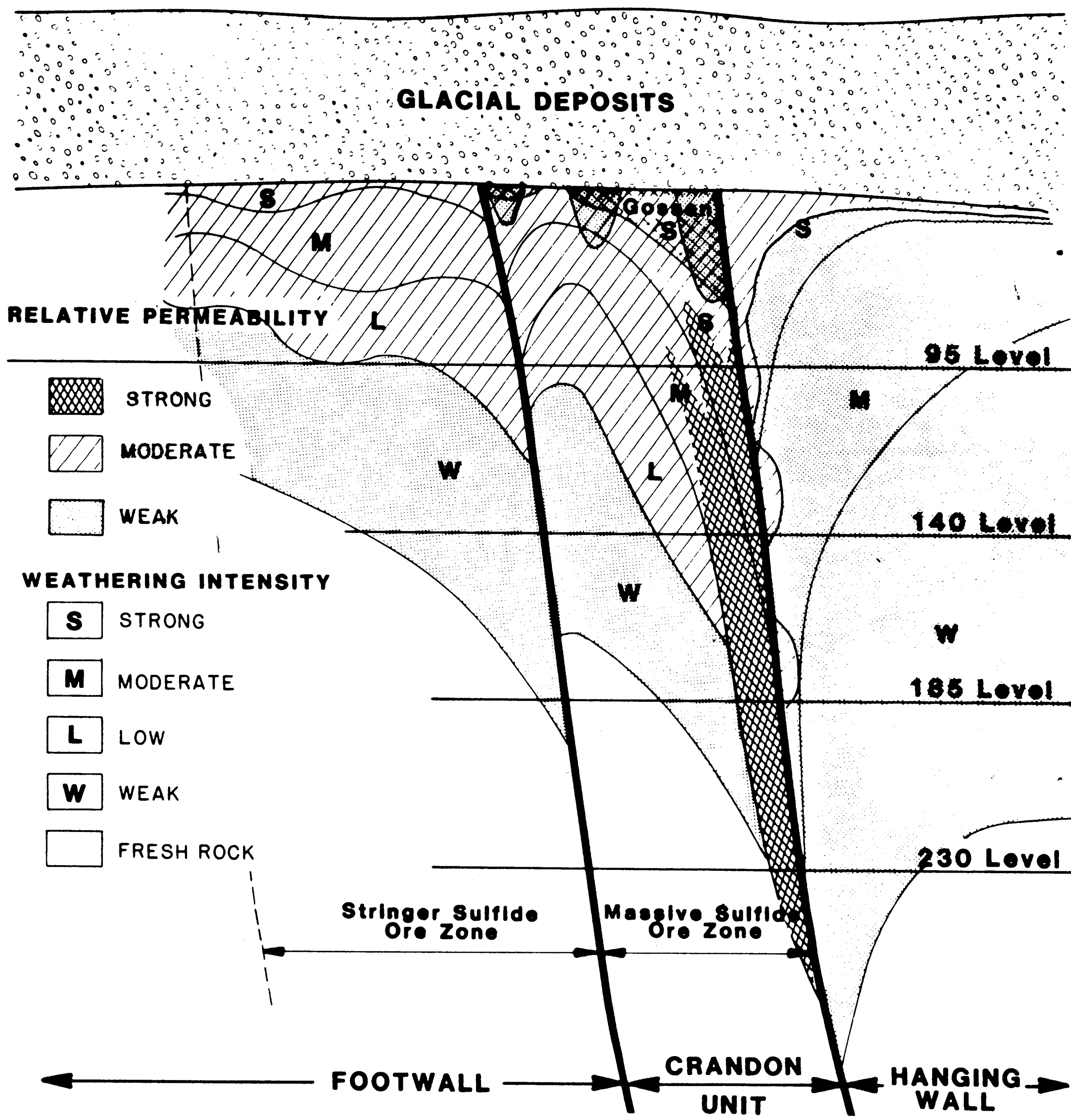
Hanging Wall - The hanging wall rock is weathered differently from either the Crandon Formation or the footwall rock because the hanging wall rock is a relatively homogeneous, nonsiliceous, fine grained chloritic tuff that contains small amounts (generally less than 1 percent) of sulfides.

Argillization is the primary destructive process, and moderate weathering commonly penetrates to a depth of 50 to 75 m (160 to 245 feet). Chlorite is readily converted to kaolinitic clay in the presence of ground water and low temperature/pressure environments. The presence of pyrite accelerates this process from the creation of acidic solutions in the weathering process. Fracturing is commonly relatively strong in the upper 10 to 50 m (30 to 160 feet), gradually fading in intensity with depth. This type of fracturing is likely to be caused by unloading stress (both weathering and glacial rebound) and near-surface ground movements in the weakened weathered rock.

Permeability of Weathered Rocks - A generalized permeability profile for the bedrock of the mine site area is presented on Figure 2.2-25. The following discussion and supporting data on bedrock permeability are based on information presented in the report entitled "Bedrock Permeability" by Exxon Minerals Company (1984).

Footwall - Strong, moderate, and low weathered rocks were all classified as moderately permeable and are likely to be in the upper 10^{-4} to mid-10^{-5} cm/s range. Weakly weathered rock was classified as weakly permeable, which is considered to be less permeable than 10^{-5} cm/s. No rock was classified as strongly permeable in the footwall.

Crandon Formation - The Crandon Formation is complex in terms of permeability. The high relative permeability is associated with the deeply leached weathering groove. It is also associated with the near-surface siliceous massive sulfide, much of which has been oxidized to gossan near the



EXXON MINERALS COMPANY

CRANDON PROJECT

GENERALIZED PERMEABILITY PROFILE OF CRANDON DEPOSIT ROCKS

R. ROWE

FIGURE 2.2-25

bedrock surface. Permeabilities were estimated to be in the 10^{-2} to 10^{-3} cm/s range. The weak relative permeability is not only associated with weakly weathered rocks, but more importantly, with oxidized chloritic massive sulfide near the subcrop. The chloritic gangue weathers to kaolinitic clay and results in a severely reduced permeability. All other strong, moderate, and low weathered rock was classified as moderately permeable.

Hanging Wall - Permeability is consistently in the 10^{-6} through 10^{-8} cm/s range in the moderate and weak weathered rock. This is true because kaolinitic clays are relatively mobile and fill the channelways for fluid movement. In the strong weathered rock, permeabilities may increase slightly to the 10^{-5} cm/s range.

The weathering profile is deep in the vicinity of the ore body when compared to the surrounding rock. The anomalous deepening of the strong and moderate weathering in these rocks is a chemical weathering response to the acidic ground water solutions generated by the leaching of sulfides in the adjacent Crandon Formation. It is also a physiochemical response to the weak movements (shearing and fracturing) along or near the upper contact of the Crandon Formation with the hanging wall rock, which promoted the circulation of ground water along that contact.

<u>Weathering Outside the Mine Site Area</u> - In the MWDF area, the bedrock weathering profile has been traced on the geologic cross sections in Figures 2.2-8 and 2.2-9. The intensity of weathering appears to be controlled primarily by rock type. On both cross sections B-B' and C-C', any core from the flows or from the crystal tuff-tuff breccia are essentially unweathered. This is because the SiO_2 content in these rocks is higher than the surrounding

rocks and because the porosity in these rocks is lower. The surrounding rocks are more heavily altered to chlorite by regional metamorphism because of their primary texture and chemistry.

Weathering probably not only follows rock types in general, but intensity is also related to fracture zones, which facilitate water movement (on a geologic timeframe) and allows for more rapid and deeper penetration of weathering. Fracturing and primary rock type are often related, the earth stresses being released in the least competent stratigraphic units. This phenomenon is illustrated by examining holes 199, 200, 206, and G41-C15, all of which penetrate the sediments and laminated tuff unit (Figure 2.2-7), the least competent stratigraphic unit in the MWDF area. All holes are fairly heavily fractured near the surface. Adjacent competent stratigraphic units, illustrated by holes 203, 205, and G41-E17, contain little to no fracturing. Because fracturing is generally restricted to incompetent stratigraphic units, water movement (in the 10^{-6} cm/s or less range, based upon permeability tests [Exxon Minerals Company, 1984]) will be essentially linear, along the trend of the fractures. Should the trend of the fractures not be parallel to the hydraulic gradient, flow will be limited further.

Only one piezometer (EX-9AL) was set into bedrock in the MWDF vicinity. The hole was drilled to test the glacial aquifer and penetrated 3 m (10 feet) into bedrock without recovering core. Permeability testing in the bedrock indicated a value of 1.8×10^{-8} cm/s (STS Consultants, Ltd., 1984). This bedrock permeability test in the MWDF was located in rock similar to the mine site hanging wall rock where there are results from several permeability tests (Exxon Minerals Company, 1984). Not only is the rock similar in composition, but the active destructive weathering effects are also similar. There is no evidence or reason to believe that permeability values are different.

The composition of the bedrock in site 40 is similar to the MWDF (site 41) area. However, in general, sulfide content is slightly higher and weathering is a little stronger (Figure 2.2-10). Permeability tests have not been conducted in this area; however, permeability values are not expected to vary markedly from site 41 or the mine/mill site hanging wall (10^{-5} through 10^{-8} cm/s).

2.2.3.3 Glacial Overburden Geology

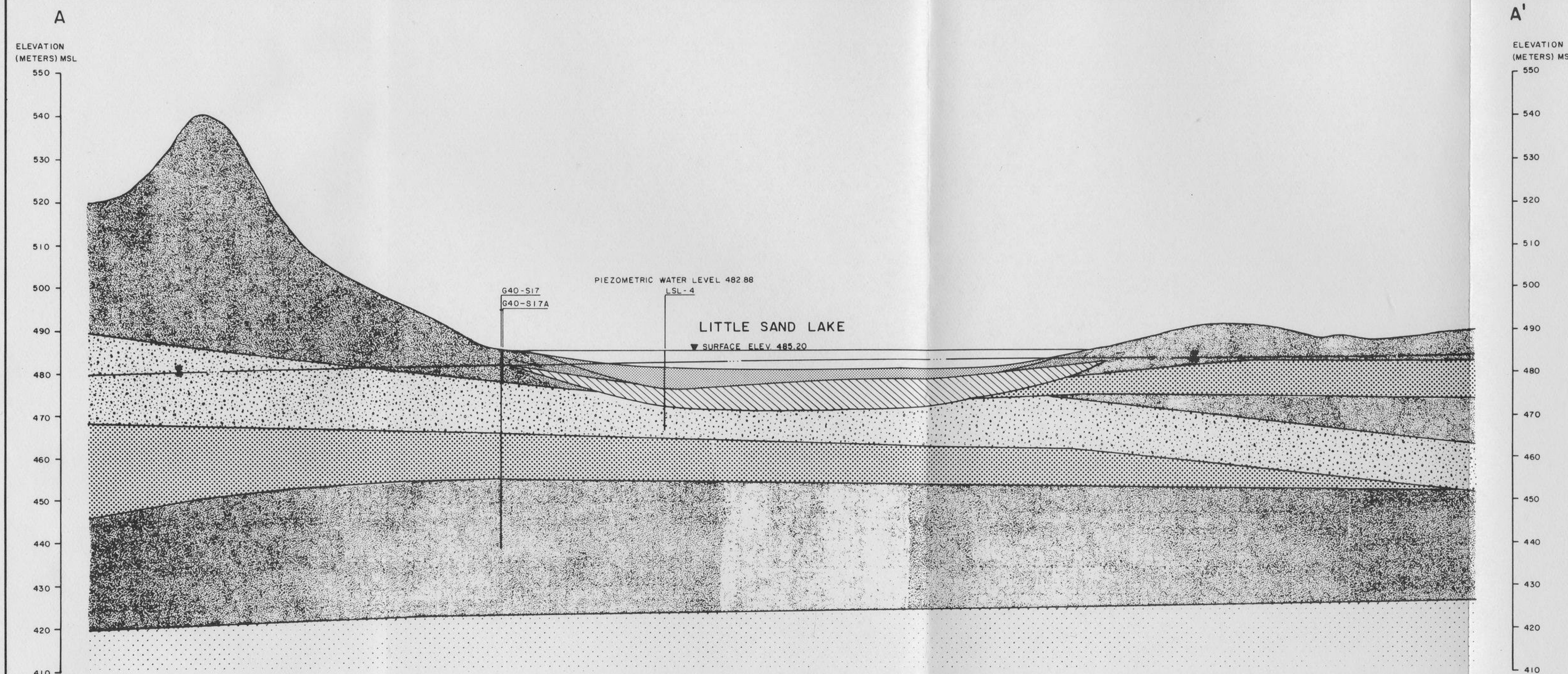
The bedrock in the mine/mill area is covered by 23 to 70 m (75 to 230 feet) of Pleistocene glacial silt, sand, and gravel. The majority of these materials are classified as till and stratified drift which are outwash and ice contact deposits. Fine grained soils, silt and clay, were present in minor amounts as lacustine deposits and are mostly associated with wetlands. The main emphasis for study in the mine/mill area was on the hydraulic characteristics of the glacial soils. As a result, most of the numerous borings (Figure 2.2-1) were interpreted by a genetic classification of soils, using such terms as glacial till, stratified drift, and lacustrine; as compared to the classification of the deposits by historical stratigraphic terminology, using such terms as Langlade till and Green Bay drift.

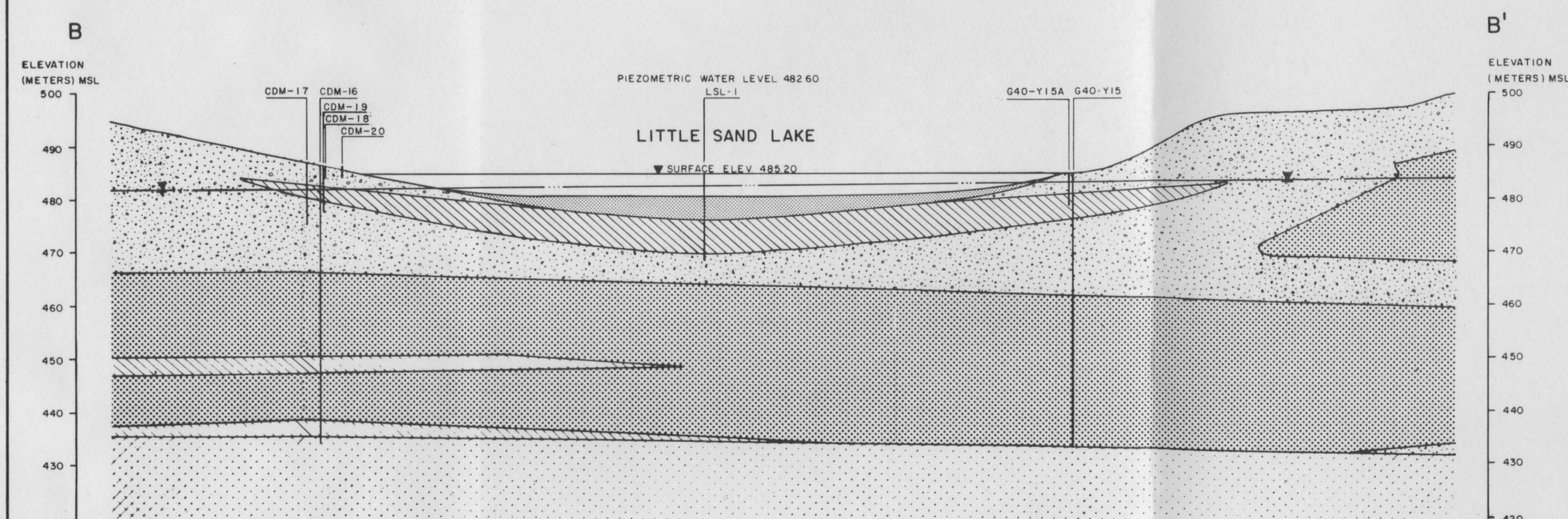
Cross sections depicting the surficial geology through the mine/mill area are shown on Figures 2.2-16 through 2.2-18. The glacial deposits were interpreted through data obtained from numerous borings and geophysical borehole logs. The lines of section for these profiles through the mine/mill area are shown on Figure 2.2-15. The results of various field and laboratory tests are presented on the logs and in Appendix 2.2A, and the logs of borings are included in Appendix 2.2B. In a study of the mine/mill area, geophysical logs were used to obtain hydrogeologic characteristics of the glacial overburden, to determine the porosity of the various weathered zones in the bedrock, and to define the contact between the glacial overburden and the bedrock (Camp Dresser & McKee Inc., 1982). The soil units, according to the genetic classification, consist of a layer of till overlying a layer of coarse grained drift, which overlies a deeper layer of till. The units are differentiated by grain size distributions and shape of the distribution curves (Golder Associates, 1981, 1982; STS Consultants, Ltd., 1984a).

There are five perched lakes in the site area. The surface water level is above the regional potentiometric surface in Little Sand, Skunk, Duck, Deep Hole, and Oak lakes. Expanded geologic cross sections of these five lakes showing the relative elevations of the surface water and potentiometric surface are presented on Figures 2.2-26 through 2.2-30.

Six borings were drilled from the ice surface of Little Sand Lake to deterimine the type of soils beneath the lake. The borings indicated that the materials beneath the lake bed consisted of very loose organic silt underlain by slightly organic silty clay. The silt ranged between 2.4 and 5.5 m (8 and 18 feet) in thickness and the clay was between 3.4 and 6.4 m (11 and 21 feet) thick. Beneath the clay, coarse grained stratified drift was encountered (STS Consultants, Ltd., 1982).

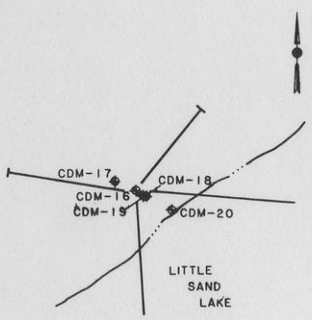
One boring was drilled from the ice surface in Skunk, Deep Hole, Duck, and Oak lakes to determine the type of soil beneath the lake. The borings indicated that the materials beneath the lake beds consisted of very loose organic silt underlain by slightly organic silty clay. The thickness of



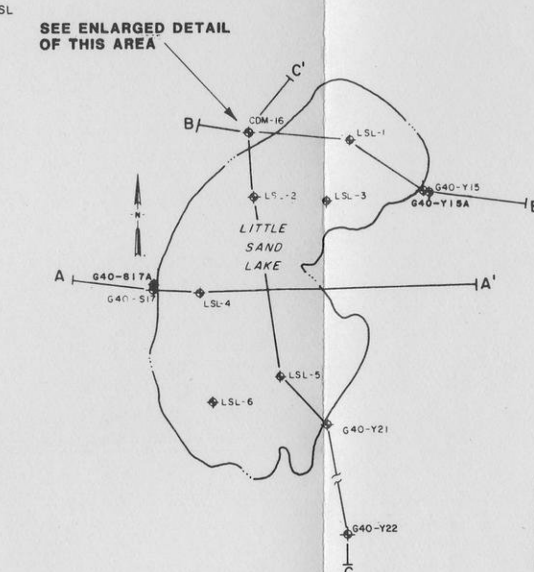


LEGEND

- ORGANIC SILT
- LACUSTRINE
- TILL
- COARSE GRAINED STRATIFIED DRIFT
- FINE GRAINED STRATIFIED DRIFT
- BASAL TILL
- BEDROCK
- LAKE WATER LEVEL
- GROUNDWATER POTENTIOMETRIC SURFACE

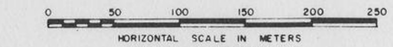


ENLARGED DETAIL
NOT TO SCALE



CROSS-SECTION INDEX
LITTLE SAND LAKE
NOT TO SCALE

NOTE: PROJECTIONS OF SOIL STRATA BASED ON DATA FROM BORING LOCATIONS. SOIL CONDITIONS BETWEEN BORINGS MAY VARY.



HORIZONTAL SCALE IN METERS
VERTICAL EXAGGERATION 5x

REFERENCE:
DRAWING No. 12959-16
TITLED: EXPANDED GEOLOGIC CROSS-SECTIONS OF LITTLE SAND LAKE
BY: STS CONSULTANTS LTD., GREEN BAY, WISCONSIN.
SCALE: AS SHOWN.

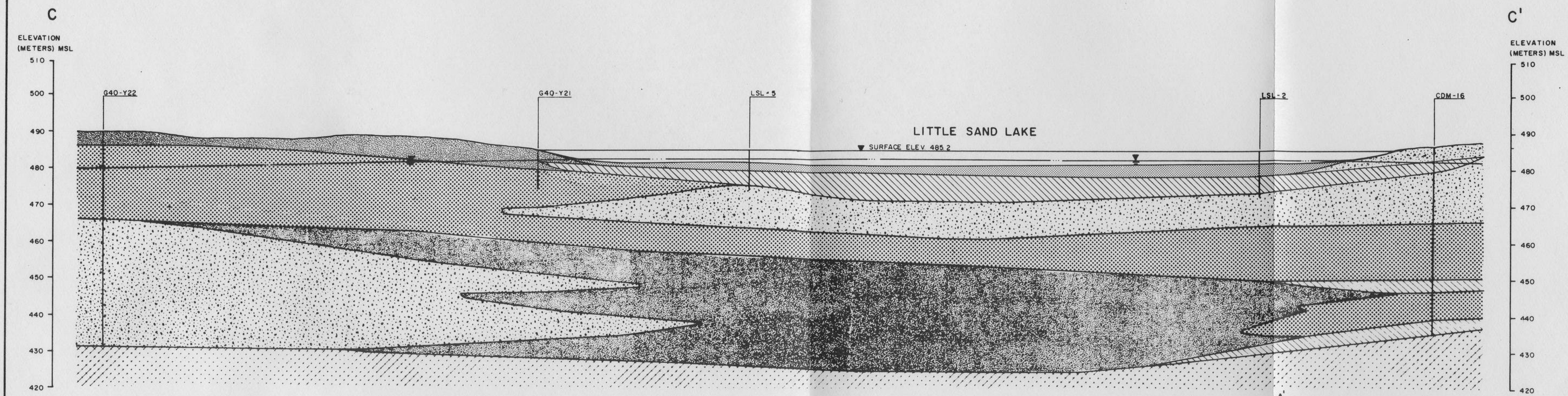
D'APPOLONIA

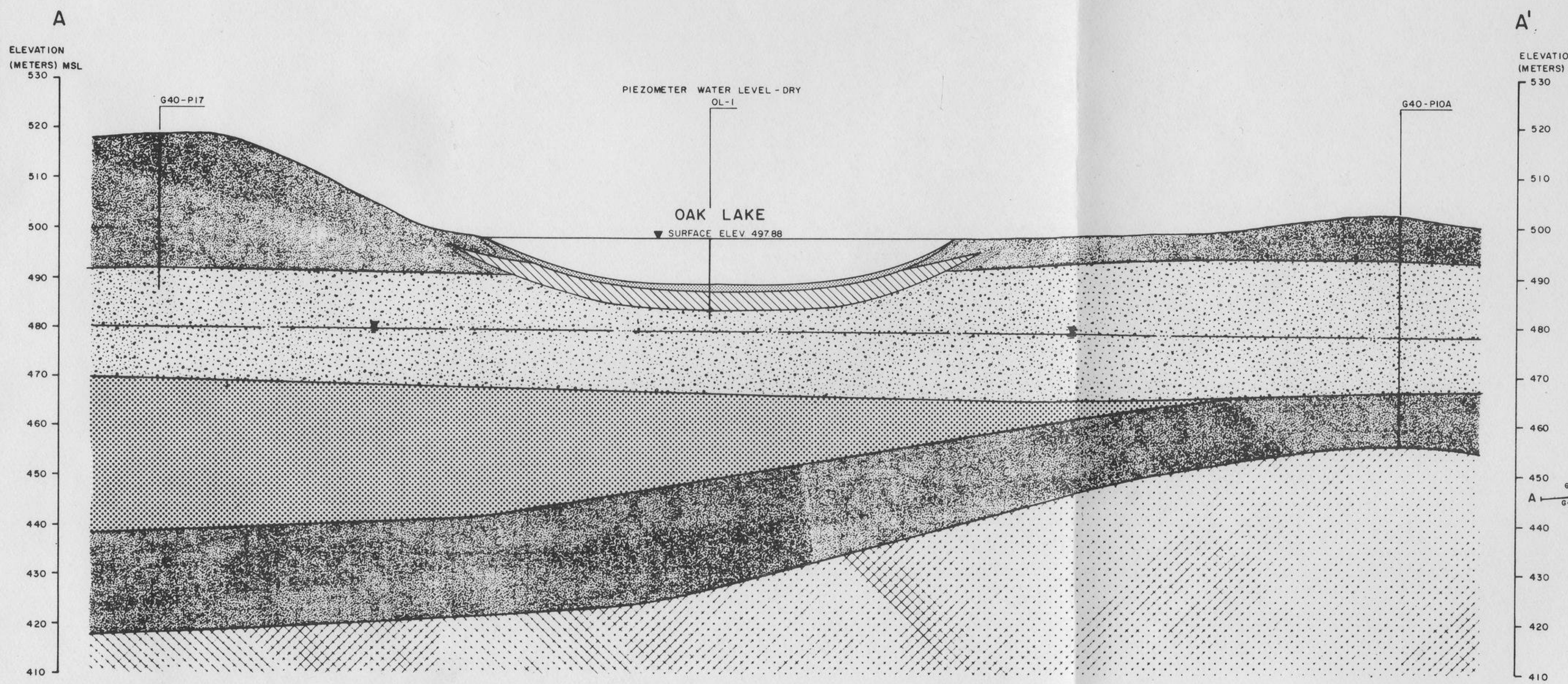
PROJ. NO. | DWG. NO. 850103-E4

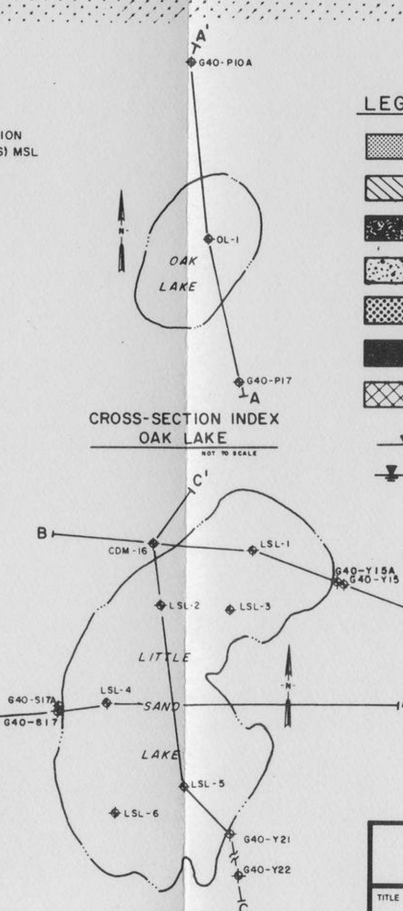
EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: GEOLOGIC SECTIONS THROUGH LITTLE SAND LAKE

SCALE AS SHOWN	STATE WISCONSIN	COUNTY FOREST
DRAWN BY RW	DATE 5-23-85	CHECKED BY
APPROVED BY	DATE	APPROVED BY
APPROVED BY	DATE	EXXON
DRAWING NO. FIGURE 2.2-26	SHEET OF	REVISION NO.







CROSS-SECTION INDEX
OAK LAKE
NOT TO SCALE

CROSS-SECTION INDEX
LITTLE SAND LAKE
NOT TO SCALE

LEGEND

- ORGANIC SILT
- LACUSTRINE
- TILL
- COARSE GRAINED STRATIFIED DRIFT
- FINE GRAINED STRATIFIED DRIFT
- BASAL TILL
- BEDROCK
- LAKE WATER LEVEL
- GROUNDWATER POTENTIOMETRIC SURFACE

NOTE: PROJECTIONS OF SOIL STRATA BASED ON DATA FROM BORING LOCATIONS. SOIL CONDITIONS BETWEEN BORINGS MAY VARY.

0 50 100 150 200 250
HORIZONTAL SCALE IN METERS
VERTICAL EXAGGERATION 5x

REFERENCE:
DRAWING No. 12959-17
TITLED: EXPANDED GEOLOGIC CROSS-SECTIONS OF LITTLE SAND LAKE AND OAK LAKE.
BY: STS CONSULTANTS LTD., GREEN BAY, WISCONSIN.
SCALE: AS SHOWN.

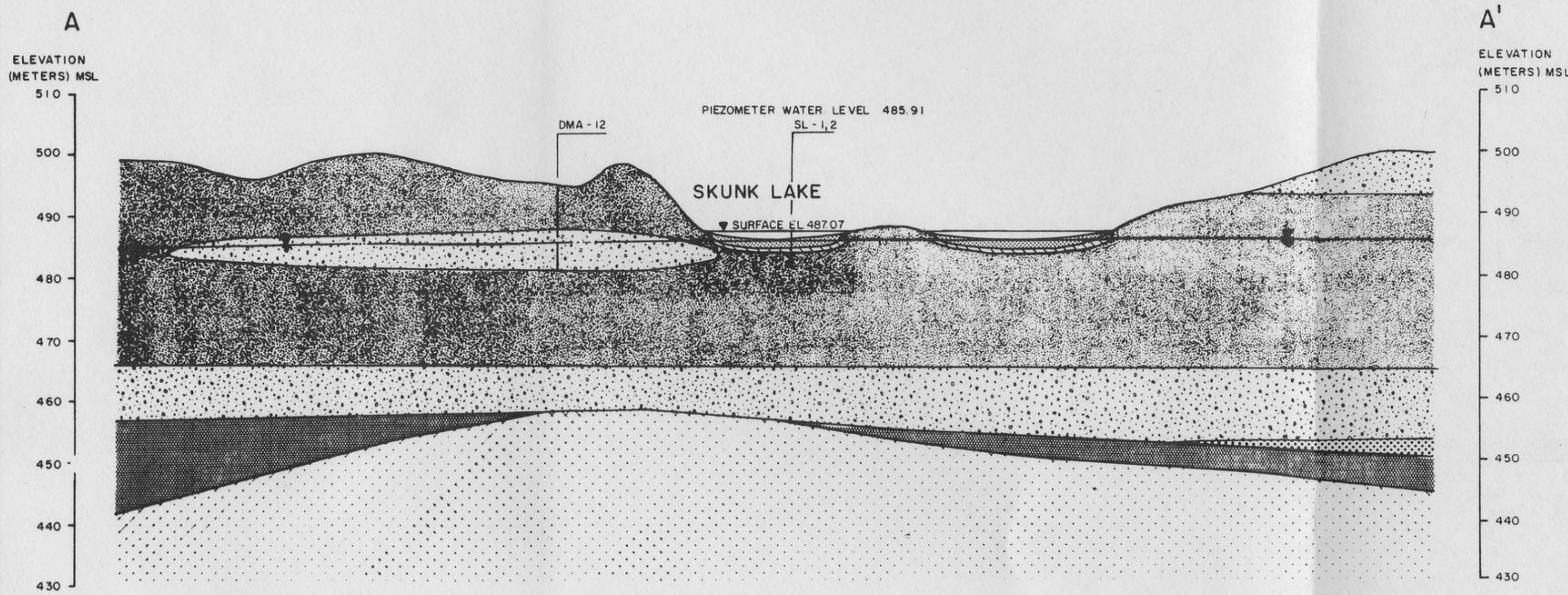
D'APPOLONIA

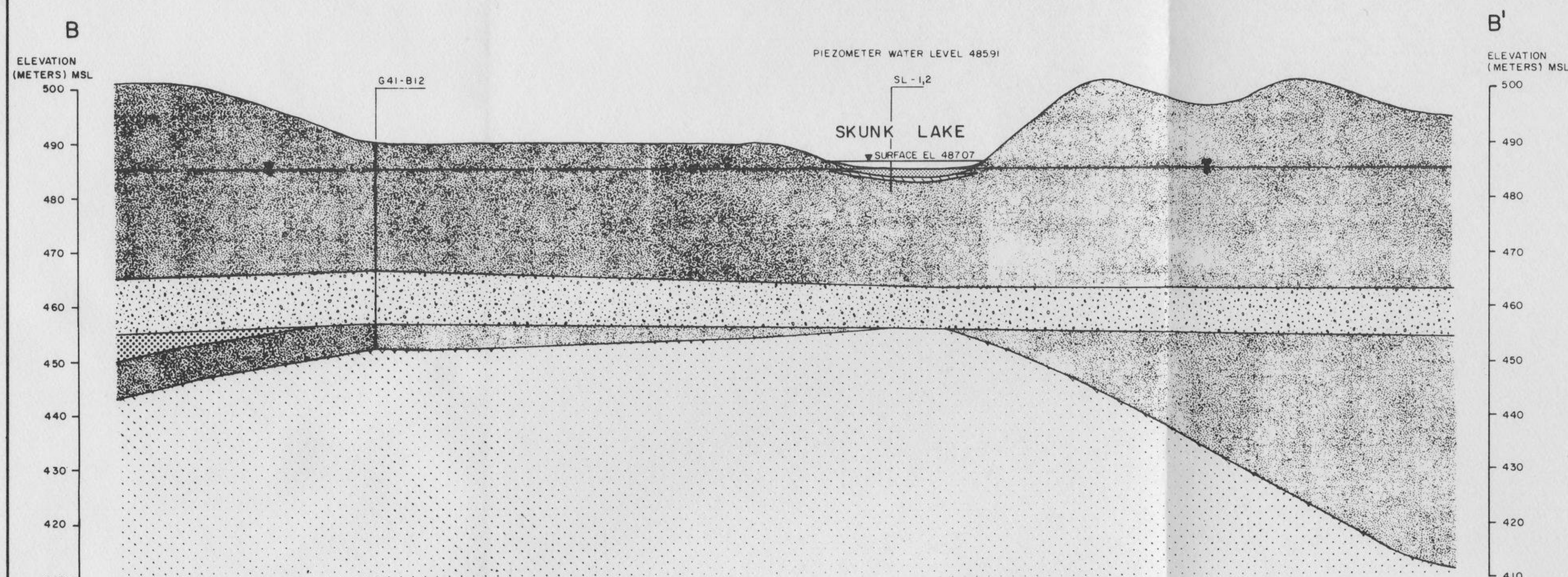
PROJ. NO. | DWG. NO. 850103-E5

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
GEOLOGIC SECTIONS THROUGH
LITTLE SAND LAKE AND OAK LAKE

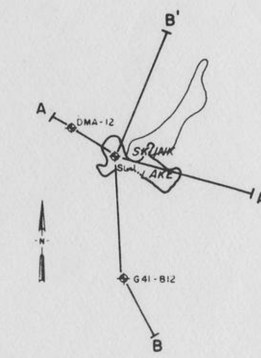
SCALE AS SHOWN	STATE WISCONSIN	COUNTY FOREST	
DRAWN BY RW	DATE 5-23-85	CHECKED BY	DATE
APPROVED BY	DATE	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE
DRAWING NO. FIGURE 2.2-27		SHEET OF	REVISION NO.





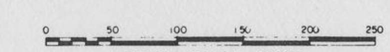
LEGEND

- ORGANIC SILT
- LACUSTRINE
- TILL
- COARSE GRAINED STRATIFIED DRIFT
- FINE GRAINED STRATIFIED DRIFT
- BASAL TILL
- BEDROCK
- LAKE WATER LEVEL
- GROUNDWATER POTENTIOMETRIC SURFACE



CROSS-SECTION INDEX
SKUNK LAKE
NOT TO SCALE

NOTE: PROJECTIONS OF SOIL STRATA BASED ON DATA FROM BORING LOCATIONS. SOIL CONDITIONS BETWEEN BORING MAY VARY



HORIZONTAL SCALE IN METERS
VERTICAL EXAGGERATION 5x

REFERENCE:
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TITLED: EXPANDED GEOLOGIC CROSS-SECTIONS OF SKUNK LAKE;
BY: STS CONSULTANTS LTD., GREEN BAY, WISCONSIN.
SCALE: AS SHOWN.

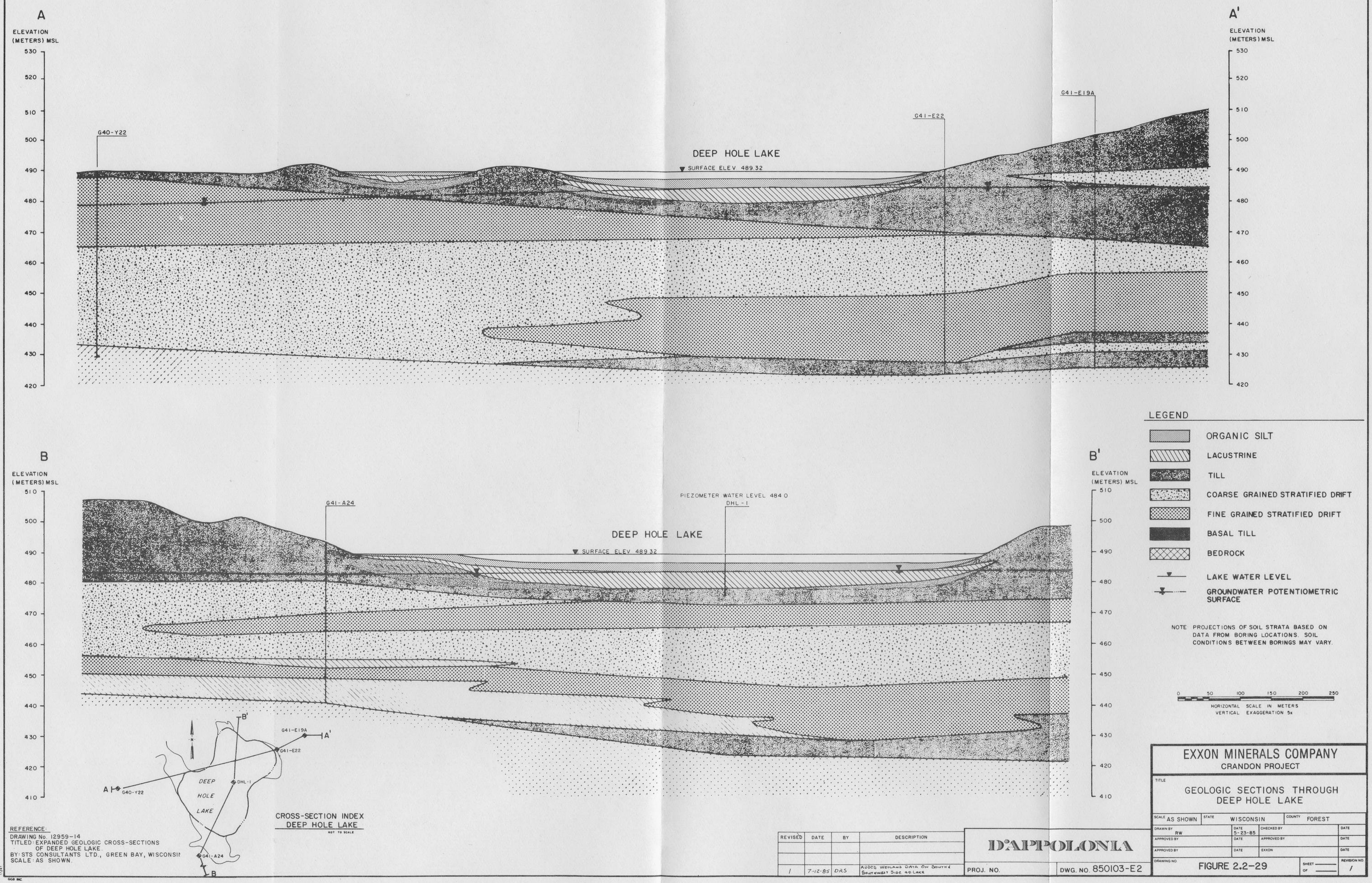
D'APPOLONIA

PROJ. NO. | DWG. NO. 850103-E1

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
GEOLOGIC SECTIONS THROUGH
SKUNK LAKE

SCALE AS SHOWN	STATE WISCONSIN		COUNTY FOREST		
DRAWN BY RW	DATE 5-23-85	CHECKED BY		DATE	
APPROVED BY	DATE	APPROVED BY		DATE	
APPROVED BY	DATE	EXXON		DATE	
DRAWING NO	FIGURE 2.2-28		SHEET ___ OF ___	REVISION NO.	



CROSS-SECTION INDEX
DEEP HOLE LAKE
NOT TO SCALE

REFERENCE:
DRAWING No. 12959-14
TITLED: EXPANDED GEOLOGIC CROSS-SECTIONS OF DEEP HOLE LAKE.
BY: STS CONSULTANTS LTD., GREEN BAY, WISCONSIN
SCALE: AS SHOWN.

REVISED	DATE	BY	DESCRIPTION
1	7-12-85	DRS	ADDED WETLAND DATA ON SOUTH & SOUTHWEST SIDE OF LAKE

D'APPOLONIA

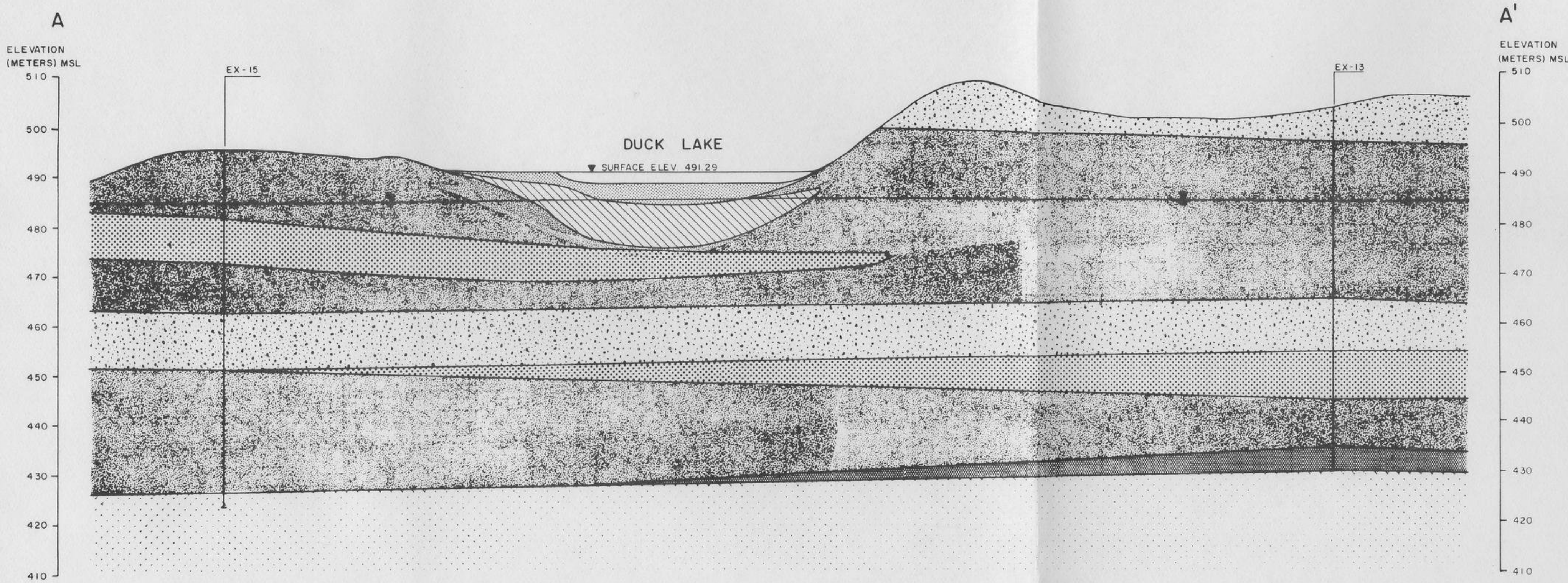
PROJ. NO.
DWG. NO. 850103-E2

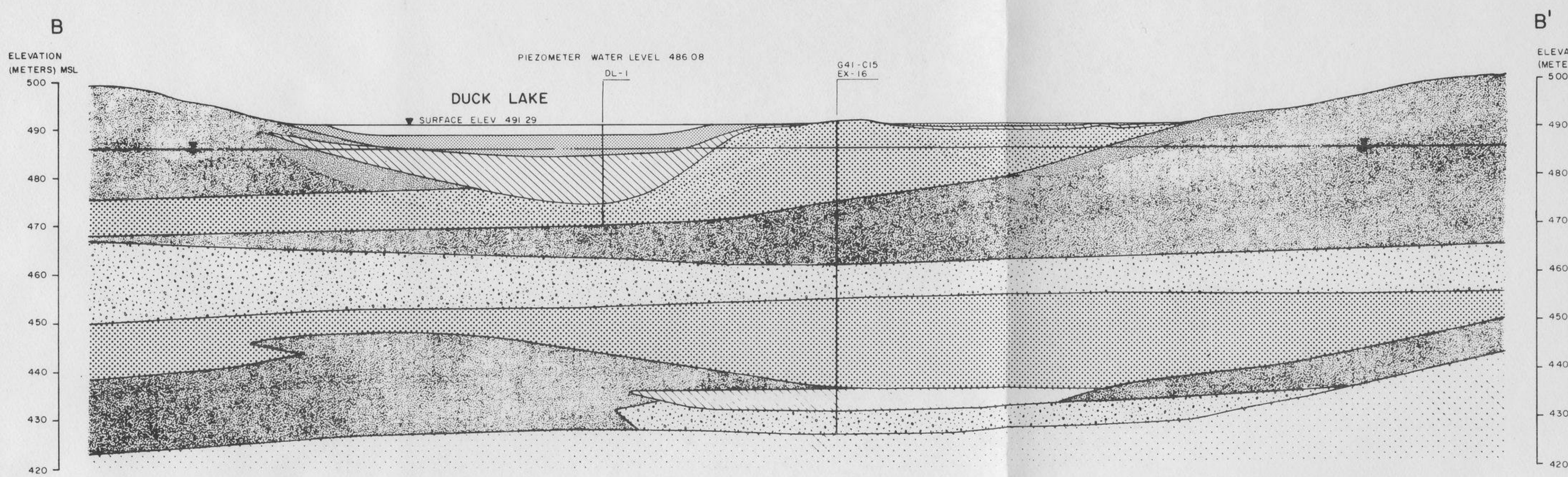
EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: GEOLOGIC SECTIONS THROUGH DEEP HOLE LAKE

SCALE AS SHOWN	STATE WISCONSIN	COUNTY FOREST	
DRAWN BY RW	DATE 5-23-85	CHECKED BY	DATE
APPROVED BY	DATE	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE
DRAWING NO. FIGURE 2.2-29		SHEET OF	REVISION NO. 1

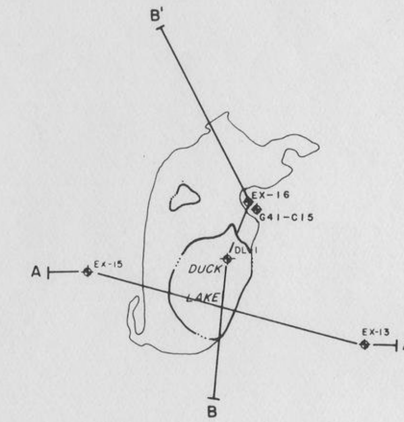
GGB INC.





LEGEND

- ORGANIC SILT
- LACUSTRINE
- TILL
- COARSE GRAINED STRATIFIED DRIFT
- FINE GRAINED STRATIFIED DRIFT
- BASAL TILL
- BEDROCK
- LAKE WATER LEVEL
- GROUNDWATER POTENTIOMETRIC SURFACE



CROSS-SECTION INDEX
DUCK LAKE
NOT TO SCALE

NOTE: PROJECTIONS OF SOIL STRATA BASED ON DATA FROM BORING LOCATIONS. SOIL CONDITIONS BETWEEN BORINGS MAY VARY.

0 50 100 150 200 250
HORIZONTAL SCALE IN METERS
VERTICAL EXAGGERATION 5x

REFERENCE:
DRAWING No. 12959-15
TITLED: EXPANDED GEOLOGIC CROSS-SECTIONS OF DUCK LAKE.
BY: STS CONSULTANTS LTD., GREEN BAY, WISCONSIN.
SCALE: AS SHOWN

REVISED	DATE	BY	DESCRIPTION
1	7-12-85	DRS	ADDED WETLAND DATA ON NORTH & WEST SIDE OF LAKE

D'APPOLONIA

PROJ. NO. DWG. NO. 850103-E3

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: GEOLOGIC SECTIONS THROUGH DUCK LAKE

SCALE	STATE	COUNTY
AS SHOWN	WISCONSIN	FOREST

DRAWN BY: RW DATE: 5-23-85 CHECKED BY: DATE:
APPROVED BY: DATE: APPROVED BY: DATE:
APPROVED BY: DATE: EXXON DATE:

DRAWING NO. FIGURE 2.2-30 SHEET: OF: REVISION NO. 1

the lake bottom soils for each lake was as follows: Skunk, 0.73 m (2.4 feet); Oak, 5.18 m (17.0 feet); Deep Hole, 8.17 m (26.8 feet); and Duck, 15.5 m (51.0 feet). Glacial till or stratified drift was encountered beneath the clay (STS Consultants, Ltd., 1984b).

Soil samples from three borings in the mine/mill area, DMA-4, DMB-10, and DMB-16, were analyzed to determine their clay mineralogy (Table 2.2-8). The clay minerals, montmorillonite, illite, chlorite, and kaolinite, were present in all samples. The most dominant non-clay mineral was quartz, which was abundant in all samples.

2.2.4 Mining Waste Disposal Facility Geology

The proposed mine waste disposal area (site 41) is shown on Figure 2.2-19. The location boundaries are approximate and show the general area but not the precise limits of any recommended waste disposal system. The focus of investigation centered on the upland area east of Duck Lake and west of Hemlock Creek.

2.2.4.1 Physiography

Ground surface elevation in the mine waste disposal area is less than 479 m (1,580 feet) MSL along the floodplain of Hemlock Creek. The highest elevation 533 m (1,760 feet) occurs at the top of a drumlin ridge between Skunk Lake and Hemlock Creek. The area consists of a broad drumlin ridge oriented in a north-south direction with flat and pitted outwash plains and lake beds forming lowlands on the east and west between Little Sand Lake and Hemlock Creek. The ground surface in the mine waste disposal area varies from nearly flat in the outwash plains to a grade of approximately 25 percent on the sides of ridges adjacent to the Hemlock Creek floodplain.

2.2.4.2 Bedrock Geology

The mine waste disposal area is underlain by Precambrian rock of the Hemlock Creek and Swamp Creek groups. The bedrock surface is relatively flat beneath the center of the area, forming a bench-type surface with a higher elevation to the northwest towards the mine/mill area, and decreasing towards the eastern edge of the area (Figure 2.2-11).

Mineral Potential of Sites 40 and 41 - Potential for economic base metal mineralization in site 41 is negligible. First, only traces of base metals were noted, which is a regional background condition. Second, the bedrock did not display any evidence of hydrothermal alteration. In the mine area, the hydrothermal fluids were the medium for moving the metals into the system. The fluids also left a "chemical imprint" on the rocks through which they passed or resided. No such chemical imprint exists in bedrock in the site 41 area. Airborne and ground geophysical investigations were also conducted in the site 41 area with negative results. The plan geologic map (Figure 2.2-6) and cross sections (Figures 2.2-8 and 2.2-9) for the site 41 area have been discussed earlier.

Mineral potential in site 40 is also low. There are local but minor concentrations of base metals in drill hole 131, as well as some evidence of hydrothermal alteration. Potential for shallow economic base metal mineralization is low; however, potential for deep mineralization would be slightly higher, but very unlikely. Geophysical investigation in site 40 supported the lack of mineral potential at shallow bedrock depths. Geophysical evaluation such as airborne or ground EM is only considered effective at shallow depths in this type of environment. One cross section (Figure 2.2-10) was constructed in the site 40 area.

2.2.4.3 Glacial Overburden Geology

The principal materials found throughout the depth of the glacial deposits in the mine waste disposal area are till and coarse grained stratified drift and fine grained stratified drift. Lesser amounts of basal till and lacustrine deposits were also identified. Weathered rock was penetrated beneath the glacial materials in some of the boreholes (Figures 2.2-8 and 2.2-9).

The subsurface glacial stratigraphy was interpreted from the numerous test borings in the mine waste disposal area (Figure 2.2-1) and from the laboratory and field tests presented in Appendix 2.2A, on the boring logs in Appendix 2.2B, and in various supplemental reports (Camp Dresser & McKee Inc., 1982; Golder Associates, 1981, 1982; STS Consultants, Ltd., 1982, 1984a).

Cross sections depicting the surficial geology through the mine waste disposal area are shown on Figures 2.2-16 through 2.2-18. Lines of section for these profiles are shown on Figure 2.2-15. The main emphasis for study in the mine waste disposal area was on the hydraulic characteristics of the glacial soils and their varying physical properties. As a result, most of the borings were not described according to specific glacial stages but were interpreted by a lithologic classification of the materials using such terms as glacial till, stratified drift, and lacustrine (Golder Associates, 1981; STS Consultants, Ltd., 1984a).

Thickness of overburden in the mine waste disposal area ranges from about 47 m (156 feet) at the northern edge of the area in the floodplain of Hemlock Creek to approximately 98 m (320 feet) at the southern edge of the area between Deep Hole and Walsh lakes.

The mine waste disposal area is primarily underlain by a relatively thick upper till unit that forms the ridge between Little Sand Lake and Hemlock Creek. This upper till is present beneath other ridges in the study region, but is very thin in lowland areas which are mostly underlain by coarse and fine grained stratified drift. The thickness of the till is much more extensive in the mine waste disposal area than most other areas of the study region. This is important because the till is less pervious than the underlying coarse or fine grained drift. The hydrological characteristics of these deposits are described in section 2.3, Ground Water. Soil samples from five borings in the mine waste disposal area, DMB-1, DMB-2, DMB-5, DMB-6, and DMB-9, were analyzed for clay mineralogy content (Table 2.2-8). The clay minerals montmorillonite, illite, and chlorite were present in all samples. Kaolinite was present in all samples except from Boring DMB-2. Quartz was the most dominant non-clay mineral and was abundant or very abundant in all samples.

2.2.5 Seismology

Historic Seismicity - Northern Wisconsin and the upper peninsula of Michigan are two of the more seismologically stable areas in the United States. Figure 2.2-3 shows the locations of the few historical seismic events and their relation to the site area and regional structural features. Table 2.2-10 lists the major historical seismic events (Modified Mercalli intensities greater than II) within a 320-km (200-mile) radius of the site area. The intensity of each seismic event is described by the Modified Mercalli Intensity Scale, described in Table 2.2-11.

TABLE 2.2-10

HISTORICAL SEISMICITY WITHIN 200 MILES OF THE CRANDON PROJECT SITE AREA[a]

DATE	LOCATION	MODIFIED MERCALLI INTENSITY
1905 Mar 13	Menominee, MI	V
1905 Jul 26	calumet, MI	VII
1906 May 26	Keweenaw Peninsula, MI	VIII
1909 Jan 22	Houghton, MI	V
1931 Oct 18	Madison, WI	III[b]
1933 Dec 6	Stoughton, WI	III
1935 Oct	Negaunee, MI	II-III[b]
1943 Feb 9	Marinette County, WI	II-III[b]
1944 Nov 16	Escanaba, MI	II-III[b]
1945 May 18	Escanaba, MI	II[b]
1947 May 6	Southeastern, WI	IV
1955 Jan 5	Calumet, MI	IV
1955 Jan 6	Hancock, MI	V
1956 Jul 18	Oostburg, WI	IV
1956 Oct 13	Milwaukee, WI	IV

[a]Docekal, 1970; Coffman and VonHake, 1973.

[b]Reported as felt by several people (Docekal, 1970).

TABLE 2.2-11

MODIFIED MERCALLI INTENSITY SCALE OF 1931 (ABRIDGED)

I. Not felt except by a very few under specially favorable circumstances. (I Rossi-Forel Scale)

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel Scale)

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel Scale)

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel Scale)

V. Felt by nearly everyone; many windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale)

VI. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale)

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars. (VIII Rossi-Forel Scale)

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII+ to IX Rossi-Forel Scale)

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. (IX+ Rossi-Forel Scale)

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from riverbanks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel Scale)

XI. Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into air.

The largest seismic events within 320 km (200 miles) of the site area occurred on the Keweenaw Peninsula (Figure 2.2-3), approximately 209 km (130 miles) north. The largest seismic event occurred on May 26, 1906. The Modified Mercalli Intensity of this event was reported as an VIII (Docekal, 1970; Coffman and VonHake, 1973). According to the regional attenuation characteristics reported by Gupta and Nuttli (1976), the intensity felt at the site area from any of the events on the Keweenaw Peninsula would have been less than Intensity V. The localized nature of some of the "felt" areas and calculation of the average radii of the reported "felt" area indicate that these events were probably not even felt at the site area. Major seismic activity may be restricted to the Keweenaw Peninsula and should not be expected in the stable, aseismic study region of the Crandon Project.

The largest seismic events reported in the midcontinent of the United States occurred during the 1811-1812 New Madrid earthquake series. During this period, events with Modified Mercalli Intensities as high as XI-XII were reported in the New Madrid, Missouri area. An isoseismal map of the December 16, 1811 event, prepared by Nuttli (1973), indicates a Modified Mercalli Intensity of IV felt in the Crandon, Wisconsin area. However, an isoseismal map prepared by Stearns and Wilson (1972) for the same event shows the Crandon area experienced a Modified Mercalli Intensity of less than II.

Site Area Seismic Design - The results of regional and site area geology studies were used to estimate the maximum probable horizontal ground acceleration that might be expected at the site area. Considering the regional geology and seismic history, it is conservatively concluded that the site should not have experienced a Modified Mercalli Intensity greater than

III to IV from any historical seismic event. Considering the tectonic stability of the study region, it is improbable that future seismic events will be larger than the historical events. Therefore, a ground horizontal acceleration of 4 percent of gravity at bedrock is recommended for engineering design. This level is derived conservatively from consideration of an intensity of IV to V felt at the site area as a result of the recurrence of any historical event. The acceleration/intensity conversion employed is derived from Trifunac and Brady (1975) wherein a "mean" acceleration in competent rock expected from an Intensity V event is less than 4 percent gravity. The design ground motion is conservative, considering the local seismicity, but allows for the possible consequences of large, distant events and their extended duration of motion from long-period seismic waves.

The existing seismic risk maps were reviewed as a check on the validity of the assumed horizontal ground motion. Algermissen and Perkins (1976) have shown that the study region lies within a region having a 90 percent probability that acceleration of approximately 4 percent gravity will not be exceeded for hardrock in a 54-year period. Milne and Davenport (1969) showed an acceleration value of 1 percent gravity with a 100-year return period. Perkins (1974) displayed a map wherein the study region lies within a zone where the earthquake risk is described as minor damage, and where distant earthquakes may cause damage to structures with fundamental periods greater than 1 second, corresponding to Modified Mercalli Intensities of V and VI.

The range of expected intensity values in the above analyses is primarily from the various assumptions used by the authors as input to their respective statistical procedures. However, all studies corroborate the low seismicity of the study region.

In reviewing all aspects of the various analyses, a design acceleration of no higher than 4 percent gravity is considered reasonable. It is emphasized, however, that this design parameter was developed for the response of firm, competent foundation material.

Since competent bedrock in the site area is overlain by approximately 61 m (200 feet) of unconsolidated glacial material, some amplification could occur so that structures at the site area might be subjected to somewhat higher levels of acceleration, particularly in certain frequency ranges. An approximation of this amplification can be made based on the responses identified for areas of similar geologic conditions. Seismic acceleration data developed for Illinois Power Company's Clinton Power Station in central Illinois (Illinois Power Company, 1974) indicate an amplification factor of 1.5 for a site underlain by more than 61 m (200 feet) of unconsolidated glacial material. This factor is in agreement with an empirical approach used by Nuttli (1973), which states that unconsolidated soils can increase ground accelerations by a factor of 1.0 to 1.5. Applying this factor to the assumed 4 percent gravity acceleration of bedrock indicates an expected ground motion of 6 percent gravity at foundation level.

2.2.6 Summary and Conclusions

1) The study region is located in the seismically stable Southern Province of the Canadian Shield, composed of Precambrian bedrock ranging in age from 960 to 3,200 million years. Massive sulfide deposits occur in volcanic rocks surrounded by granitic gneisses within the province. These deposits, including the Crandon ore deposit, are generally tabular-shaped bodies consisting of more than 50 percent sulfide by volume.

2) The Crandon sulfide deposit is identifiable for a distance of approximately 1,524 m (5,000 feet) along strike and to a depth of approximately 732 m (2,400 feet) below the bedrock surface. Its thickness varies from less than 0.3 m (1 foot) on the west to 76 m (250 feet) near its center.

3) The Crandon bedrock was formed during two volcanic cycles that deposited rock referred to as the Hemlock Creek and the Swamp Creek groups. Each group is subdivided into formations that are composed of rock of a similar lithologic character and depositional history.

4) In the environmental study area, glacial overburden has been differentiated on the basis of historical glacial stratigraphy. Differentiation between the Green Bay and Langlade drifts was made on the basis of color, calcareous composition, and carbonate pebble content. Laboratory tests were performed on samples to determine these differences.

5) In the environmental study area, glacial overburden has also been differentiated from a hydrologic perspective on the basis of genetic glacial stratigraphy. Five major categories have been identified as till, basal till, coarse grained stratified drift, fine grained stratified drift, and lacustrine. Differentiation was made on the basis of Unified Soil Classification System, geophysical logging, permeability testing, grain size analysis, and other laboratory testing.

6) The Crandon deposit bedrock has been subjected to uninterrupted weathering since Precambrian time. At present, the total thickness of weathered rock is relatively thin because of extensive stripping by glacial action.

7) There are five perched lakes in the site area. The surface water level is above the regional potentiometric surface in Little Sand, Skunk, Duck, Deep Hole, and Oak lakes.

8) The surficial topography is primarily the result of the final Langlade ice advance and is characterized by southwest trending ridges and valleys.

9) The largest seismic events in the region occurred on the Keweenaw Peninsula, north of the site area. The largest of these occurred in 1906 and had a Modified Mercalli Intensity of VIII. The intensity felt at the site would have been relatively minor because of regional attenuation characteristics.

2.2.7 Glossary

The following is a glossary of terms used in section 2.2. It is modified from Gary et al. (1972) and Bates and Jackson (1980).

alluvium - Clay, silt, sand, gravel, or similar detrital material deposited by running water.

aquifer - Soil or rock strata capable of yielding usable quantities of water to wells. As used in this report, it includes both fine and coarse grained stratified drift.

argillite - A compact rock, derived either from mudstone (claystone or siltstone) or shale, that has undergone a somewhat higher degree of induration than is present in mudstone or shale but that is less clearly laminated than, and without the fissility of, shale, or that lacks the cleavage distinctive of slate.

argillization - Development of clay minerals in rock adjacent to mineral veins.

asbestiform - Mineral that is fibrous, like asbestos.

basalt - A general term for dark-colored mafic igneous rocks, commonly extrusive but locally intrusive (for example, as dikes) composed chiefly of calcic plagioclase and clinopyroxene; the fine grained equivalent of gabbro.

basalt flows - See basalt, flow.

basal till - Glacial till deposit found on the bedrock surface.

batholith - A large, generally discordant plutonic mass that has more than 100 km^2 (40 square miles) of surface exposure and no known floor. Its formation is believed by most investigators to involve magmatic processes.

breccia - A coarse grained clastic rock, composed of angular broken rock fragments held together by a mineral cement or in a fine grained matrix, originating by igneous, or volcanic, processes.

chert - A hard, extremely dense or compact, dull to semivitreous, microcrystalline sedimentary rock, consisting dominantly of interlocking crystals of quartz; it may contain amorphous silica (opal). It may be an original organic or inorganic precipitate or a replacement product.

cherty - Containing chert (for example, "cherty" limestone).

chlorite - A group of platy, monoclinic, usually greenish minerals of the general formula $(Mg,Fe^{+2},Fe^{+3})_6AlSi_3O_{10}(OH)_8$. It is characterized by prominent ferrous iron and by the absence of calcium and alkalis; chromium and manganese may be present. Chlorites are associated with and resemble the micas; they may also be considered as clay minerals.

chloritic - Containing chlorite.

colluvium - (a) A general term applied to any loose, heterogeneous, and incoherent mass of soil material and/or rock fragments deposited by rainwash, sheetwash, or slow continuous downward creep, usually collecting at the base of gentle slopes or hillsides. (b) Alluvium deposited by unconcentrated surface runoff or sheet erosion, usually at the base of a slope.

dip - The angle that a structure surface (for example, a bedding or fault plane) makes with the horizontal, measured perpendicular to the "strike" of the structure and in the vertical plane.

dolomite - (a) A common rock-forming rhombohedral mineral: $CaMg(CO_3)_2$; commonly is white, colorless, or tinged yellow, brown, pink, or grey. Part of the magnesium may be replaced by ferrous iron and less frequently by manganese. (b) A carbonate sedimentary rock more than 50 percent by weight of the mineral dolomite or approximating the mineral dolomite.

drift - A general term applied to all rock material (clay, silt, sand, gravel, boulders) transported by a glacier and deposited directly by or from the ice, or by running water emanating from a glacier. Drift includes unstratified material (till) that forms moraines, and stratified deposits that form outwash plains, eskers, kames, glaciofluvial sediments, etc.

drumlin - A low, smoothly rounded, elongate oval hill, mound, or ridge of compact glacial till or, less commonly, other kinds of drift (sandy till, varved clay), built under the margin of the ice and shaped by its flow, or carved out of an older moraine by readvancing ice; its longer axis is parallel to the direction of movement of the ice. It usually has a blunt nose pointing in the direction from which the ice approached, and a gentler slope tapering in the other direction.

esker - A long, narrow, sinuous, steep-sided ridge composed of irregularly stratified gravel and sand that was deposited by a subglacial or englacial stream flowing between ice walls or in an ice tunnel of a stagnant or retreating glacier, and was left behind when the ice melted. It may be branching and is often discontinuous, and its course is usually at a high angle and to the edge of the glacier.

eutaxitic - Said of the banded structure of certain volcanic rocks, which results in a streaked or blotched appearance.

flow - (a) A mass movement of unconsolidated material that exhibits a continuity of motion and a plastic or semifluid behavior resembling that of a viscous fluid. Water is usually required for most types of flow movement. (b) The mass of material moved by a flow.

fold - A curve or bend of a planar structure such as rock strata, bedding planes, foliation, or cleavage. A fold is usually a product of deform although its definition is descriptive and not generic and may include primary structures.

footwall - The underlying side of an ore body or mine working.

gabbro - A group of dark-colored, basic intrusive igneous rocks composed principally of basic plagioclase (commonly labradorite or bytownite) and clinopyroxene (augite), with or without olivine and orthopyroxene; also, any member of that group. It is the approximate intrusive equivalent of basalt.

gangue - A nonmetallic, or a worthless metallic, mineral associated with ore minerals.

glacial outwash - See outwash.

glacial till - Non-sorted, non-stratified sediment deposited directly by a glacier.

gneiss - A foliated rock formed by regional metamorphism, in which bands or lenticles of granular materials alternate with bands or lenticles in which minerals having flaky or elongate prismatic habits predominate. Generally less than 50 percent of the minerals show preferred parallel orientation. Although a gneiss is commonly feldspar- and quartz-rich, the mineral composition is not an essential factor in its definition.

gossan - Oxidized massive sulfide.

granitic - Pertaining to or composed of granite.

granodiorite - A group of coarse grained plutonic rocks intermediate in composition between quartz diorite and quartz monzonite, containing quartz, plagioclase, and potassium feldspar, with biotite, hornblende, or, more rarely, pyroxene, as the mafic components; also, any member of that group; the approximate intrusive equivalent of rhyodacite.

greenstone belt - Term applied to elongate or beltlike areas within Precambrian shields that are characterized by abundant "greenstone" (any compact dark-green altered or metamorphosed basic igneous rock that owes its color to the presence of chlorite, actinolite, or epidote).

greywacke - An old rock name that has been variously defined but is now generally applied to a dark grey firmly indurated coarse grained sand that consists of poorly sorted angular to subangular grains of quartz and feldspar, with a variety of dark rock and mineral fragments imbedded in a compact clayey matrix having the general composition of slate and containing an abundance of very fine grained illite, sericite, and chloritic minerals.

hanging wall - The overlying side of an ore body or mine working.

intrusion - The process of emplacement of magma in preexisting rock; magmatic activity; also, the igneous rock mass so formed within the surrounding rock.

kame - A low mound, knob, hummock, or short irregular ridge, composed of stratified sand and gravel deposited by a subglacial stream as a fan or delta at the margin of a melting glacier; by a superglacial stream in a low place or hole on the surface of the glacier; or as a ponded deposit on the surface or at the margin of stagnant ice.

kame terrace - A terracelike ridge consisting of stratified sand and gravel formed as a glaciofluvial or glaciolacustrine deposit between a melting glacier or a stagnant ice lobe and a higher valley wall or lateral moraine, and left standing after the disappearance of the ice. A kame terrace terminates a short distance downstream from the terminal moraine; it is commonly pitted with kettles and has an irregular ice-contact slope.

lacustrine - As used in this report, it refers to soil (usually fine grained) deposited at the bottom of lakes, both glacial and recent deposits under the Little Sand, Oak, Skunk, Deep Hole, and Duck lakes.

lapilli - Volcanic ejecta that may be either essential, accessory, or accidental in origin, of a size range from 4 to 32 mm (0.16 to 1.25 inches).

leaching - The extraction or selective removal, of soluable constinuents from an ore or rock by slowly percolating water.

metric ton - A metric ton equals 1,000,000 grams. Its approximate U.S. equivalent is 1.1 tons.

outwash - (a) Stratified detritus (chiefly sand and gravel) removed or "washed out" from a glacier by meltwater streams and deposited in front of or beyond the end moraine or the margin of an active glacier. The coarser material is deposited nearer to the ice. (b) The meltwater from a glacier.

overlap - A general term referring to the extension of marine, lacustrine, or terrestrial strata beyond underlying rocks whose edges are thereby concealed or "overlapped," and to the unconformity that commonly accompanies such a relation; especially the relationship among conformable strata such that each successively younger stratum extends beyond the boundaries of the stratum lying immediately beneath.

perched lake - The surface water level is above the ground water potentiometric surface (water table).

piezometer - Ground water observation well sealed into a particular soil or rock stratum used to measure ground water head or hydrostatic pressure.

pitted outwash deposits - Deposits of outwash (see outwash) with pits or kettles, produced by the partial or complete burial of glacial ice by outwash and the subsequent thaw of the ice and collapse of the surficial materials.

porphyritic - Said of the texture of an igneous rock in which larger crystals (phenocrysts) are set in a finer grained ground mass, which may be crystalline or glassy or both. Also, said of a rock with such texture, or of the mineral forming the phenocrysts.

potentiometric surface map - Subsurface contour map showing the elevation of the water table.

pyroclastics - A general term for a deposit of pyroclasts. A pyroclast is an individual particle ejected during a volcanic eruption. It is usually classified according to size.

rift - A long, narrow continental trough that is bound by normal faults.

sericite - A white, fine grained potassium mica occurring in small scales and flakes as an alteration product of various aluminosilicate minerals, having a silky luster, and found in various metamorphic rocks (especially in schists and phyllites) or in the wall rocks, fault gouge, and vein fillings of many ore deposits.

sericitic - Pertaining to or composed of sericite.

short ton - A short ton equals 2,000 pounds and its metric equivalent is 0.907 metric ton.

stockwork - A mineral deposit consisting of a three-dimensional network of planar to irregular veinlets closely enough spaced that the whole mass can be mined.

stratified drift - Synonymous with glacial outwash.

strike - The direction or trend taken by a structural surface (for example, a bedding or fault plane) as it intercepts the horizontal.

subcrop - The top of bedrock immediately beneath the glacial overburden.

terminal moraine - The end moraine, extending across a glacial valley as an arcuate or crescentic ridge, that marks the farthest advance or maximum extent of a glacier or ice sheet. It is formed at or near a more or less stationary edge, or at a place marking the cessation of an important glacial advance.

till - Dominantly unsorted and unstratified drift, generally unconsolidated, deposited directly by and underneath a glacier without subsequent reworking by meltwater, and consisting of a heterogeneous mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape.

tremie pipe - Usually a small diameter pipe used to conduct bentonite or grout into the borehole annulus.

tuff - A rock formed of compacted volcanic fragments, generally smaller than 4 mm (0.16 inch) in diameter.

varves - A series of thin layers of soil representing seasonal sedimentation typically found in lacustrine deposits.

2.2.8 References

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2.3 GROUND WATER

The purpose of the ground water investigations was to determine and assess the existing conditions with respect to ground water occurrence, the ground water recharge-discharge regime, and ground water quality within the environmental study area. The ground water investigations were conducted in five main phases, and each phase included extensive drilling and the installation of monitoring wells and piezometers. In addition, four special studies were completed involving the evaluation of ground water conditions. In total, 141 borings were drilled and 228 piezometers installed in the environmental study area to facilitate monitoring of ground water levels and water quality. The locations of these borings and piezometers are shown on Figure 2.3-1. A summary of the construction details for each of the piezometers is contained in Appendix 2.3A, Table A-1. The logs for these borings and the results of any soil testing performed are contained in Appendix 2.2B.

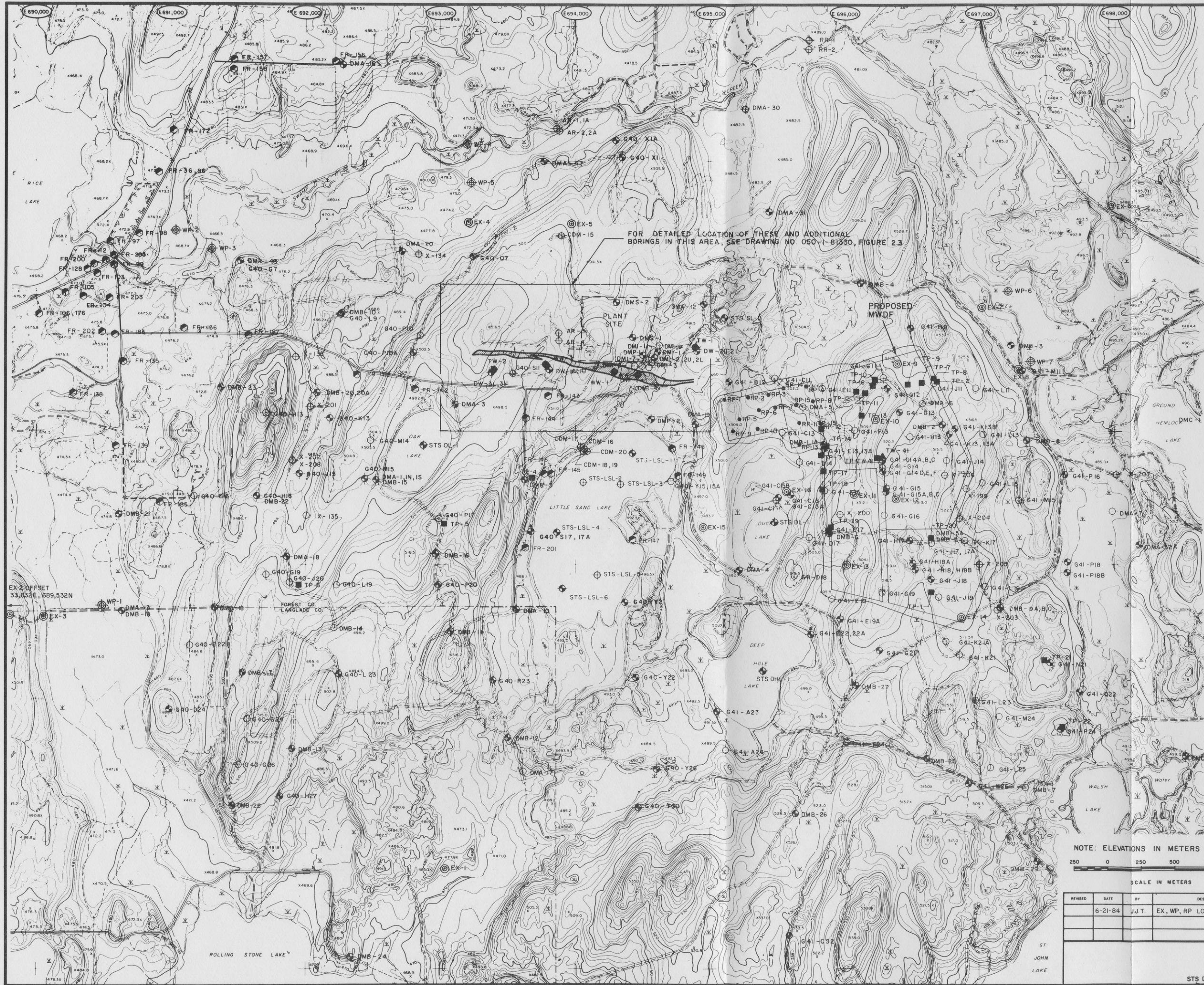
Specific information on sampling times, methodologies, and rationale for the ground water investigations in the environmental study area is presented below.

2.3.1 Field and Laboratory Methods

The ground water studies were designed to document and describe the ground water resources within the environmental study area. Initially, information on the ground water resources of southwestern Forest County was reviewed. This information included U.S. Geological Survey publications on Wisconsin ground water resources (USGS, unpublished), topographic maps of the site area, and information available from Exxon's exploratory drilling in

1976. Locations were then selected for borings and piezometer installation (DMA series). This phase was designed to provide a basic understanding of ground water resources in the site area. Information obtained from this phase and a field reconnaissance were then used to select locations for the next phase of borings and piezometers (DMB series). The third phase of borings (DMC series) was conducted to obtain information on the ground water resources at the eastern edge of the site area. The purpose of the fourth phase of borings (G40 and G41 series) was to determine the hydrogeologic characteristics of two areas being considered for tailings disposal (Areas 40 and 41). The final phase of borings (STS, WP, and EX series) was performed to complete the definition of the overall hydrogeologic system in the site area.

From February 1977 through March 1984, 141 boreholes were drilled and 228 piezometers installed for the hydrogeologic and geotechnical studies. Piezometer screens were set in the saturated zones. At locations where more than one water-bearing unit was encountered in drilling, additional piezometers were installed in these units. The locations of these borings and piezometers are shown on Figure 2.3-1 where the prefixes DMA, DMB, DMC, G40, G41, STS, WP, and EX refer to the different phases of drilling. The DMI, DMP, DMS, DW, TW, and WW designations refer to borings drilled for special studies undertaken to evaluate the feasibility of various design alternatives. Information obtained from borings and piezometers associated with other studies conducted by Golder Associates and STS Consultants Ltd. was also used. A discussion of the methods used to drill the boreholes is presented in section 2.2, Geology. The logs for these borings and the results of any soil testing performed are contained in Appendix 2.2B.



LEGEND

- TEST BORING LOCATION
- TEST BORING INCLUDING GROUNDWATER OBSERVATION WELL
- TEST BORING INCLUDING MULTIPLE GROUNDWATER OBSERVATION WELL
- WELL DATA PROVIDED BY U.S.G.S.
- GOLDER ASSOCIATES TEST PIT LOCATION
- GOLDER ASSOCIATES TEST WELL LOCATION
- DAMES & MOORE TEST WELL LOCATION
- CRANDON FORMATION
- EX BORINGS AND PIEZOMETER LOCATIONS
- WP WELL POINT LOCATIONS
- RECLAIM POND BORINGS

NOTE

SUPERVISION OF BORINGS AND GROUNDWATER OBSERVATION WELL INSTALLATION DETERMINED BY THE FOLLOWING DESIGNATION PREFIXES:

G	GOLDER ASSOCIATES
DM	DAMES & MOORE
DW	DAMES & MOORE
BE	BRAUN ENGINEERING TESTING
X	EXXON MINERALS COMPANY
STS	SOIL TESTING SERVICES OF WISCONSIN, INC.
AR,RR	SOIL TESTING SERVICES OF WISCONSIN, INC.
CDM	CAMP DRESSER & McKEE, INC.
EX	STS CONSULTANTS LTD.

NOTE: ELEVATIONS IN METERS MSL

250 0 250 500 750 1000

SCALE IN METERS

REVISED	DATE	BY	DESCRIPTION
	6-21-84	J.J.T.	EX, WP, RP LOCATIONS

STS DRWG. 12959-1

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE **LOCATION OF BORINGS & PIEZOMETERS IN THE ENVIRONMENTAL STUDY AREA**

SCALE AS SHOWN	STATE WISCONSIN	COUNTY FOREST	
DRAWN BY CAB	DATE 4-12-82	CHECKED BY DB	DATE 4-12-82
APPROVED BY [signature]	DATE 4-12-82	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE
DRAWING NO **FIGURE 2.3-1**		SHEET OF	REVISION NO

DESIGN PRODUCTS CO.

2.3.1.1 Piezometer Installations

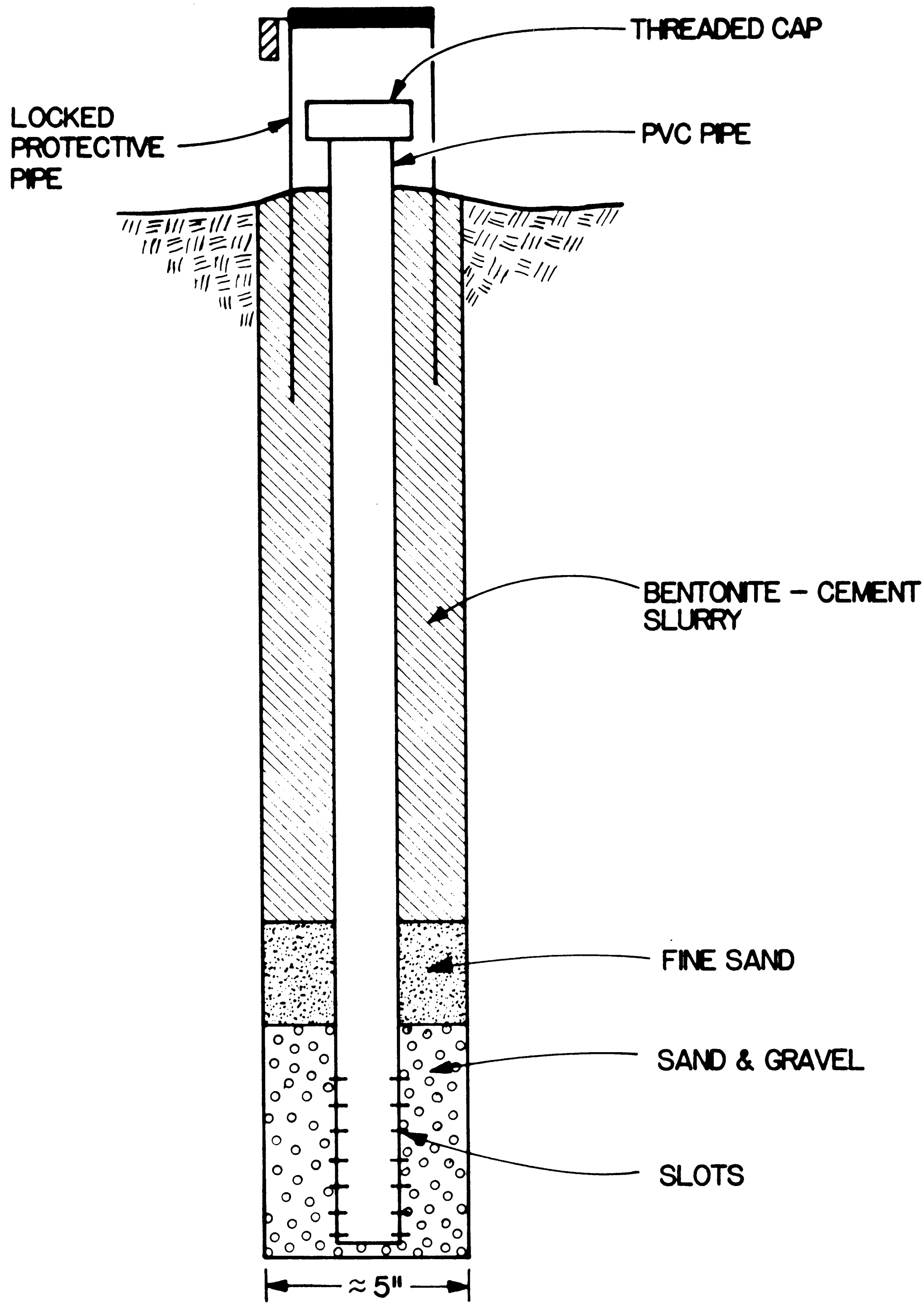
Piezometers constructed of 50.8-mm (2-inch) schedule 40 plastic tubing fitted with a 0.9- to 4.6-m (3- to 15-foot) section of slotted tubing (with 0.25-mm [0.01-inch] slots) were installed in the following manner. Once the borehole drilling was completed, 0.3 to 0.6 m (1 to 2 feet) of sand and/or pea gravel was poured into the hole. The slotted section of the piezometer was wrapped with a geofabric to discourage fouling of the piezometer slots with silts or sands. The piezometer was then lowered into position so that it rested on the sand and/or pea gravel. Once in position, sand and/or pea gravel was added to the annulus until the material was approximately 0.6 m (2 feet) above the screened interval of the piezometer. A layer of fine sand was then added to prevent the bentonite-cement slurry from migrating downward and possibly plugging the piezometer screen. In multiple piezometer installations, this process was repeated between each screen setting. A bentonite-cement slurry was added to fill the annulus between screens and to the ground surface. This material was used to prevent the downward migration of water from water-bearing strata located above the screened interval. Before the bentonite-cement slurry solidified, a protector pipe with a locking protective cap was installed over the top of the piezometer. As each piezometer was installed, construction data were recorded on preprepared forms. A summary of the construction details for each of the piezometers is contained in Appendix 2.3A, Table A-1. A typical piezometer installation is shown on Figure 2.3-2.

Piezometers were not disturbed for a minimum of 24 hours after construction to allow the bentonite-cement slurry time to harden. The piezometers were then developed using a pitcher pump, bailer, or air lift to surge the water back and forth through the screened interval. This was done to remove the fine material resulting from boring and piezometer installations and was continued until a relatively clear water sample was obtained.

2.3.1.2 Ground Water Levels

In each of the initial three phases of the ground water investigation, the ground water levels and water quality in each of the completed piezometers were measured monthly for 3 months following installation and quarterly thereafter for a 1-year period. Records of the fluctuations of ground water levels and water quality in selected piezometers are available for the period July 1977 to August 1980. Ground water level recording times are summarized in Table 2.3-1. Piezometers installed after August 1980 were measured on an intermittent basis. The record of these measurements is shown in Appendix 2.3B, Table B-2.

The 29 piezometers installed in the DMA boreholes were measured regularly between May or June 1977 and September 1978. After this time, several DMA piezometers were measured on an intermittent basis until November 1979. The 33 DMB piezometers were measured on a regular basis from July 1978 through September 1980. Water levels in the DMC piezometers were recorded regularly from November 1979 to September 1980. Water levels in 13 piezometers installed during special studies were measured regularly between June 1977 and September 1978, and intermittently thereafter until November 1979. The DMP series piezometers were measured once in January 1980 and again in September 1980. An additional 14 piezometers installed by Golder Associates were measured quarterly from November 1979 to August 1980. In



NOTE:
NOT TO SCALE

EXXON MINERALS COMPANY
CRANDON PROJECT

TYPICAL PIEZOMETER INSTALLATION

FIGURE 2.3-2

TABLE 2.3-1

SCHEDULE OF GROUND WATER LEVEL READINGS IN THE ENVIRONMENTAL STUDY AREA
MAY 1977 THROUGH SEPTEMBER 1980

PIEZOMETER	1977										1978								
	MAY				JUN	JUL	AUG	SEP	DEC		JAN		FEB		MAR		APR		
NUMBER	01	18	24	28	28	30/31	25-27	25/26	02/03	27-29	03	30/31	01/02	23/24	01/03	30/31	03/07	21-24	25-27
DMI-1						X	X	X	X	X			X		X		X		X
DMI-2U						X	X	X	X	X			X		X		X		X
DMI-2L						X	X	X	X	X			X		X		X		X
DMS-1																			
DW-1A				X	X	X	X	X	X	X			X		X		X	X	
DW-1U				X	X	X	X	X	X	X			X				X	X	
DW-1L				X	X	X	X	X	X	X			X				X	X	
DW-2U				X	X	X	X	X	X	X			X		X	X			X
DW-2L				X	X	X	X	X	X	X			X		X	X			X
DW-3U				X	X	X	X	X	X	X			X		X		X	X	
DW-3L				X	X	X	X	X	X	X								X	
WW-2																			
DMA-1N				X	X	X	X	X	X									X	
DMA-1S				X	X	X	X	X	X									X	
DMA-3				X	X	X	X	X	X									X	
DMA-4				X	X	X	X	X	X	X			X		X	X		X	
DMA-10	X			X	X	X	X	X		X			X	X		X		X	
DMA-12	X			X	X	X	X	X	X	X			X		X		X		X
DMA-13				X	X	X	X	X				X		X		X			
DMA-16	X			X	X	X	X	X	X	X						X		X	
DMA-17				X	X	X	X	X				X		X		X			
DMA-18			X	X	X	X	X	X		X		X		X			X		X
DMA-19	X			X	X	X	X	X	X	X			X		X	X		X	
DMA-20				X	X	X	X	X	X	X		X		X			X		X
DMA-29				X	X	X	X	X	X	X		X			X	X		X	
DMA-29AU				X	X	X	X	X		X		X			X	X		X	X
DMA-29AL				X	X	X	X	X		X									X
DMA-31				X	X	X	X	X	X				X						
DMA-32A				X	X	X	X	X			X	X		X		X			X
DMA-34				X	X	X	X	X	X	X		X		X		X			
DMA-35				X	X	X	X	X	X	X		X		X		X			X
DMA-38		X	X	X	X	X	X	X	X										
DMA-43				X	X	X	X	X	X	X			X		X	X		X	
DMA-45				X	X	X	X	X	X										
DMA-46				X	X	X	X	X	X										
DMA-47				X	X	X	X	X				X		X			X		X
DMA-48				X	X	X	X	X			X		X	X		X			X
DMB-1A																			
DMB-2																			
DMB-3																			
DMB-4																			
DMB-5																			
DMB-5A																			
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DMC-1																			
DMC-2																			
DMC-3																			
DMA-22B																			
DMP-1																			
DMP-2																			
DMP-3																			
G40-J15																			
G40-K13																			
G40-L23																			
G40-Q7																			
G40-R23																			
G41-C15																			
G41-E13																			
G41-G14A																			
G41-G14B																			
G41-G14C																			
G41-G15A																			
G41-G15B																			
G41-P18B																			
G41-P24																			

PIEZOMETER NUMBER	1978 MAY				JUN					JUL							AUG		
	02	19	24/25	30/31	05-09	10	12/13	20-22	24-30	06/07	12	13	19	20/25	27	31	02/07	09/10	12/13
DMI-1										X									X
DMI-2U				X						X									X
DMI-2L				X						X									X
DMS-1				X															X
DW-1A					X					X									X
DW-1U										X									X
DW-1L					X					X									X
DW-2U				X						X									X
DW-2L				X						X									X
DW-3U				X						X									X
DW-3L				X						X									X
WW-2																			
DMA-1N				X							X								X
DMA-1S				X							X								X
DMA-3				X							X								X
DMA-4				X						X									
DMA-10			X								X						X		X
DMA-12				X						X									X
DMA-13	X		X								X						X		X
DMA-16				X						X									X
DMA-17	X		X								X						X		X
DMA-18					X					X									X
DMA-19			X							X									
DMA-20					X						X								X
DMA-29					X						X								
DMA-29AU					X						X								X
DMA-29AL					X						X								X
DMA-31	X			X							X								X
DMA-32A			X								X								X
DMA-34	X				X						X								X
DMA-35					X						X								X
DMA-38	X				X						X								X
DMA-43					X					X									X
DMA-45	X				X					X									X
DMA-46	X				X					X									X
DMA-47					X						X								X
DMA-48			X								X								X
DMB-1A				X		X								X	X			X	
DMB-2						X		X											
DMB-3		X				X	X										X		
DMB-4				X		X	X	X	X										
DMB-5						X		X	X										
DMB-5A																			
DMB-6						X		X										X	
DMB-7								X						X	X		X		
DMB-8									X					X	X		X		
DMB-9A																	X		
DMB-9B																	X		
DMB-9C																	X		
DMB-10												X	X	X					
DMB-11																	X		X
DMB-12									X								X		X
DMB-13																	X		
DMB-14																	X		
DMB-15								X					X				X	X	
DMB-16								X											
DMB-17								X									X		
DMB-18									X			X	X		X				
DMB-19									X			X	X				X	X	
DMB-20							X	X	X				X			X			
DMB-20A																			
DMB-21									X			X				X	X		
DMB-22								X	X			X		X					
DMB-23									X							X	X		
DMB-24																			
DMB-25																			
DMB-26																			
DMB-27																			
DMB-28																			
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G41-G14B																			
G41-G14C																			
G41-G15A																			
G41-G15B																			
G41-P18B																			
G41-P24																			

PIEZOMETER	1978												1979								
	SEP					OCT		DEC					JAN			FEB	MAR	APR	MAY	JUL	
NUMBER	01	02/03	05/06	15	30	01	03-05	02	08	16	19	21	08-11	12/15	17/18	12-14	20-22	17-25	30	15/16	31
DMI-1		X			X																
DMI-2U		X			X																
DMI-2L		X			X																
DMS-1		X			X																
DW-1A		X			X																
DW-1U		X			X																
DW-1L		X			X																
DW-2U		X			X																
DW-2L		X			X																
DW-3U		X			X																
DW-3L		X			X																
WW-2				X	X																
DMA-1N		X																			
DMA-1S		X																			
DMA-3		X																			
DMA-4		X			X								X								
DMA-10		X			X								X								
DMA-12		X			X																
DMA-13		X			X																
DMA-16		X			X								X								
DMA-17		X			X																
DMA-18		X																			
DMA-19		X			X																
DMA-20		X			X																
DMA-29		X																			
DMA-29AU		X																			
DMA-29AL		X																			
DMA-31		X				X															
DMA-32A		X				X															
DMA-34		X																			
DMA-35		X																			
DMA-38		X																			
DMA-43		X			X																
DMA-45		X																			
DMA-46		X																			
DMA-47		X			X																
DMA-48		X			X																
DMB-1A		X	X			X	X				X		X			X	X	X	X		X
DMB-2	X	X				X													X		
DMB-3		X			X																
DMB-4		X			X		X						X					X		X	
DMB-5	X					X															
DMB-5A													X		X	X	X	X	X		
DMB-6		X				X							X								
DMB-7		X	X			X	X						X					X		X	
DMB-8		X	X		X		X				X		X			X	X	X	X	X	X
DMB-9A	X	X				X							X								
DMB-9B	X	X				X							X								
DMB-9C	X	X				X							X								
DMB-10		X			X																
DMB-11		X			X																
DMB-12		X			X						X		X					X	X		X
DMB-13		X			X									X							
DMB-14		X			X								X	X							
DMB-15		X			X								X								
DMB-16		X			X																
DMB-17		X			X																
DMB-18		X	X		X		X				X		X			X	X	X			X
DMB-19		X			X																
DMB-20		X	X		X		X				X		X			X		X	X		X
DMB-20A									X	X	X	X	X	X		X	X	X	X		
DMB-21		X	X		X		X				X				X	X	X	X			X
DMB-22		X			X																
DMB-23		X	X		X		X								X			X			
DMB-24													X	X		X	X	X		X	
DMB-25														X	X	X	X	X		X	
DMB-26														X		X	X	X	X		
DMB-27											X	X	X	X			X	X	X	X	
DMB-28										X		X	X	X	X	X	X	X		X	
DMB-29								X	X	X	X	X	X	X		X	X	X	X	X	
DMC-1																					
DMC-2																					
DMC-3																					
DMA-22B																					
DMP-1																					
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G41-P18B																					
G41-P24																					

PIEZOMETER NUMBER	1979 AUG 31	1979 SEP 24	1979 OCT 25	1979 NOV 07-14	1979 NOV 20	1979 NOV 29	1979 DEC 11/12	1980 JAN 09/10	1980 FEB 11-14	1980 FEB 18-21	1980 MAR 19	1980 MAY 12-20	1980 AUG 11-20	1980 SEP 10/11
DMI-1														
DMI-2U														
DMI-2L														
DMS-1														
DW-1A														
DW-1U														
DW-1L														
DW-2U														
DW-2L														
DW-3U														
DW-3L														
WW-2														
DMA-1N														
DMA-1S														
DMA-3														
DMA-4														
DMA-10														
DMA-12														
DMA-13														
DMA-16														
DMA-17														
DMA-18														
DMA-19														
DMA-20														
DMA-29														
DMA-29AU														
DMA-29AL														
DMA-31														
DMA-32A														
DMA-34														
DMA-35														
DMA-38														
DMA-43														
DMA-45														
DMA-46														
DMA-47														
DMA-48														
DMB-1A	X	X	X	X		X	X			X		X	X	X
DMB-2														
DMB-3														
DMB-4				X						X		X	X	X
DMB-5														
DMB-5A														
DMB-6														
DMB-7														
DMB-8	X	X	X	X		X	X			X		X	X	X
DMB-9A														
DMB-9B														
DMB-9C														
DMB-10														
DMB-11														
DMB-12	X	X	X	X		X	X							
DMB-13														
DMB-14														
DMB-15														
DMB-16														
DMB-17														
DMB-18	X	X	X	X		X	X			X		X	X	X
DMB-19														
DMB-20	X	X	X	X		X	X			X		X	X	X
DMB-20A					X		X							
DMB-21	X	X	X		X	X	X							
DMB-22														
DMB-23				X						X		X	X	X
DMB-24				X						X		X	X	X
DMB-25				X						X		X	X	X
DMB-26														
DMB-27				X						X		X	X	X
DMB-28				X										
DMB-29														
DMC-1				X			X	X		X		X	X	X
DMC-2				X			X	X		X		X	X	X
DMC-3				X			X	X		X		X	X	X
DMA-22B				X			X	X		X		X	X	X
DMP-1								X			X			X
DMP-2								X			X			X
DMP-3								X			X			X
G40-J15				X										
G40-K13				X										
G40-L23									X			X	X	
G40-Q7									X			X	X	
G40-R23									X			X	X	
G41-C15				X					X			X	X	
G41-E13				X										
G41-G14A									X			X	X	
G41-G14B									X			X	X	
G41-G14C									X			X	X	
G41-G15A				X										
G41-G15B				X										
G41-P18B									X			X	X	
G41-P24									X			X	X	

addition to monthly and quarterly measurements, a water level recorder was installed on Test Well No. 1 (TW-1) in October 1977 and operated continuously through October 1978 and again from December 1979 through December 1980. Since December 1980, 33 additional piezometers and piezometer nests have been installed. These new piezometers, along with the older ones, were measured on an intermittent basis through July 1984 (Table 2.3-2; Appendix 2.3B). In addition, four continuous water level recorders were installed on wells DMS-1, G41-E22, G41-H9, and DMA-18 in June 1983 and have been maintained through July 1984.

To facilitate the preparation of a potentiometric surface[1] map for the environmental study area, a joint Dames & Moore - Golder Associates study was undertaken to measure water levels in all existing piezometers. In total, the water levels in 109 piezometers were measured during a 2-day period in September 1980. The results were used in the development of a contour map of the potentiometric surface for the environmental study area. The resulting ground water level data and potentiometric contour map are presented in the Crandon Project Report No. 7 (Golder Associates, 1981a). Since September of 1980, the water levels have been recorded and stored in a computerized data base, and potentiometric contour maps have been prepared as needed (Appendix 2.3B).

Six locations (DW-1, DW-2, DW-3, DMA-29A, DMB-19 and DMI-2) have two piezometers with the screened interval on each piezometer located at

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[1]The potentiometric surface, which is used synonymously with the term piezometric surface, is a surface that represents the static head within a particular aquifer or stratum. As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells or piezometers.

TABLE 2.3-2

SCHEDULE OF GROUND WATER QUALITY SAMPLING IN THE ENVIRONMENTAL STUDY AREA, JULY 1977 THROUGH AUGUST 1980

PIEZOMETER NUMBER	1977					1978						1979							1980			
	JUL*	AUG	SEP	OCT*	NOV	FEB*	MAR	MAY*	JUL	SEP	OCT*	JAN*	FEB	MAR	APR*	JUL*	NOV*	DEC	JAN	FEB*	MAY*	AUG*
WW-1	X																					
WW-2	X	X	X	X	X	X	X	X									X			X	X	X
TW-1	X	X	X	X	X	X	X	X														
DMA-10	X	X	X	X	X	X	X	X														
DMA-13	X	X	X	X	-	-		X														
DMA-17	X	X	X	X	-	-		X														
DMA-19	X	X	X	X	X	X	X	X														
DMA-32A	X	X	X	X	X	X	X	X														
DMA-48	X	X	X	X	X	X	X	X														
Walentowski Well		X	X		-	-		X														
DMB-1A									X	X	X	X			X		X			X	X	X
DMB-4											X	X			X	X	X			X	X	X
DMB-7									X	X	X	X			X							
DMB-8									X	X	X	X			X		X			X	X	X
DMB-18									X	X	X	X			X		X			X	X	X
DMB-20									X	X	X	X			X		X			X	X	X
DMB-21									X	X	X	X			X							
DMB-23									X	X	X	X			X		X			X	X	X
Fox Well										X	X	X			X	X	X			X	X	X
McGeshick Well										X	X	X			X	X						
Reynolds Resort Well											X											
Simonsen Well											X											
Vollmar Well											X											
DMA-16												X										
DMB-5A												X										
DMB-24												X	X	X	X	X	X			X	X	X
DMB-25												X	X	X	X	X	X			X	X	X
DMB-27														X			X			X	X	X
DMB-28												X	X	X	X	X	X					
DMB-20A													X									
DMB-29													X									
DMA-4														X								
DMC-1																	X	X	X	X	X	X
DMC-2																	X	X	X	X	X	X
DMC-3																	X	X	X	X	X	X
DMA-22B																	X	X	X	X	X	X
G40-J15																	X					
G40-K13																	X					
G40-L23																				X	X	X
G40-Q7																				X	X	X
G40-R23																				X	X	X
G41-C15																	X			X	X	X
G41-E13																	X					
G41-G14A																				X	X	X
G41-G14B																				X	X	X
G41-G14C																				X	X	X
G41-G15A																	X					
G41-G15B																	X					
G41-P18B																				-	X	X
G41-P24																				X	X	X

Note: - Indicates no data due to frozen water in piezometer.
*Water chemistry samples analyzed for the "seasonal" list of parameters are listed in Table 2.3-3. The parameters on the "monthly" list were analyzed for the other months. Exceptions include samples analyzed for the "monthly" list during January 1979 for DMA-16 and DMB-5A, and during April 1979 for DMB-8.

different depths. One location (DMB-9) has piezometers at three depths. In addition, there are multiple level piezometers installed in the G41-E22, -G14 and -G15, all of the EX series, and all of the WP series piezometer locations (Golder Associates, 1982; STS Consultants Ltd., 1984a).

The ground water level in the piezometers was measured with an electronic water level sounder. Water levels were measured from the top of the piezometer casing. Piezometer locations and the elevation of the top of the piezometer casings above mean sea level were established by surveyors. Water levels were then corrected to mean sea level and depth below ground surface.

A Leopold and Stevens continuous water level recorder (Type F, Model 68, 8-day wind-up drive, precision ± 3.0 mm [0.12 inch]) was installed on Test Well 1 (TW-1) in October 1977 and was operated continuously to October 1978 and again from December 1979 to December 1980 to obtain a comprehensive record of water level fluctuations. This well was chosen because it was one of the few wells large enough to facilitate the installation of the recorder. During June and July 1983, piezometers DMS-1, G41-E22, G41-H9, and DMA-18 were equipped with Stevens Type F, Model 68 battery powered water level recorders with W. G. Keck Model SD 62-B water level sensing devices. These recorders have run continuously since installation. The continuous records are used as a reference for comparison with the intermittent water level records obtained from the piezometers.

2.3.1.3 Ground Water Quality

Ground water quality was assessed during subphases of the boring phases, and ground water samples were collected for chemical analysis according to the schedule indicated in Table 2.3-2. The sampling times were chosen because it was anticipated that the ground water quality characteristics would be stable with time and, therefore, did not require more frequent sampling. On several occasions, samples were obtained from ground water sources not a part of the regular sampling program. These samples were collected so that their results could be used to clarify the ground water-surface water relationship.

Samples of the ground water were collected from the piezometers using a pitcher pump or bailer. A pitcher pump was used to sample those piezometers with a static water level of approximately 6.1 m (20 feet) or less below ground level. The suction obtained from the pump was not sufficient to lift the column of water if the water level occurred below this depth. A bailer was used for sampling piezometers with deeper water levels. In several instances, a bailer was used for convenience in sampling piezometers with water levels of 6.1 m (20 feet) or less.

Prior to withdrawing a water sample from a piezometer, the volume of water contained in the piezometer was calculated. This volume was determined from the distance between the elevation of the static water level and the elevation of the bottom of the piezometer, which was multiplied by the interior area of the piezometer. Two to three piezometer volumes of water were removed from the piezometer using a pitcher pump, bailer, or "air" lift before collecting a water sample for chemical analysis. Inert gas (argon) was used whenever "air" lifting was the selected method for well sampling. The ground water samples were filtered in the field prior to laboratory analyses for consistency. The filtering apparatus consisted of a vacuum pump, Erlenmyer flask, Buchner funnel, and coarse glass fiber filters.

The water chemistry parameters analyzed are listed in Table 2.3-3. The expanded list of parameters was analyzed on a "seasonal" basis to minimize the cost of analyses over the sampling period. Water sample containers and methods of preservation of all water chemistry parameters, and procedures and detection limits are listed in Tables 2.3-4 and 2.3-5, respectively.

Immediately after collection, all water samples were placed on ice in an insulated container and shipped to the laboratory via air freight on the day of collection. Water chemistry analyses were initiated by Aqualab, Inc. of Streamwood, Illinois (see section 2.3.1.7) within 24 hours after collection. The holding time for each parameter prior to analysis was in accordance with U.S. EPA methods (1974).

A description of conditions was recorded during all field surveys. This description included collection time, static ground water level, volume of water removed prior to sampling, and water conditions. Field conductivity (LaMotte Model DA-1 or a YSI Model No. 33), temperature (temperature mode of YSI Model No. 33 or a Standard Celsius/Fahrenheit thermometer), pH (LaMotte Model HA, Markson Model No. 85 or a Taylor Model No. 6000) and total alkalinity (APHA et al., 1971) were measured on site for samples collected during water chemistry collections.

Arithmetic means were calculated for all parameters (which for pH is the antilog of the geometric mean of the H^+ ion concentration). Concentrations reported below the limit of detection were signified by the "less than" sign (<). These values were considered to be at the level of detection for calculation of the mean and the mean was reported as a "less than" value. In these cases, the mean lies between the reported numerical value and a minimum value that could be calculated assuming all "less than" values to be 0.

TABLE 2.3-3

GROUND WATER CHEMISTRY LABORATORY PARAMETERS

PARAMETER	MONTHLY	SEASONAL
Total laboratory alkalinity	X	X
Specific conductance	X	X
Laboratory pH	X	X
Total hardness	X	X
Total dissolved solids	X	X
Chemical oxygen demand		X
Total phosphorus (P)	X	X
Anions		
Arsenic*	X	X
Chloride	X	X
Cyanide, total	X	X
Fluoride		X
Nitrate nitrogen (N)	X	X
Total phosphate (PO_4)	X	X
Sulfate	X	X
Cations*		
Aluminum		X
Barium		X
Cadmium		X
Calcium		X
Chromium, total		X
Cobalt		X
Copper	X	X
Iron	X	X
Lead	X	X
Magnesium		X
Manganese	X	X
Mercury		X
Molybdenum		X
Nickel		X
Selenium		X
Silver		X
Zinc	X	X

*Trace metals were determined as total metal present.

TABLE 2.3-4

WATER SAMPLE CONTAINERS AND PRESERVATIVES FOR LISTED PARAMETERS

PARAMETER	CONTAINER*	PRESERVATIVE
Total alkalinity	P,G	Cool, 4°C
Specific conductance	P,G	Cool, 4°C
Laboratory pH	P,G	Cool, 4°C
Total hardness	P,G	Cool, 4°C
Total dissolved solids	P,G	Cool, 4°C
Chemical oxygen demand	P,G	H_2SO_4 to pH<2
Total phosphorus (P)	P,G	Cool, 4°C
Chloride	P,G	None required
Cyanide, total	P,G	Cool, 4°C; NaOH to pH 12
Fluoride	P,G	Cool, 4°C
Nitrate nitrogen (N)	P,G	Cool, 4°C; H_2SO_4 to pH<2
Total phosphate (PO_4)	P,G	Cool, 4°C
Sulfate	P,G	Cool, 4°C
Aluminum	P,G	HNO_3 to pH<2
Arsenic	P,G	HNO_3 to pH<2
Barium	P,G	HNO_3 to pH<2
Cadmium	P,G	HNO_3 to pH<2
Calcium	P,G	HNO_3 to pH<2
Chromium, total	P,G	HNO_3 to pH<2
Cobalt	P,G	HNO_3 to pH<2
Copper	P,G	HNO_3 to pH<2
Iron	P,G	HNO_3 to pH<2
Lead	P,G	HNO_3 to pH<2
Magnesium	P,G	HNO_3 to pH<2
Manganese	P,G	HNO_3 to pH<2
Mercury	P,G	HNO_3 to pH<2
Molybdenum	P,G	HNO_3 to pH<2
Nickel	P,G	HNO_3 to pH<2
Selenium	P,G	HNO_3 to pH>2
Silver	P,G	HNO_3 to pH<2
Zinc	P,G	HNO_3 to pH<2

*P - plastic
G - glass

TABLE 2.3-5

PROCEDURE SUMMARY AND DETECTION LIMITS FOR WATER CHEMISTRY PARAMETERS

PARAMETER	REPORTED AS	METHOD	REFERENCES (PAGE NUMBERS) U.S. EPA 1974	APHA et al. 1976	DETECTION LIMIT
Total alkalinity	$CaCO_3$	Titrametric to pH 4.5 end point	3	278	1 mg/l
Specific conductance	µmhos/cm	Electrolytic measurement at 25°C	275	71	1 µmhos/cm
Laboratory pH	-	Electrometric measurement at 25°C	239	460	0.01 standard unit
Total hardness	$CaCO_3$	EDTA titration or sum of Ca and Mg as their carbonates	68	202	1 mg/l
Total dissolved solids	-	Total filterable residue dried at 180°C	266	92	1 mg/l
Chemical oxygen demand	COD	Dichromate reflux	20	550	1 mg/l
Total phosphorus	P	Persulfate digestion followed by ascorbic acid reduction	249	481	0.01 mg/l
Chloride	Cl	Mercuric nitrate	29	304	1 mg/l
Cyanide, total	CN	Distillation followed by barbituric acid	40	361	0.001 mg/l
Fluoride	F	SPADNS with Bellack distillation	59	393	0.1 mg/l
Nitrate nitrogen	N	Cadmium reduction	201	423	0.05 mg/l
Total phosphate	PO_4	Persulfate digestion followed by ascorbic acid reduction	249	481	0.01 mg/l
Sulfate	SO_4	Turbidimetric	277	496	1 mg/l
Metals, total	element	Acid digestion followed by atomic absorption spectroscopy	78	147	
Aluminum					0.01 mg/l
Arsenic					0.001 mg/l
Barium					0.01 mg/l
Cadmium					0.001 mg/l
Calcium					0.002 mg/l
Chromium					0.001 mg/l
Cobalt					0.01 mg/l
Copper					0.001 mg/l
Iron					0.01 mg/l
Lead					0.01 mg/l
Magnesium					0.001 mg/l
Manganese					0.001 mg/l
Mercury					0.0001 mg/l
Molybdenum					0.01 mg/l
Nickel					0.01 mg/l
Selenium					0.001 mg/l
Silver					0.001 mg/l
Zinc					0.001 mg/l

2.3.1.4 Soil Permeabilities

Permeabilities of the soils in the environmental study area were determined using both field and laboratory methods. The types of permeability tests conducted on borehole samples and in piezometers are summarized in Table 2.3-6. The information on in-situ permeabilities (field) was collected by conducting falling and rising head tests on selected piezometers and during a pumping test conducted in April 1977.

A falling head test is conducted by adding water to a piezometer until it is full and then monitoring the change ("fall") in water level in the piezometer over time until equilibrium is reached (Bentall, 1963). A rising head test is conducted by removing water from a piezometer, substantially lowering the water level, and then monitoring the change ("rise") in water level over time until equilibrium is reached (Bentall, 1963).

Rising or falling head tests were conducted in 36 piezometers. In some piezometers, water levels reached equilibrium so fast that this return to equilibrium could not be recorded. Permeability data for these piezometers were estimated from soil characteristics.

The field data gathered during falling and rising head tests were analyzed using Hvorslev's Relationship (1951) for the determination of permeability. Hvorselv's Relationship is an exponential curve function relating the change in head in a piezometer to time and thus determining in-situ permeability. Among the stated assumptions of the method are negligible hydraulic losses in pipes and well points (i.e., 100 percent efficiency).

TABLE 2.3-6

SUMMARY OF PERMEABILITY TESTS*

BOREHOLE	PERMEABILITY TESTS FIELD	PERMEABILITY TESTS LABORATORY	BOREHOLE	PERMEABILITY TESTS FIELD	PERMEABILITY TESTS LABORATORY	BOREHOLE	PERMEABILITY TESTS FIELD	PERMEABILITY TESTS LABORATORY
DMA-1-N	FH	--	DMI-8	--	H(2)	DMB-14	FH	--
DMA-1-S	FH	H	DMI-9	--	H(2)	DMB-15	FH(3)	H
DMA-3	FH	--				DMB-16	--	H(2)
DMA-4	FH	H	DW-1L	PT	--	DMB-17	--	H(2)
DMA-5	--	H	DW-2U	PT	--	DMB-18	FH,RH	H
DMA-6	--	H				DMB-19	FH,RH	H
DMA-13	--	H	TW-1	PT	--	DMB-20	FH,RH	H(3)
DMA-14	--	H				DMB-20A	FH	--
DMA-16	--	H(2)	WW-2	PT	--	DMB-21	FH(2)	H(2)
DMA-17	--	H(2)				DMB-22	FH	--
DMA-18	--	H(3),CH	DMB-1A	FH	H	DMB-23	FH,RH(2)	--
DMA-19	FH	--	DMB-2	FH	H(2)	DMB-24	FH	--
DMA-22	--	H	DMB-3	FH,RH	H	DMB-25	FH	--
DMA-29	--	H,CH	DMB-4	FH	H(3)	DMB-26	FH	--
DMA-30	--	H,CH	DMB-5	FH	--	DMB-27	FH	--
DMA-34	--	H,CH	DMB-5A	FH	--	DMB-28	FH	--
DMA-39	--	H	DMB-6	FH	H(2)	DMB-29	FH	--
DMA-43	FH	--	DMB-7	FH	H(2)			
DMA-44	--	H	DMB-8	FH	--	DMC-1	--	FH
DMA-45	--	H	DMB-9A	FH	--	DMC-2	--	H
DMA-48	--	H(2)	DMB-9B	FH	--	DMC-3	--	FH
			DMB-9C	FH	--			
DMI-1	--	H(4)	DMB-10	FH,RH	H	DMP-1	--	H(4)
DMI-2U	--	H	DMB-12	RH	H	DMP-2	--	H(2)
DMI-4	--	H(4)	DMB-13	FH	H	DMP-3	--	H(4)
DMI-7	--	H(2)						

Note: Digit in parentheses signifies number of test runs.

*FH - Falling head test
RH - Rising head test
PT - Pumping test
H - Hazen's approximation
CH - Constant head test

In the spring of 1984, rising and falling head field permeability tests were performed on the EX, WP, and selected G40, G41, DMS, DMI, BE, and DW series piezometers (STS Consultants Ltd., 1984a). The results of these tests were analyzed using the methods described in the Department of the Navy Design Manual -- Soil Mechanics, Foundations and Earth Structures (1971). The results of this testing are summarized in Table 2.3-6a.

Two pumping tests, conducted as a special study, were also used to determine in-situ permeabilities. These tests were conducted following the procedure of Kruseman and DeRidder (1976). In the first pumping test, Test Well 1 (TW-1), a 203.2-mm (8-inch) inside diameter well was pumped at a continuous rate of 18.2 m^3/hour (80 gallons/minute) for 24 hours. During this time period, water levels in TW-1 and piezometer DW-2U were recorded 14 and 19 times, respectively, during the first hour and 26 and 27 times, respectively, thereafter. Water levels were also recorded in TW-1 and DW-2U after pumping was stopped and continued until the ground water level recovered. During the recovery period, measurements were taken 12 and 17 times, respectively, during the first hour and 7 and 9 times, respectively, thereafter for TW-1 and DW-2U (Dames & Moore, 1977).

In the second pumping test, Water Well 2 (WW-2), also a 203.2-mm (8-inch) inside diameter well, was pumped at a continuous rate of 10.9 m^3/hour (48 gallons/minute) for 48 hours. Water levels in WW-2 and piezometer DW-1L were measured during this time and after pumping in the same manner as the first test (Dames & Moore, 1977).

Analysis of pumping test data following the procedures of Lohman (1972) yields a value for aquifer transmissivity. This value, when divided by aquifer thickness, is equal to permeability. Aquifer thicknesses were determined from borehole stratigraphic data (Dames & Moore, 1977).

TABLE 2.3-6a

FIELD PERMEABILITY TEST DATA
STATISTICAL ANALYSIS

GEOLOGIC UNIT	NUMBER OF TESTS	PERMEABILITY[a] RANGE (cm/s)	ARITHMETIC MEAN (cm/s)	GEOMETRIC MEAN (cm/s)	STANDARD DEVIATION (cm/s)
Coarse drift	15	1×10^{-2} to 1×10^{-3}	4×10^{-3}	3×10^{-3}	3×10^{-3}
Fine drift	12	6×10^{-3} to 7×10^{-4}	2×10^{-3}	1×10^{-3}	7×10^{-4}
Till	10	3×10^{-3} to 9×10^{-6}	6×10^{-4}	2×10^{-4}	9×10^{-4}
Basal till	7	9×10^{-4} to 9×10^{-5}	4×10^{-4}	3×10^{-4}	3×10^{-4}
Glacial lacustrine	4	5×10^{-4} to 1×10^{-5}	2×10^{-4}	9×10^{-5}	2×10^{-4}
Lake lacustrine[b]	59	2×10^{-6} to 4×10^{-8}	5×10^{-7}	2×10^{-7}	6×10^{-7}

[a]Horizontal permeability.

[b]Laboratory vertical permeability test results from Shelby tube samples for the recent deposits under Little Sand, Skunk, Oak, Deep Hole, and Duck lakes (STS Consultants Ltd., 1982, 1984).

During the summer of 1980, Golder Associates conducted a pumping test on a test well (TW-41) located approximately 1.6 km (1 mile) east of Little Sand Lake and midway between piezometers DMB-1 and DMB-2 (Golder Associates, 1981b). The test well was pumped for 24 days, producing at a rate of 0.09 m^3/s (1,420 gallons/minute). The response to pumping was monitored in 13 observation wells within 457 m (1,500 feet) and 16 other observation wells within 3,200 m (10,500 feet) (Golder Associates, 1981b).

Camp Dresser and McKee, Inc. (CDM) performed a series of pumping tests in the summer of 1981 (CDM, 1982). These pumping tests were performed in the vicinity of the proposed mine on well WW4 and on exploratory boreholes 211 and 213. The WW4 test was performed to assess the main aquifer properties in the vicinity of the mine. This well was pumped at a rate of 1.4×10^{-2} m^3/s (225 gallons/minute) for 70 hours. The response to pumping was monitored in eight observation wells in the overburden and the bedrock. Boreholes 211 and 213 were pumped to determine if there was a hydraulic connection between the bedrock and the glacial overburden and, if so, the location of the greatest inflow potential for ground water to the proposed mine. The test on borehole 211 was done at a pumping rate of 1.4×10^{-2} m^3/s (225 gallons/minute) for 170 hours. The results were monitored in 15 observation wells in the overburden and bedrock. Borehole 213 was pumped at a rate of 3.5×10^{-2} m^3/s (560 gallons/minute) for 170 hours. The results were monitored in 22 observation wells in the overburden and bedrock.

Eighty laboratory permeability tests were completed on undisturbed soil samples collected during borehole drilling (Table 2.3-6). These soil samples were selected for these permeability tests because of their cohesiveness. Constant head and falling head laboratory tests (Lombe, 1951) were conducted on four and two samples, respectively, in the soils laboratory of the Dames & Moore Park Ridge, Illinois office. A constant head permeameter was used in accordance with American Society for Testing and Materials (ASTM) Standard Methods for Permeability of Granular Soils (constant head) (American Society for Testing and Materials, 1977). This apparatus allows water to move through a saturated soil sample while maintaining a constant head (constant head test) or by allowing the head to decrease over time (falling head test). For a more complete description of the procedure, the reader is referred to ASTM Part 19 Standard Methods D-2434, Permeability of Granular Soils (constant head). The other samples had high sand content and their permeabilities were estimated using Hazen's approximation (Hazen, 1911).

The Hazen approximation also was used to determine permeabilities of the remaining 74 samples. The Hazen Equation represents the relationship between permeability and soil texture based on grain size distribution. It relies on the effective grain size, d_{10}, and predicts a power-law relation with permeability, K:

$$K = A(d_{10})^2$$

The d_{10} value was obtained directly from a grain-size graduation curve as determined by sieve analysis. "A" is a constant that is equal to 1.0 for most soils in the fine sand to gravel range. In the area east of Little Sand Lake, estimates of permeabilities using Hazen's relationship correlated very well with those derived from pumping test data (Clerici, 1981).

To assess the permeability characteristics of the bedrock, a series of packer tests was performed in deep exploration boreholes drilled by Exxon Minerals Company. A discussion of the specific tests performed and results of testing are given in subsection 2.3.3.6, Bedrock. Water samples also were obtained from selected intervals within the bedrock for chemical analyses.

2.3.1.5 Water Well Inventory

Ground water users within and adjacent to the environmental study area were inventoried to document and quantify the present uses of ground water. Well information was gathered from the Wisconsin DNR (Wisconsin DNR, unpublished), the USGS (USGS, unpublished), and from personal contacts with well owners. The data collected during the water well inventory included owner, year the well was completed, installation and well completion details, well depth, diameter, depth to water, date of measurement, and use. The water well inventory resulted in identification of 165 well locations with a total of 168 wells in the environmental study area. The above information on 105 of these wells was obtained either from well logs or from personal communication with the owners. An inventory of each well within and adjacent to the environmental study area was completed in July 1984, and the results are currently being tabulated and will be included in the High Capacity Well Permit Application.

2.3.1.6 Spring Seep and Intermittent Stream Survey

In September of 1978, a reconnaissance was undertaken within the environmental study area to identify ground water discharge areas other than the permanent streams. Topographic maps were reviewed prior to field reconnaissance. The characteristics that were visually determined for each spring or intermittent stream included apparent water color, bottom sediment material, estimated rate of discharge, and direction of flow. In addition, specific conductance (conductivity), temperature, and pH were measured on site.

2.3.1.7 Chemical Analyses

Chemical analyses were completed by Aqualab, Inc., an independent analytical laboratory located in Streamwood, Illinois. As a member of the American Council of Independent Laboratories (ACIL), Aqualab subscribes to the ACIL Code of ethics and quality control program that provides standards for personnel, equipment and reference sample programs. In addition, Aqualab, Inc. operates an in-house quality control program that is described in a formal quality assurance manual. This quality control program includes systems for administration, sample analysis, and documentation.

Preparation of Sample Containers and Labware - The quality control program included specific procedures for the preparation of containers and labware used in sample collection or laboratory analysis according to the Manual of Methods for Chemical Analysis of Water and Wastes (U.S. EPA, 1974). Each shipment of plastic disposable containers was tested for contaminants using deionized water as a leaching agent.

Prior to use, all glassware and glass containers were washed with phosphate-free detergent, tap water rinsed, rinsed with deionized water, and air dried. This washing procedure also included a solvent rinse, when appropriate, for particular sampling applications. For example, for atomic absorption spectrophotometric analysis, individual rinses of glassware with phosphate-free detergent and tap water were followed by a thorough rinse or 30-minute soak with 1 N nitric acid, prior to a final rinse with deionized water.

The type of sample container and preservative used for sample collection was selected on the basis of standards outlined by the U.S. EPA (1974). The preservative or "bottle treatment" was noted on each sample bottle. Reagent grade chemicals were added to sample bottles by laboratory personnel prior to sampling. Micropipettes and/or auto-repipettes were used to assure uniform volume delivery in all sample bottles. Each container also had an attached label with space provided for the identification of the date, time and location of collection, client's name, and sample description.

Sample Handling - Once the sample had been collected, it was shipped to the laboratory within 10 hours. The laboratory received the samples 12 to 16 hours after they were collected. After receipt of samples at the laboratory, a Sample Work Order Form was completed containing the client name, sample description, time and date of collection, time and date of receipt, analysis required, and any special analysis instructions. A number, assigned to each sample set, was recorded in a bound logbook and noted on the sample containers and the Sample Work Order Form.

Once the samples were properly identified and logged in, they were taken to the Analysis Control Center. Samples were then placed on a holding table or refrigerated, if required. At the end of each work day, samples were either returned to cold storage or the sample table. Upon completion of the analysis, a representative aliquot of each sample was dated and retained for at least 30 days.

Sample Analysis - The analytical techniques and the detection limits for the parameters measured were in accordance with standard procedures (U.S. EPA, 1974; APHA et al., 1976).

2.3.1.8 Quality Control

Quality control procedures were utilized by field and office personnel as well as by subcontracted laboratory personnel during the ground water study as a means of assuring that the study was completed according to currently accepted standards and methods.

Field Procedures - All piezometer installations were supervised by a Dames & Moore, Golder Associates, or STS Consultants Ltd. field representative who maintained a record of piezometer construction details. In addition, he monitored the development of the piezometer after construction. Piezometer construction information and piezometer development data were reported on daily memos of field activities.

Recordings of ground water levels in piezometers, ground water sampling from piezometers, and in-situ permeability tests were conducted by trained personnel. In addition to recording these activities on daily memos of field activities, the resulting data were recorded on special forms designed for each activity.

Analytical Quality Control - Monitoring of analytical performance was accomplished by the analysis of duplicate ("split") samples. Duplicates were handled as regular samples and were always included in a specific sample analysis sequence.

Approximately every tenth sample submitted to the laboratory was split into duplicate samples with the same designated sample number. The second portion of the sample was designated "QA." The analysis of the "QA" sample was used to document that reproducible data were being generated by comparison of the data with the known precision of the analytical method. Precision specifies the upper and lower control limits for test results as compared to a standard deviation. The standard deviation accepted for the various parameters can be found in publications of the U.S. EPA (1974) or APHA et al., (1976), or it can be derived from the data.

Approximately every twentieth sample submitted to the laboratory was split into triplicate subsamples. Each of these subsamples retained the same designated sample number. The second subsample was additionally designated "QA" and the third "spike." The "QA" subsample was sampled as described in the preceding paragraph. The "spike" portion was spiked with known concentrations of the parameters being analyzed. The analysis of the percent recovery of the known quantities was used to assess if the procedure is reliable and is measuring within an acceptable range of accuracy. The lower control limit for recovery is based on the standard deviation accepted for the various parameters by the U.S. EPA (1974) and APHA et al. (1976), or it can be derived from the data.

As part of the quality control program for the present study, samples were split at intervals specified by the DNR or as part of in-house QA/QC. These splits were conducted in the field for separate analysis by Aqualab, Inc., and the Wisconsin DNR. The Aqualab laboratory facilities were also audited by Dames & Moore, Wisconsin DNR, and Exxon personnel regarding laboratory analysis records and compliance with procedures outlined in the Quality Assurance Manual.

Constant head and falling head laboratory tests were performed using a constant head permeameter in accordance with ASTM methods. All laboratory equipment was calibrated in accordance with Dames & Moore standard soils laboratory procedures. The soils laboratory is inspected and audited at least once a year by Dames & Moore quality assurance personnel.

Data Analyses - All data were rechecked by a Dames & Moore employee other than the original investigator. This review included checking of all calculations, tables, graphs, maps, and figures a minimum of two times before being incorporated into the report.

2.3.2 Regional[2] Hydrogeology

2.3.2.1 Geologic Setting

The environmental study area is situated in an area of Precambrian volcanic rocks of the Rhinelander-Ladysmith greenstone belt. The Precambrian rocks are overlain by as much as 91 m (300 feet) of glacial drift, resulting in a rolling topography. The term "drift" refers to any rock material transported by a glacier and deposited by or from the ice, or by or in water derived from the melting of the ice. The Precambrian bedrock is part of a southern extension of the Canadian Shield, referred to as the Southern Province. The more common rock types found in the Shield include volcanic flows and sediments, gneisses, granitic intrusions, sandstone, and shale. Volcanic rocks are usually found as irregularly shaped belts surrounded by granitic gneiss. These belts are comprised of volcanic flows and pyroclastics with interbedded sedimentary rocks such as shale, sandstone, and conglomerate. Locally, the volcanic belts are intruded by large masses of granite or

[2]The term "regional" as used herein refers to northern Wisconsin and geologically associated areas. The use of the term is consistent with the usage in section 2.2, Geology.

granodiorite. It is within these volcanic belts that massive sulfide deposits may be found (section 2.2, Geology).

The Precambrian rocks that form the bedrock in the region are surrounded on the west, south, and east by overlapping sedimentary rocks ranging in age from Cambrian to Devonian (Ostrom, 1976). These units are relatively flat-lying sandstone, limestones, and shale. None of the post-Precambrian units outcrop or subcrop within the environmental study area.

The bedrock throughout much of northern Wisconsin, Minnesota, and Michigan is overlain by glacial drift deposited during the Pleistocene Epoch. The majority of the drift, however, was deposited during the most recent glacial advance, the Wisconsin age, 75,000 years ago.

The thickness and character of the drift vary across the environmental study area. The drift may exceed 91 m (300 feet) in thickness in buried preglacial valleys that are found in extreme northern and southeastern Wisconsin and locally along the present Wisconsin River Valley (Hadley, 1976). The glacial history of northeastern Wisconsin is complex and is described briefly in section 2.2, Geology.

2.3.2.2 Ground Water Occurrence

On a regional basis, the glacial drift that directly overlies the surface of the Precambrian bedrock contains the principal ground water aquifers. These usually consist of water-bearing lenses and sheets of outwash sand and gravel at the base of, within, or at the top of the drift (McGuinness, 1963). The Precambrian rocks, although they are locally fractured and exhibit secondary permeability, typically yield only small amounts of water to wells.

In general, the availability of ground water varies spatially; however, there are few localities where at least small supplies are difficult to develop and many where moderate to large supplies are available (McGuiness, 1963).

2.3.3 Hydrogeology of the Environmental Study Area

2.3.3.1 Geology

The bedrock and surficial geology within the environmental study area are discussed in section 2.2, Geology. As described, the Crandon massive sulfide deposit is contained within a sequence of Precambrian pyroclastic and sedimentary rocks. These are mantled by 30 to 70 m (100 to 230 feet) of Pleistocene sand and gravel.

The Precambrian bedrock in the proposed mine area strikes approximately north 80 degrees west and dips from 70 degrees north to vertical. The Crandon rocks were formed during two volcanic cycles. During the first volcanic cycle, the Hemlock Creek group, which consists of a series of basaltic flows, was deposited. Later, the Duck Lake gabbro dike intruded these flows and overlying rocks. Overlying the flows is the Sand Lake Formation - a thick sequence of tuff with interbedded, coarse volcanic debris. The upper portion of this formation consists of a sequence of volcanic chloritic and siliceous breccias. The breccias, in turn, are overlain by the Crandon Formation, which consists of a sequence of sedimentary rocks composed of fine tuff, chert, argillite, and massive sulfide. The rocks are generally fine-grained, thinly-bedded, and contain no coarse volcanic debris.

The Crandon Formation is, in turn, overlain by the Mole Lake, Rice Lake, and Skunk Lake Formations and the Swamp Creek Group. The strata comprising this sequence consist mainly of volcanic tuff, chert, and pumice.

The bedrock in the environmental study area has been subjected to uninterrupted weathering since Precambrian time. At present, the total thickness of weathered rock is relatively thin because of extensive stripping by glacial action. Weathering is highly variable and dependent upon fracture density and rock type. Additional details on geology and weathering are presented in section 2.2. Erosion, glaciation, and deposition of drift between 7,000 and 75,000 years ago caused the last major geologic change in the area. Since the end of glaciation, surface water has percolated through the surficial deposits.

The drift materials, which directly overlie the Precambrian rocks, consist of Pleistocene sand and gravel of glacial and glacial-fluvial origin. Within the environmental study area, the thickness of the drift materials, as determined by drilling, varies from less than 8 m (25 feet) to more than 110 m (360 feet). In general, the drift deposits from bedrock to the ground surface consist of brown, undifferentiated, calcareous sand with some gravel and a trace of silt (Green Bay Drift). These deposits are generally overlain by reddish brown to brown, noncalcareous, nonbedded sand with gravel and some silt and boulders (Langlade Drift). Locally, these deposits are overlain and/or are separated by bedded sand and gravel and/or sand and silt (outwash). A map of the surficial geology of the environmental study area is presented as Figure 2.2-12 (section 2.2, Geology).

In summary, the surficial materials within the environmental study area are glacial drift, consisting of interbedded glacial till and outwash.

Both of these consist mainly of sand and gravel. As described in section 2.2, Geology, the glacial till contains more silt and gravel than the outwash. The outwash, being of glaciofluvial origin, tends to be better sorted than the till.

2.3.3.2 Ground Water Occurrence

In the environmental study area, ground water occurs under water table or unconfined conditions and confined or partially confined conditions, both within the glacial drift and within the Precambrian bedrock. In general, the principal aquifers within the environmental study area are contained within the unconsolidated glacial drift overlying bedrock. The bedrock that subcrops beneath the site area is typically of low to very low permeability except in weathered zones or highly fractured and jointed zones (section 2.2, Geology). Locally "perched" ground water conditions have been identified within the glacial drift. Perched ground water is defined as unconfined ground water separated from underlying ground water by an unsaturated zone (Lohman et al., 1970). On the basis of the existing geologic (section 2.2, Geology) and ground water information, however, these perched or local[3] aquifers appear to be limited in areal extent (Golder Associates, 1982).

The drift overlies the entire environmental study area and, therefore, constitutes the main ground water aquifer system. As will be discussed, the drift, because of its depositional history, is highly variable spatially and with depth. For example, there are lenses and zones within the

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[3] As used herein, the terms "perched aquifer" and "local aquifer" are used synonymously.

drift, which because of their lower permeability restrict the downward percolation of incident precipitation and snowmelt, resulting in local ground water conditions perched above the main ground water table. Also, the lithologic variability within the drift results in the separation or partial separation of zones of higher permeability within the zone of saturation.

A contour map of the main ground water table surface within the unconsolidated drift is shown on Figure 2.3-3. The potentiometric contour map is based on water level observations in established wells and piezometers within the environmental study area in April 1984 (STS Consultants Ltd., 1984a). The water level data on which the potentiometric contour map is based are summarized in Appendix 2.3B, Table B-2.

In general, the configuration of the potentiometric surface is a subdued reflection of the surface topography. In this regard, the potentiometric surface tends to rise beneath the upland areas, whereas in the lowland areas, it tends to be at or close to the ground surface. In the upland areas, the surface elevation of many of the lakes is above the elevation of the main ground water table potentiometric surface, suggesting that the lakes are behaving as areas of recharge to the main ground water aquifer. In contrast, many of the lakes in the low-lying areas, for example along the major surface water drainages, receive ground water discharge from the surrounding areas (see Figure 2.3-15). The elevation of the potentiometric surface tends to be highest in the northeast and northwest portions of the environmental study area and in the central portion of the site area overlying ore body.

2.3.3.3 Ground Water Recharge-Discharge Regime

Locally in the environmental study area, ground water is collected and transmitted to the main ground water aquifer, while in other portions of the environmental study area the main ground water aquifer nears the ground surface and ground water is discharged as surface water. These areas are termed ground water recharge and ground water discharge areas, respectively.

The direction of ground water flow within the main ground water aquifer system is shown on Figure 2.3-3. The direction of ground water flow is perpendicular to the potentiometric contour lines as shown. Ground water flow is outward from the upland area located directly east of Little Sand, Skunk, Oak, Duck, and Deep Hole lakes. This area constitutes the principal area of ground water recharge within the site area. Other areas of ground water recharge occur in the north-central and northeast portions of the site area as shown on Figure 2.3-3.

As mentioned previously, the surface elevations of several lakes, notably Oak, Little Sand, Duck, Deep Hole, and Skunk, are above the existing elevation of the main ground water table (Figure 2.3-3). Because of their position above the water table or potentiometric surface, these lakes are areas of recharge to the main ground water aquifer. The rate of ground water recharge to the main ground water aquifer from Skunk, Oak, Little Sand, and Duck lakes ranges from 3.6×10^3 m^3/y (9.5×10^5 gallons per year) for Skunk Lake to approximately 8.7×10^4 m^3/y (2.3×10^6 gallons per year) for Oak Lake. Those lakes located within ground water recharge areas are underlain by low permeability materials, which limit the rate of seepage losses and thus the rate of ground water recharge from them (Table 2.3-7) (STS Consultants Ltd., 1982, 1984b).


NORTH
LEGEND
482 CONTOURS IN METERS ABOVE MSL APRIL, 1984
CRANDON FORMATION
GROUNDWATER FLOW DIRECTION
PLANT SITE
SURFACE ELEV. 497.88
SURFACE ELEV. 485.2
SURFACE ELEV. 487.07
SURFACE ELEV. 491.29
SURFACE ELEV. 489.32
NOTE: DATA FROM APRIL 27, 1984 FOR OLDER WELLS
DATA FROM MAY 24, 1984 FOR EX WELLS
SCALE IN METERS
EXXON MINERALS COMPANY
CRANDON PROJECT
POTENTIOMETRIC CONTOURS OF MAIN GROUND WATER AQUIFER IN THE ENVIRONMENTAL STUDY AREA
SCALE AS SHOWN
STATE WISCONSIN
COUNTY FOREST, LANGLADE
DRAWN BY J.J.T.
DATE 6-20-84
APPROVED BY J.A.S.
APPROVED BY R. ROWE
EXXON
REVISED 1 8-22-84 DRS REVISED GROUNDWATER CONTOURS
FIGURE 2.3-3
REVISION NO 1
STS DRWG. 12959 - 9
DESIGN PRODUCTS CO.

TABLE 2.3-7

SUMMARY OF LABORATORY TEST RESULTS FROM LAKE DRILLING PROGRAMS IN DUCK, SKUNK, OAK, DEEP HOLE, AND LITTLE SAND LAKES

BORING NUMBER	SAMPLE NUMBER	DEPTH (feet)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ORGANIC CONTENT (%)	PERCENT P-200	PERCENT CLAY[a]	ATTERBERG LIMITS (%) LL	PL	PI	USCS CLASSIFICATION	PERMEABILITY COEFFICIENT (cm/s)
DL-1	10	25.5 - 28.0	19.9	104.	--	78.	--	--	--	--	(CL)	1.3×10^{-6}
DL-1	15	38.0 - 40.0	28.7	99.	1.4	93.	--	30.4	21.3	9.1	(CL)	1.0×10^{-7}
SL-2	1A	9.1 - 10.0	20.6	108.	1.8	93.	--	31.9	19.5	12.4	(CL)	4.3×10^{-8}
OL-1	4	37.5 - 39.5	27.2	103.	--	88.	--	--	--	--	(CL)	2.3×10^{-6}
OL-1	6	42.5 - 44.5	32.4	101.	0.7	93.	--	29.2	21.1	8.1	(CL)	3.5×10^{-7}
DHL-1	6	21.0 - 23.0	43.6	95.	1.7	95.	--	28.8	25.0	3.8	(ML)	6.8×10^{-7}
DHL-1	11	33.5 - 35.2	35.2	92.	--	88.	--	--	--	--	(ML)	6.8×10^{-8}
LSL-1	9[b]	30.0 - 32.0	51.5	73.1	--	99.2	14.0	37.1	11.8	25.3	--	1.4×10^{-7}
LSL-1	15	44.5 - 47.0	33.6	88.6	--	94.4	19.0	--	--	--	--	1.7×10^{-7}
LSL-2	5	24.5 - 26.5	36.6	80.0	--	97.7	11.5	--	--	--	--	7.3×10^{-7}
LSL-2	12	39.0 - 40.5	--	--	--	4.6	0.0	--	--	--	--	--
LSL-3	8	28.0 - 30.0	56.3	67.1	--	99.0	19.0	--	--	--	--	3.7×10^{-7}
LSL-3	12	37.0 - 39.0	35.9	87.8	--	99.5	15.0	--	--	--	--	1.5×10^{-7}
LSL-3	15	43.5 - 45.0	--	--	--	4.2	0.0	--	--	--	--	--
LSL-4	9	30.5 - 32.5	43.3	81.0	0.8	96.8	15.0	32.0	15.8	16.2	--	1.1×10^{-7}
LSL-4	16	45.5 - 47.0	--	--	--	18.7	--	--	--	--	--	--
LSL-5	5	20.0 - 22.0	45.7	78.5	--	98.4	17.0	--	--	--	--	1.6×10^{-4}[c]
LSL-5	9	28.0 - 30.0	37.3	84.5	--	96.8	19.0	--	--	--	--	1.5×10^{-7}
LSL-6	4	16.0 - 18.0	107.4	41.8	5.4	93.3	8.0	115.3	62.6	52.7	--	3.7×10^{-7}
LSL-6	10	28.0 - 30.0	34.8	86.8	--	98.3	19.0	--	--	--	--	1.6×10^{-6}

[a]Percent clay based on 0.005 mm size.

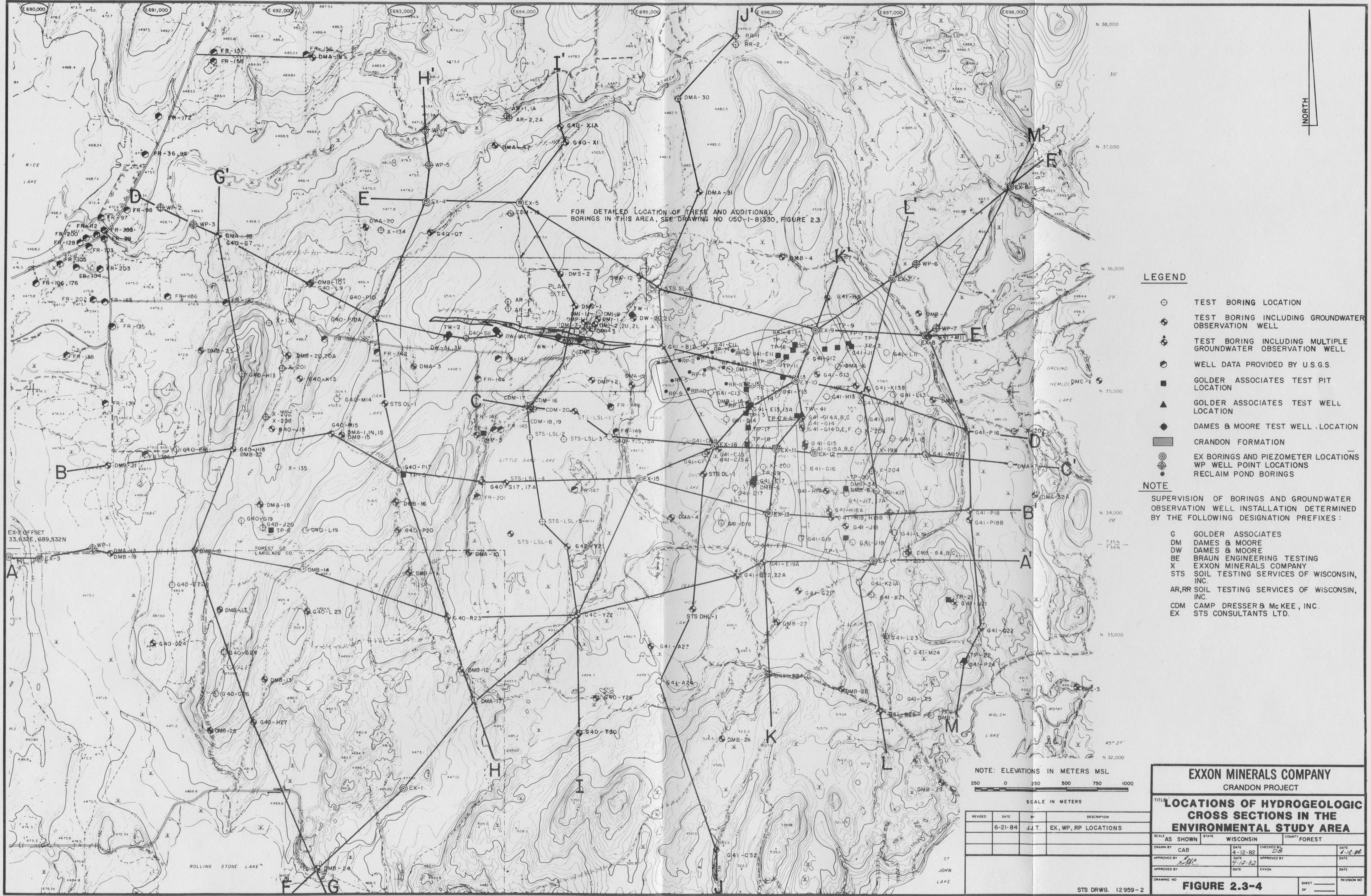
[b]Specific gravity = 2.66.

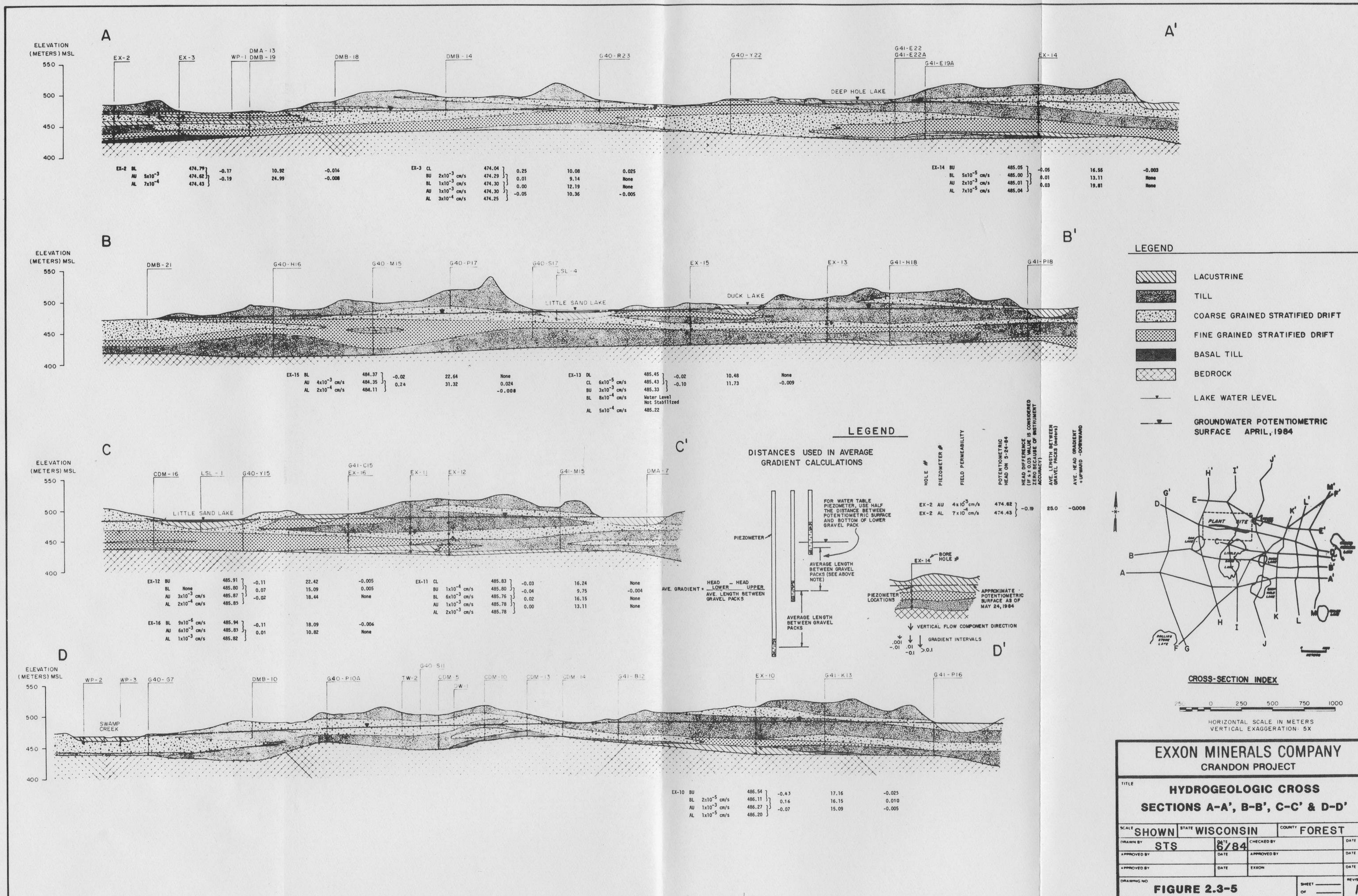
[c]Erroneous permeability coefficient due to side channeling.

For example, the water surface elevation in Oak Lake is approximately 19.8 m (65 feet) above the main ground water table in piezometer DMB-15, located adjacent to the lake, and in OL-1, located in the center of the lake. The bottom of Oak Lake has an approximate elevation of 483 m (1,585 feet), which is approximately 4 m (13.1 feet) above the main ground water table. In comparison, the surface water elevation of Little Sand Lake is approximately 485.2 m (1,591 feet), which is about 3 m (10 feet) above the elevation of the main ground water table, whereas the bottom of the lake is approximately 3 m (10 feet) below the elevation of the main ground water table.

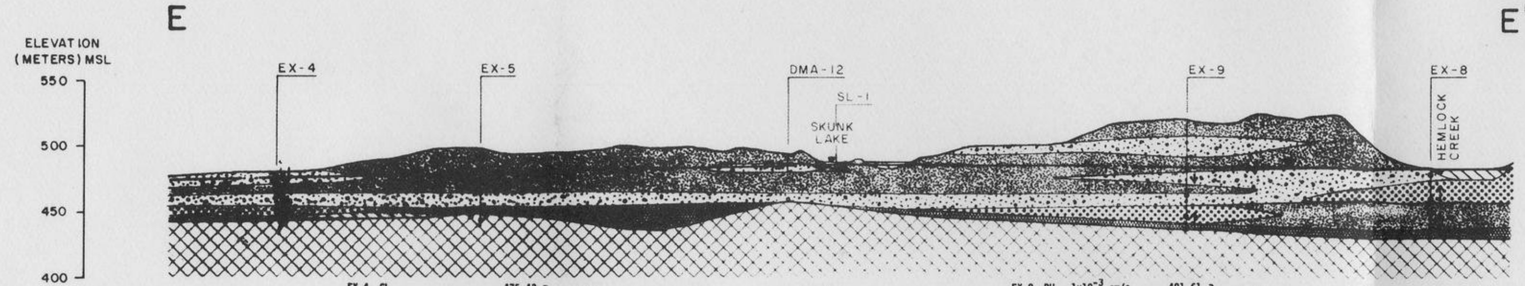
In contrast, the principal areas of ground water discharge from the main ground water aquifer are along the surface water drainages: for instance, Hemlock, Swamp, and Pickerel creeks. Rolling Stone, Mole, Rice, and Ground Hemlock lakes are located within areas of ground water discharge from the main ground water aquifer, as shown by the surface water elevations, potentiometric contours, and ground water flow directions (Figure 2.3-3).

The locations of a series of hydrogeologic cross sections through the environmental study area, which also show the locations of all borings and piezometers along the cross-sectional lines, are indicated on Figure 2.3-4. As shown on the hydrogeologic cross sections, Figures 2.3-5 through 2.3-7, the surficial materials existing in the environmental study area are glacial drift consisting of interbedded glacial till and outwash, which overlie the surface of the Precambrian bedrock. The thickness of the drift within the site area ranges from approximately 30 to 91 m (100 to 300 feet) and thins to as little as 8 m (25 feet) over bedrock knolls in the surrounding areas. Lenses of lower permeability material exist within the drift and

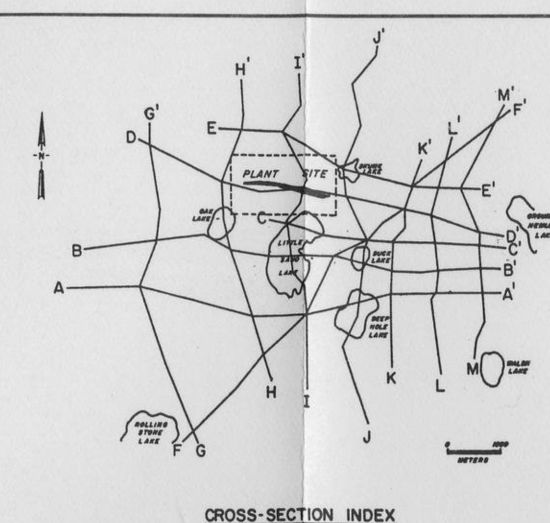

LEGEND
TEST BORING LOCATION
TEST BORING INCLUDING GROUNDWATER OBSERVATION WELL
TEST BORING INCLUDING MULTIPLE GROUNDWATER OBSERVATION WELL
WELL DATA PROVIDED BY U.S.G.S.
GOLDER ASSOCIATES TEST PIT LOCATION
GOLDER ASSOCIATES TEST WELL LOCATION
DAMES & MOORE TEST WELL LOCATION
CRANDON FORMATION
EX BORINGS AND PIEZOMETER LOCATIONS
WP WELL POINT LOCATIONS
RECLAIM POND BORINGS
NOTE
SUPERVISION OF BORINGS AND GROUNDWATER OBSERVATION WELL INSTALLATION DETERMINED BY THE FOLLOWING DESIGNATION PREFIXES:
G GOLDER ASSOCIATES
DM DAMES & MOORE
DW DAMES & MOORE
BE BRAUN ENGINEERING TESTING
X EXXON MINERALS COMPANY
STS SOIL TESTING SERVICES OF WISCONSIN, INC.
AR,RR SOIL TESTING SERVICES OF WISCONSIN, INC.
CDM CAMP DRESSER & McKEE, INC.
EX STS CONSULTANTS LTD.
NORTH
FOR DETAILED LOCATION OF THESE AND ADDITIONAL BORINGS IN THIS AREA, SEE DRAWING NO 050-1-81330, FIGURE 2.3
PLANT SITE
RICE LAKE
LITTLE SAND LAKE
DUCK LAKE
ROLLING STONE LAKE
ST JOHN LAKE
WALSH LAKE
HEMLOCK CREEK
FOREST CO.
LANGLADE CO.
EX-2 OFFSET 33,632E, 689,532N
NOTE: ELEVATIONS IN METERS MSL
250 0 250 500 750 1000
SCALE IN METERS
REVISED | DATE | BY | DESCRIPTION
6-21-84 | J.J.T. | EX, WP, RP LOCATIONS
EXXON MINERALS COMPANY
CRANDON PROJECT
TITLE LOCATIONS OF HYDROGEOLOGIC CROSS SECTIONS IN THE ENVIRONMENTAL STUDY AREA
SCALE AS SHOWN
STATE WISCONSIN
COUNTY FOREST
DRAWN BY CAB
DATE 4-12-82
CHECKED BY DB
DATE 4-12-82
APPROVED BY
DATE 4-12-82
APPROVED BY
DATE
EXXON
DRAWING NO
FIGURE 2.3-4
SHEET OF
REVISION NO
STS DRWG. 12959-2
DESIGN PRODUCTS CO

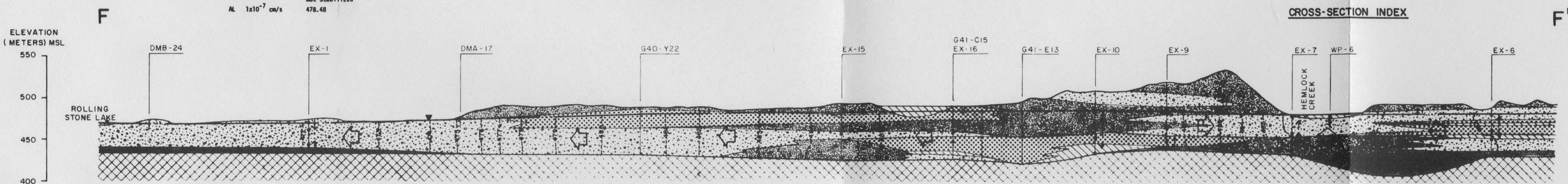


A
A'
ELEVATION (METERS) MSL
550
500
450
400
EX-2
EX-3
WP-1
DMA-13
DMB-19
DMB-18
DMB-14
G40-R23
G40-Y22
G41-E22
G41-E22A
G41-E19A
EX-14
DEEP HOLE LAKE
EX-2 BL 474.79 -0.17 10.92 -0.016
AU 5x10^-3 474.62 -0.19 24.99 -0.008
AL 7x10^-4 474.43
EX-3 CL 474.04 0.25 10.08 0.025
BU 2x10^-3 cm/s 474.29 0.01 9.14 None
BL 1x10^-3 cm/s 474.30 0.00 12.19 None
AU 1x10^-3 cm/s 474.30 -0.05 10.36 -0.005
AL 3x10^-4 cm/s 474.25
EX-14 BU 485.05 -0.05 16.55 -0.003
BL 5x10^-5 cm/s 485.00 0.01 13.11 None
AU 2x10^-3 cm/s 485.01 0.03 19.81 None
AL 7x10^-5 cm/s 485.04
B
B'
DMB-21
G40-H16
G40-M15
G40-P17
G40-S17
LSL-4
LITTLE SAND LAKE
EX-15
DUCK LAKE
EX-13
G41-H18
G41-P18
EX-15 BL 484.37 -0.02 22.64 None
AU 4x10^-3 cm/s 484.35 0.24 31.32 0.024
AL 2x10^-4 cm/s 484.11 -0.008
EX-13 DL 485.45 -0.02 10.48 None
CL 6x10^-5 cm/s 485.43 -0.10 11.73 -0.009
BU 3x10^-3 cm/s 485.33
BL 8x10^-4 cm/s Water Level Not Stabilized
AL 5x10^-4 cm/s 485.22
C
C'
CDM-16
LSL-1
G40-Y15
LITTLE SAND LAKE
G41-C15
EX-16
EX-11
EX-12
G41-M15
DMA-7
EX-12 BU 485.91 -0.11 22.42 -0.005
BL None 485.80 0.07 15.09 0.005
AU 3x10^-3 cm/s 485.87 -0.02 18.44 None
AL 2x10^-4 cm/s 485.85
EX-16 BL 9x10^-6 cm/s 485.94 -0.11 18.09 -0.006
AU 6x10^-3 cm/s 485.83 0.01 10.82 None
AL 1x10^-3 cm/s 485.82
EX-11 CL 485.83 -0.03 16.24 None
BU 1x10^-4 cm/s 485.80 -0.04 9.75 -0.004
BL 6x10^-3 cm/s 485.76 0.02 16.15 None
AU 1x10^-3 cm/s 485.78 0.00 13.11 None
AL 2x10^-3 cm/s 485.78
D
D'
WP-2
WP-3
G40-G7
SWAMP CREEK
DMB-10
G40-P10A
TW-2
G40-S11
CDM-5
OW-1
CDM-10
CDM-13
CDM-14
G41-B12
EX-10
G41-K13
G41-P16
EX-10 BU 486.54 -0.43 17.16 -0.025
BL 2x10^-5 cm/s 486.11 0.16 16.15 0.010
AU 1x10^-3 cm/s 486.27 -0.07 15.09 -0.005
AL 1x10^-5 cm/s 486.20
LEGEND
DISTANCES USED IN AVERAGE GRADIENT CALCULATIONS
PIEZOMETER
FOR WATER TABLE PIEZOMETER, USE HALF THE DISTANCE BETWEEN POTENTIOMETRIC SURFACE AND BOTTOM OF LOWER GRAVEL PACK
AVERAGE LENGTH BETWEEN GRAVEL PACKS (SEE ABOVE NOTE)
AVERAGE LENGTH BETWEEN GRAVEL PACKS
AVE. GRADIENT = (HEAD LOWER − HEAD UPPER) / AVE. LENGTH BETWEEN GRAVEL PACKS
HOLE #
PIEZOMETER #
FIELD PERMEABILITY
POTENTIOMETRIC HEAD ON 5-24-84
HEAD DIFFERENCE (IF ± 0.03 VALUE IS CONSIDERED ZERO BECAUSE OF INSTRUMENT ACCURACY)
AVE. LENGTH BETWEEN GRAVEL PACKS (meters)
AVE. HEAD GRADIENT + UPWARD - DOWNWARD
EX-2 AU 4x10^-3 cm/s 474.62 -0.19 25.0 -0.008
EX-2 AL 7x10^-4 cm/s 474.43
EX-14 BORE HOLE #
PIEZOMETER LOCATIONS
APPROXIMATE POTENTIOMETRIC SURFACE AS OF MAY 24, 1984
VERTICAL FLOW COMPONENT DIRECTION
GRADIENT INTERVALS
.001 -.01
.01 -.1
>0.1
LEGEND
LACUSTRINE
TILL
COARSE GRAINED STRATIFIED DRIFT
FINE GRAINED STRATIFIED DRIFT
BASAL TILL
BEDROCK
LAKE WATER LEVEL
GROUNDWATER POTENTIOMETRIC SURFACE APRIL, 1984
PLANT SITE
CROSS-SECTION INDEX
250 0 250 500 750 1000
HORIZONTAL SCALE IN METERS
VERTICAL EXAGGERATION: 5X
EXXON MINERALS COMPANY
CRANDON PROJECT
TITLE
HYDROGEOLOGIC CROSS SECTIONS A-A', B-B', C-C' & D-D'
SCALE SHOWN
STATE WISCONSIN
COUNTY FOREST
DRAWN BY STS
DATE 6/84
CHECKED BY
APPROVED BY
EXXON
DRAWING NO.
FIGURE 2.3-5
SHEET OF
REVISION NO. 1



Hole #	Piezometer #	Field permeability	Potentiometric head on 5-24-84	Head difference	Ave. length between gravel packs (meters)	Ave. head gradient
EX-4	CL		475.43	-0.44	5.21	-0.085
	BU	7×10^{-4} cm/s	474.99	-0.06	7.77	-0.008
	BL	1×10^{-3} cm/s	474.93	-0.12	8.84	-0.014
	AU	1×10^{-3} cm/s	474.81	0.13	7.01	0.019
	AL	7×10^{-4} cm/s	474.94			
EX-5	CL		479.46	-0.53	12.53	-0.042
	BL	1×10^{-2} cm/s	478.93			
	AU	2×10^{-6} cm/s	Water Level Not Stabilized			
	AL	1×10^{-7} cm/s	478.48			
EX-8	BU	1×10^{-3} cm/s	481.61	-0.02	19.26	None
	BL	2×10^{-3} cm/s	481.59	0.94	9.14	0.103
	AU	2×10^{-4} cm/s	482.53	0.53	17.98	0.030
	AL	1×10^{-4} cm/s	483.06			
EX-9	BU		486.14	-0.09	19.24	-0.005
	BL	2×10^{-3} cm/s	486.05	-0.01	17.07	None
	AU	6×10^{-3} cm/s	486.04	0.65	9.75	0.067
	AL	2×10^{-8} cm/s	486.69			

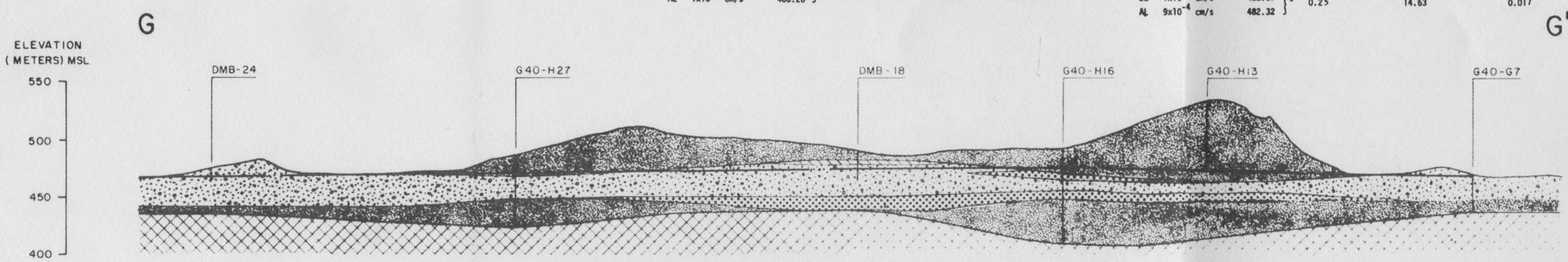




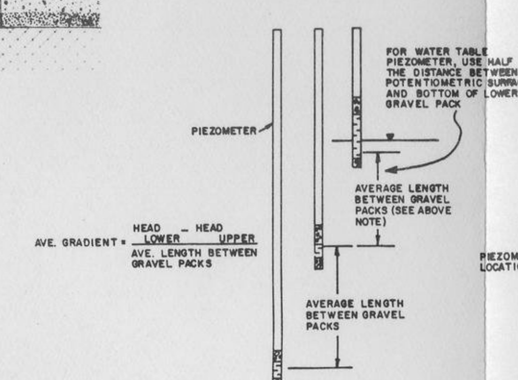
Hole #	Piezometer #	Field permeability	Potentiometric head on 5-24-84	Head difference	Ave. length between gravel packs (meters)	Ave. head gradient
EX-1	BU		472.14	-0.16	8.96	-0.017
	BL	6×10^{-3} cm/s	471.98	0.00	18.59	None
	AU	6×10^{-3} cm/s	471.98	+0.05	7.24	0.007
	AL	9×10^{-5} cm/s	472.03			
EX-15	BL		484.37	-0.02	22.64	None
	AU	4×10^{-3} cm/s	484.35	-0.24	31.32	-0.008
	AL	2×10^{-4} cm/s	484.11			
EX-16	BL	9×10^{-6} cm/s	485.94	-0.11	18.09	-0.006
	AU	6×10^{-3} cm/s	485.83	-0.01	10.82	None
	AL	1×10^{-3} cm/s	485.82			
EX-10	BU		486.54	-0.43	17.16	-0.025
	BL	2×10^{-5} cm/s	486.11	0.16	16.15	0.010
	AU	1×10^{-3} cm/s	486.27	-0.07	15.09	-0.005
	AL	1×10^{-5} cm/s	486.20			
EX-9	BU		486.14	-0.09	19.24	-0.005
	BL	2×10^{-3} cm/s	486.05	-0.01	17.07	None
	AU	6×10^{-3} cm/s	486.04	0.65	9.75	0.067
	AL	2×10^{-8} cm/s	486.69			
EX-7	CL		481.18	0.42	19.52	0.022
	BU	1×10^{-3} cm/s	481.60	0.47	11.58	0.041
	BL	1×10^{-3} cm/s	482.07	0.25	14.63	0.017
	AL	9×10^{-4} cm/s	482.32			
EX-6	BU		483.33	0.26	17.36	0.016
	BL	2×10^{-3} cm/s	483.59	-0.61	11.28	-0.054
	AU	4×10^{-3} cm/s	482.98	0.00	17.07	None
	AL	3×10^{-4} cm/s	482.98			

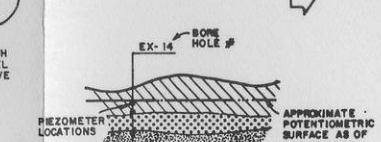
LEGEND

- LACUSTRINE
- TILL
- COARSE GRAINED STRATIFIED DRIFT
- FINE GRAINED STRATIFIED DRIFT
- BASAL TILL
- BEDROCK
- LAKE WATER LEVEL
- GROUNDWATER POTENTIOMETRIC SURFACE APRIL, 1984
- ---483--- ESTIMATED EQUIPOTENTIAL LINES
- OVERALL GROUNDWATER FLOW DIRECTION



DISTANCES USED IN AVERAGE GRADIENT CALCULATIONS





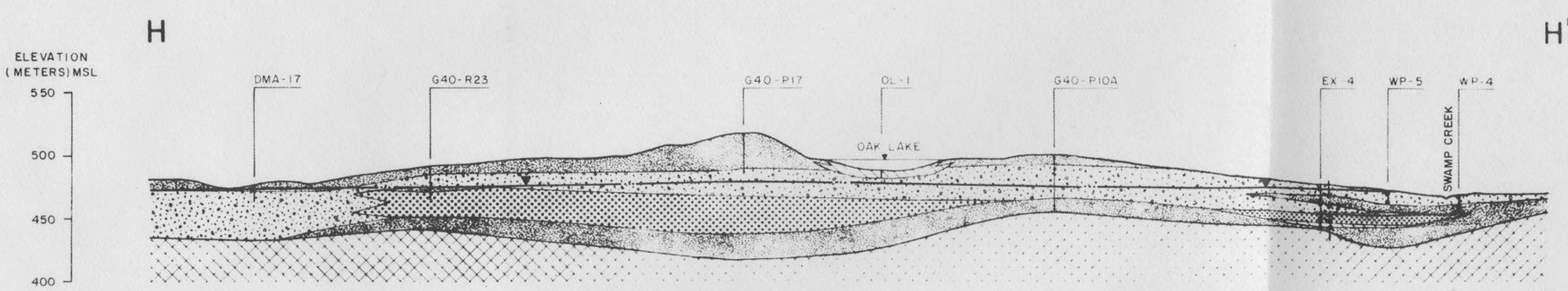
VERTICAL FLOW COMPONENT DIRECTION

GRADIENT INTERVAL

.001 – -.01 | .01 – -0.1 | >0.1

250 0 250 500 750 1000

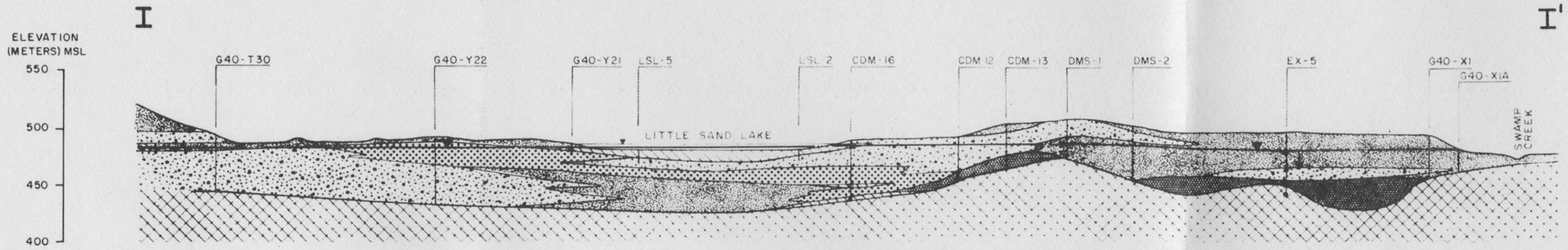
HORIZONTAL SCALE IN METERS
VERTICAL EXAGGERATION: 5X



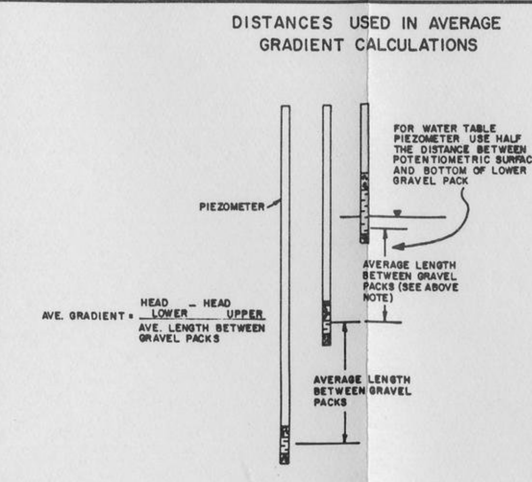
Hole #	Piezometer #	Field permeability	Potentiometric head on 5-24-84	Head difference	Ave. length between gravel packs (meters)	Ave. head gradient
EX-4	CL		475.43	-0.44	5.21	-0.085
	BU	7×10^{-4} cm/s	474.99	-0.06	7.77	-0.008
	BL	1×10^{-3} cm/s	474.93	-0.12	8.84	-0.014
	AU	1×10^{-3} cm/s	474.81	0.13	7.01	0.019
	AL	7×10^{-4} cm/s	474.94			

HOLE #	PIEZOMETER #	FIELD PERMEABILITY	POTENTIOMETRIC HEAD ON 5-24-84	HEAD DIFFERENCE (IF ≤ ± 0.03 VALUE IS CONSIDERED ZERO BECAUSE OF INSTRUMENT ACCURACY)	AVE. LENGTH BETWEEN GRAVEL PACKS (meters)	AVE. HEAD GRADIENT + UPWARD - DOWNWARD
EX-2	AU	4×10^{-3} cm/s	474.62	-0.19	25.0	-0.008
EX-2	AL	7×10^{-4} cm/s	474.43			

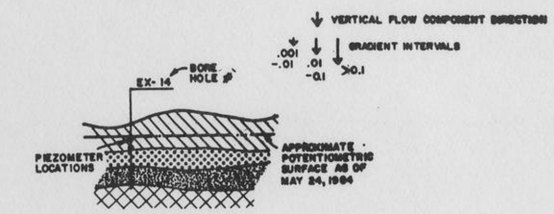
EXXON MINERALS COMPANY CRANDON PROJECT			
TITLE **HYDROGEOLOGIC CROSS SECTIONS E-E', F-F', G-G' & H-H'**			
SCALE SHOWN	STATE WISCONSIN	COUNTY FOREST	
DRAWN BY STS	DATE 6/84	CHECKED BY	DATE
APPROVED BY	DATE	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE
DRAWING NO **FIGURE 2.3-6**		SHEET ___ OF ___	REVISION NO 1

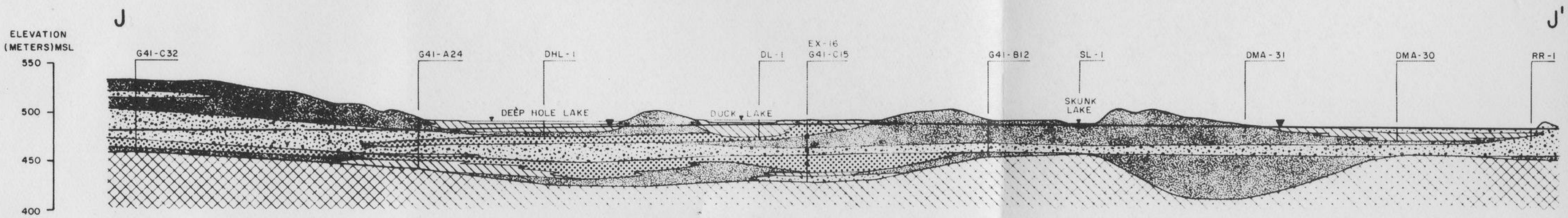


EX-5	CL		479.46	-0.53	12.53	-0.042
	BL	$1x10^{-2}$ cm/s	478.93			
	AU	$2x10^{-6}$ cm/s	Water Level Not Stabilized			
	AL	$1x10^{-7}$ cm/s	478.48			



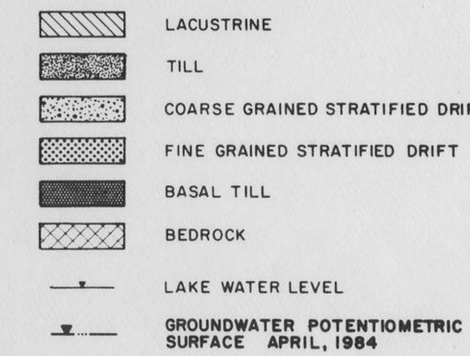
HOLE #	PIEZOMETER #	FIELD PERMEABILITY	POTENTIOMETRIC HEAD ON 5-24-84	HEAD DIFFERENCE (IF ± 0.05 VALUE IS CONSIDERED ZERO BECAUSE OF INSTRUMENT ACCURACY)	AVE. LENGTH BETWEEN GRAVEL PACKS (meters)	AVE. HEAD GRADIENT + UPWARD − DOWNWARD
EX-2	AU	$4x10^{-3}$ cm/s	474.62	-0.19	25.0	-0.006
EX-2	AL	$7x10^{-4}$ cm/s	474.43			

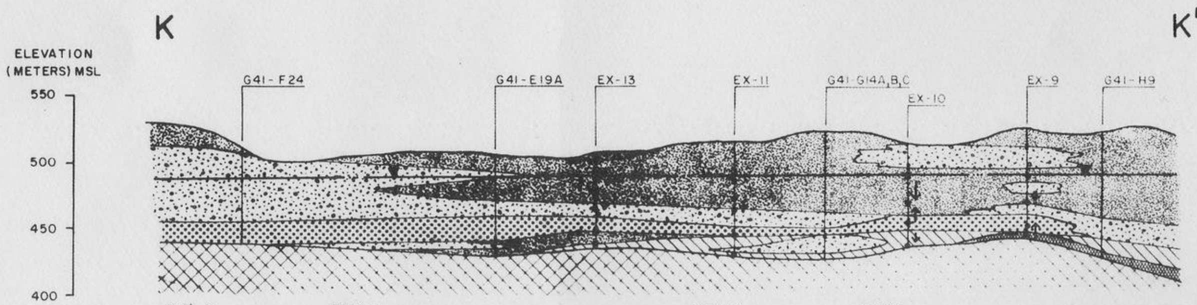




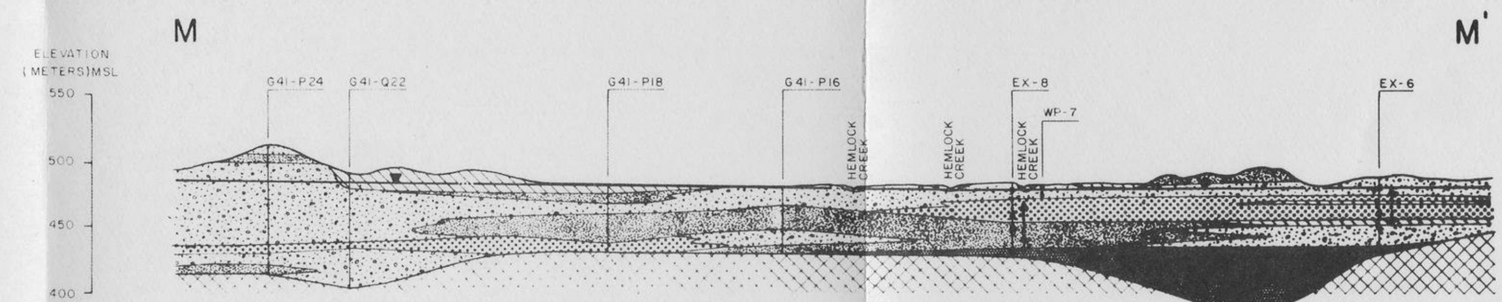
EX-16	BL	$9x10^{-6}$ cm/s	485.94	-0.11	18.09	-0.006
	AU	$6x10^{-3}$ cm/s	485.83	-0.01	10.82	None
	AL	$1x10^{-3}$ cm/s	485.82			

LEGEND

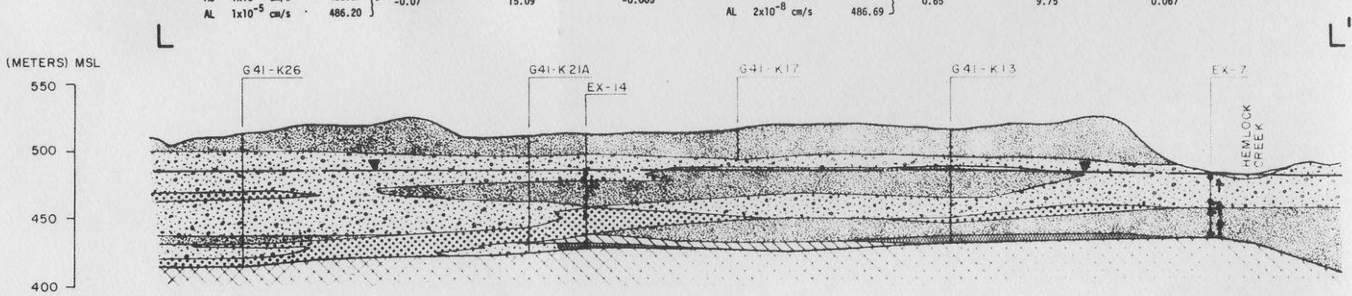




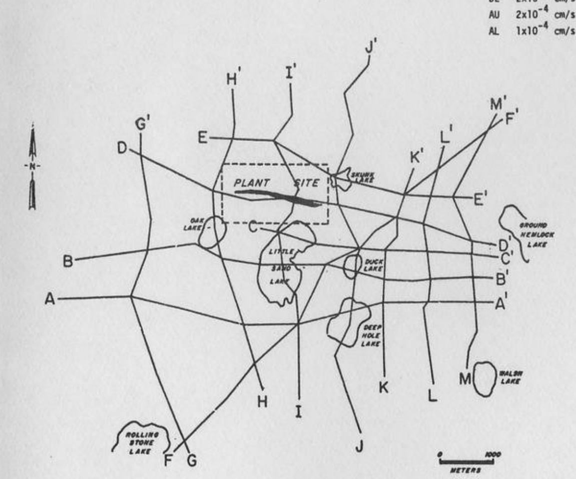
EX-13	DL		485.45	-0.02	10.48	None
	CL	$6x10^{-5}$ cm/s	485.43	-0.10	11.73	-0.009
	BU	$3x10^{-3}$ cm/s	485.33			
	BL	$8x10^{-4}$ cm/s	Water Level Not Stabilized			
	AL	$5x10^{-4}$ cm/s	485.22			
EX-10	BU		486.54	-0.43	17.16	-0.025
	BL	$2x10^{-5}$ cm/s	486.11	0.16	16.15	0.010
	AU	$1x10^{-3}$ cm/s	486.27	-0.07	15.09	-0.005
	AL	$1x10^{-5}$ cm/s	486.20			
EX-11	CL		485.83	-0.03	16.24	None
	BU	$1x10^{-4}$ cm/s	485.80	-0.04	9.75	-0.004
	BL	$6x10^{-3}$ cm/s	485.76	0.02	16.15	None
	AU	$1x10^{-3}$ cm/s	485.78	0.00	13.11	None
	AL	$2x10^{-3}$ cm/s	485.78			
EX-9	BU		486.14	-0.09	19.24	-0.005
	BL	$2x10^{-3}$ cm/s	486.05	-0.01	17.07	None
	AU	$6x10^{-3}$ cm/s	486.04	0.65	9.75	0.067
	AL	$2x10^{-8}$ cm/s	486.69			



EX-8	BU	$1x10^{-3}$ cm/s	481.61	-0.02	19.26	None
	BL	$2x10^{-3}$ cm/s	481.59	0.94	9.14	0.103
	AU	$2x10^{-4}$ cm/s	482.53	0.53	17.98	0.030
	AL	$1x10^{-4}$ cm/s	483.06			
EX-6	BU		483.33	0.26	17.36	0.015
	BL	$2x10^{-3}$ cm/s	483.59	-0.61	11.28	-0.054
	AU	$4x10^{-3}$ cm/s	482.98	0.00	17.07	None
	AL	$3x10^{-4}$ cm/s	482.98			



EX-14	BU		485.05	-0.05	16.55	-0.003
	BL	$5x10^{-5}$ cm/s	485.00	0.01	13.11	None
	AU	$2x10^{-3}$ cm/s	485.01	0.03	19.81	None
	AL	$7x10^{-5}$ cm/s	485.04			
EX-7	CL		481.18	0.42	19.52	0.022
	BU	$1x10^{-3}$ cm/s	481.60	0.47	11.58	0.041
	BL	$1x10^{-3}$ cm/s	482.07	0.25	14.63	0.017
	AL	$9x10^{-4}$ cm/s	482.32			



CROSS-SECTION INDEX

250 0 250 500 750 1000

HORIZONTAL SCALE IN METERS
VERTICAL EXAGGERATION: 5X

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE **HYDROGEOLOGIC CROSS SECTIONS I-I', J-J', K-K', L-L' & M-M'**

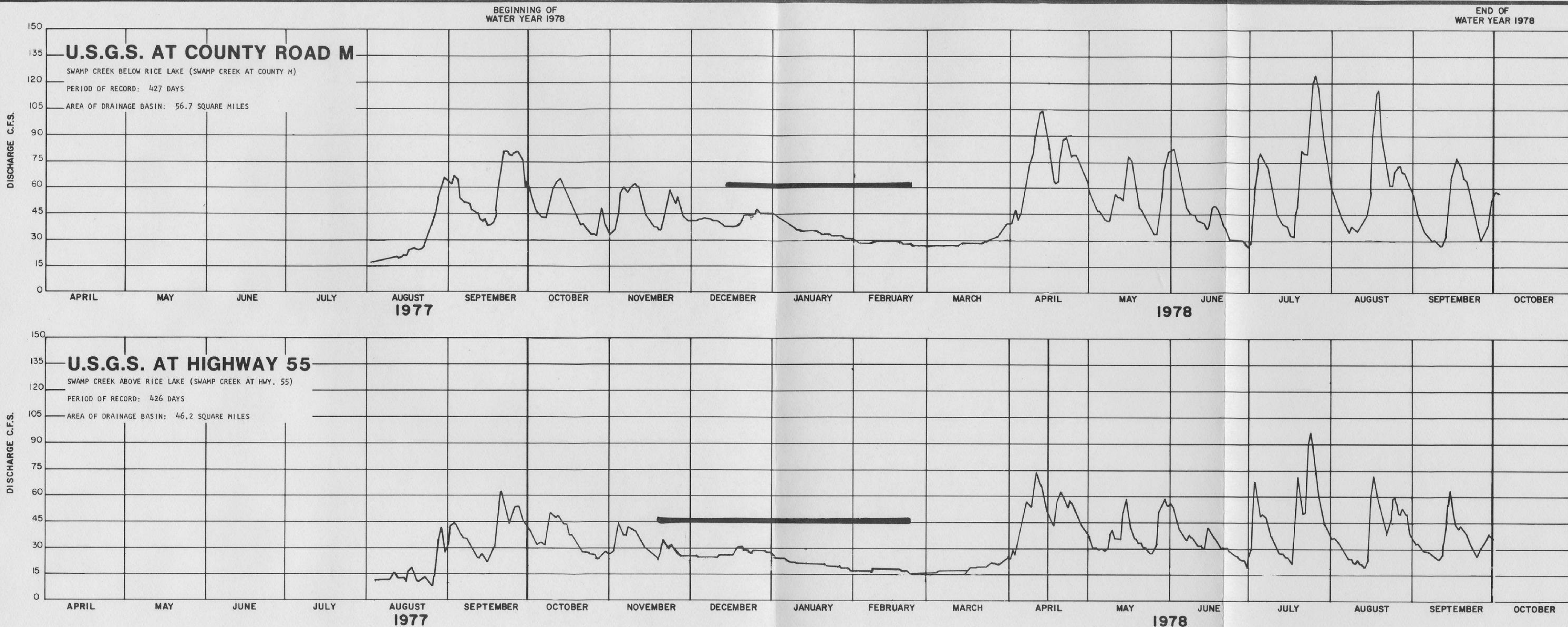
SCALE SHOWN	STATE WISCONSIN	COUNTY FOREST	
DRAWN BY STS	DATE 6/84	CHECKED BY	DATE
APPROVED BY	DATE	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE
DRAWING NO **FIGURE 2.3-7**		SHEET OF	REVISION NO 1

retard the downward percolation of water to the main ground water aquifer, resulting in local aquifer conditions. One such local aquifer condition is located in the vicinity of DMB-20, which is located 0.8 km (0.5 mile) northwest of Oak Lake (Figure 2.3-1). Localized sand and gravel lenses of higher permeability than the surrounding glacial drift also occur, but the results of the drilling programs to date show that these are not common nor extensive. As a result of the heterogeneity of the glacial drift, it is expected that the aquifer characteristics of the environmental study area will vary both spatially and with depth. These conditions are represented on the hydrogeologic cross sections (Figures 2.3-5 through 2.3-7) (STS Consultants Ltd., 1984a).

The ground water hydrographs showing the variations in water levels with time are presented in Appendix 2.3B. Ground water levels in most piezometers fluctuated approximately 1.2 m (4.0 feet) during the monitoring period from May 1977 to July 1984. These fluctuations are primarily from seasonal variations in precipitation and infiltration, particularly in the upland areas, which comprise the primary ground water recharge areas.

Limited precipitation data in the site area are available. However, a long-term precipitation record is available from Nicolet College in Rhinelander, Wisconsin. These data indicate that the maximum precipitation occurs from May through September. From May through September, rainfall is approximately 63 percent of the annual total precipitation.

The USGS stream gage at State Highway 55 above Rice Lake is the nearest sampling station to the site area with a long-term record of surface water flow rates. As indicated on Figure 2.3-8, the months with highest surface water flow rates are from April to October. This record closely



KEY:

TOTAL STREAM FLOW

PERIOD OF ICE COVER

EXXON MINERALS COMPANY
CRANDON PROJECT

STREAM DISCHARGE HYDROGRAPHS FOR U.S.G.S. GAGING STATIONS 1977—1978

DAMES & MOORE

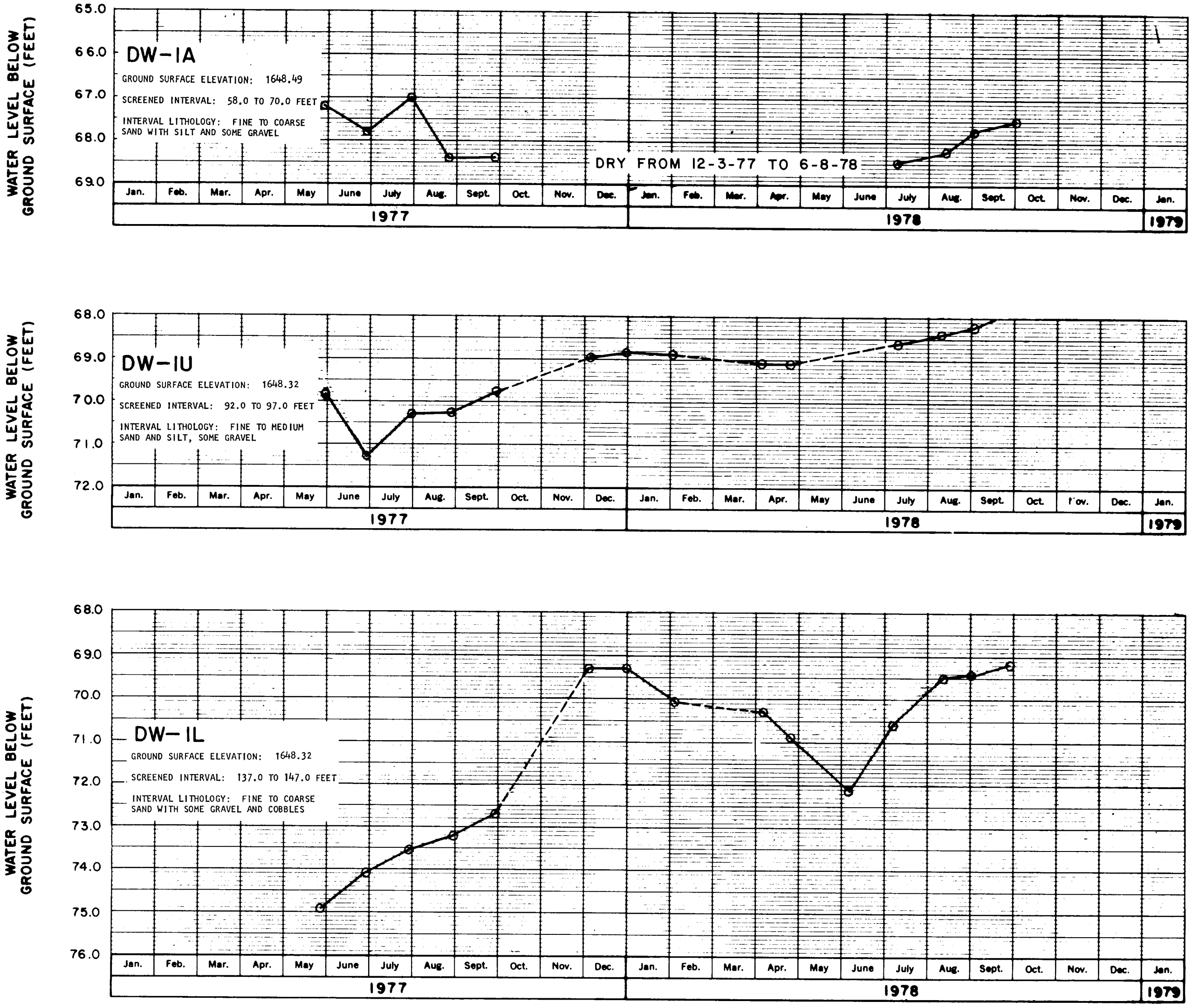
FIGURE 2.3–8

follows the average monthly precipitation totals (see Table 2.4-14). With the exception of April, the surface water flow rate data suggest a lag time of approximately 1 month between increased precipitation and higher flow rates. The increase in April surface water flow rates is a result of increased precipitation (i.e., 4.9 to 7.6 percent from March to April) and surface water drainage from melting snow.

Similarly, the piezometer hydrographs for boring locations DW-1A, DW-1U, and DW-1L (Figure 2.3-9) indicate an increase in ground water elevation in June, July, and August of 1978. An increase is also evident in 1977 for hydrograph DW-1L. The increase in the ground water elevation also appears to occur from 1 to 2 months later than the melting snow or precipitation percolation to the main ground water table. This pattern is more evident in hydrograph DW-1L than in DW-1A and DW-1U during 1977.

In comparison (see Appendix 2.3B, Figure B-5), ground water levels in piezometers located in low-lying areas within areas of ground water discharge from the main ground water aquifer (for example, DMA-13 and DMA-17) are not as seasonally affected as those piezometers located in recharge areas. Ground water levels in the discharge areas are strongly influenced by the relatively constant rates of ground water inflow through the main ground water aquifer.

Records of other piezometers, DMA-4, DMA-10, DMA-12, DMA-18, DMA-19, DMA-20, DMA-31, DMA-32A, and DMA-35, showed similar ground water levels over the same time period (Appendix 2.3B). Records of piezometers DMA-13 and DMA-17, which are in the main ground water aquifer discharge areas, showed less fluctuation. The ground water level fluctuation in these two piezometers was about 0.15 m (0.5 foot) between May 1977 and September 1978.



KEY:

⊙ GROUND WATER LEVEL MEASUREMENTS

--- INFERRED WHEN DATA MISSING

EXXON MINERALS COMPANY

CRANDON PROJECT

PIEZOMETER HYDROGRAPHS

DAMES & MOORE

FIGURE 2.3-9

Ground water level monitoring began in the summer of 1978 for those piezometers designated with a DMB prefix. Several of these piezometers (DMB-1A, DMB-4, DMB-8, DMB-18, DMB-20, and DMB-23) have periods of record that extended from May or June 1978 to September 1980. Continuous monitoring of the ground water levels in TW-1 was initiated again during December 1979 and continued to December 1980. The continuous monitoring record of TW-1 provided a reference to which the intermittent records of the other piezometers could be compared. Comparison of selected piezometer hydrographs (DMA-4, DMA-10, DMA-12, DMA-18, DMA-19, DMA-20, DMA-31, DMA-32A, and DMA-35) having a similar period of record to that of the first continuous monitoring period (October 1977 to October 1978) for TW-1 showed that the intermittent piezometer records accurately reflected the seasonal variation in ground water levels over the period of record. This also was true when a comparison was made among selected piezometer hydrographs (DMB-1A, DMB-4, DMB-8, DMB-18, DMB-20, and DMB-23) and the TW-1 hydrograph for the second continuous monitoring period (December 1979 to December 1980). Since there is good agreement between the intermittent piezometer records and the continuous monitoring record, the intermittent records were used to describe the general ground water level variation within the main ground water aquifer recharge area during the period when continuous records were not available for TW-1 (October 1978 to December 1979).

The contribution of the ground water to the stream flow (base flow) remained uniform throughout the period of record (May 1977 to December 1980). The total stream flow (i.e., ground water and surface water contributions) was influenced directly by precipitation (section 2.4, Surface Water). Piezometer records indicated that the seasonal variations in the potentiometric surface were affected by the amount of recharge available from precipitation. Therefore, the variation in the water available for storage is a seasonal phenomenon and is not a major influence on the stream base flow. The relative uniformity of the ground water levels within the site area indicates that the amount of ground water in storage at any given time is also uniform and, therefore, the change in ground water storage can be considered negligible.

2.3.3.4 Main Ground Water Aquifer Characteristics

The surficial materials comprising the drift in the site area consist mainly of glacial till and outwash deposits of variable thickness. These glacial deposits directly overlie the Precambrian rocks in which the Crandon massive sulfide deposit is found (Golder Associates, 1982). The glacial drift is composed primarily of sand with some gravel, silt, and clay (section 2.2, Geology). In general, the glacial till contains a larger silt and clay size fraction than does the glacial outwash (section 2.2, Geology). Fine-grained alluvial and lacustrine deposits also occur within the environmental study and site areas. These deposits generally occur at or near the surface, although they also are occasionally found within the glacial till and outwash deposits. As a consequence of the variability in the physical and textural characteristics of the glacial drift, it can be expected that hydraulic or aquifer characteristics will also be variable, both spatially and with depth.

2.3.3.5 Glacial Drift

To assess the permeability characteristics of the glacial drift, two pumping tests and a series of rising and falling head permeability tests were performed in the field. The results of the field permeability tests are summarized in Appendix 2.3E.

In addition to the field permeability tests, constant and falling head permeability tests also were conducted on selected samples to determine their permeability characteristics. The rationale for sample selection was to evaluate samples of different lithology, depth, and location. Physical limitations also were considered in the sample selection process. Only undisturbed samples are suitable for laboratory permeability testing. Because of the granular nature of most of the subsurface materials, relatively few undisturbed samples were available from which to choose. From the available suitable samples, tests were performed on those that appeared to be representative of the various soil types present at the site. Soil samples of similar types but from different depths and locations were also evaluated. This information was supplemented by estimating the hydraulic conductivity from grain size analyses using Hazen's approximation. Agreement between the two methods was generally good.

The permeability of some glacial drift samples was also estimated from the grain size distribution using the Hazen approximation (Hazen, 1911). The Hazen approximation provides a good estimate of the permeability of sand and gravel, or a combination of the two, such as is present within the environmental study area. The reliability of the method, however, decreases with the increase in the amount of fines (clay and silt) present. The results of the laboratory permeability tests and the Hazen permeability approximations are summarized in Appendix 2.3F.

The permeability of the glacial drift was variable, as indicated by both the field and laboratory test results (Appendices 2.3E and 2.3F). The permeabilities for the drift ranged over four to five orders of magnitude (10^{-2} to 10^{-7} cm/s), which is common for glacial drift. The permeability of the glacial drift varied both with differences in texture or grain size characteristics and with the method by which the permeability was determined or estimated. The ranges of permeabilities, as determined by the various methods in the field and the laboratory, are summarized below.

SUMMARY OF RANGE OF PERMEABILITIES
FOR GLACIAL DRIFT IN SITE AREA

Method of Determination	Permeability Range (cm/s)
Field	
Pumping Test	2.9×10^{-2} to 5.4×10^{-2}
Falling Head	1.1×10^{-6} to 5.8×10^{-3}
Rising Head	3.7×10^{-5} to 7.2×10^{-4}
Laboratory	
Constant Head	2.6×10^{-7} to 8.6×10^{-5}
Falling Head	6.8×10^{-4} to 4.1×10^{-3}
Hazen Approximation	9.0×10^{-6} to 9.0×10^{-2}
Constant Head	2.6×10^{-7} to 8.6×10^{-5}
Falling Head	6.8×10^{-4} to 4.1×10^{-3}
Hazen Approximation	9.0×10^{-6} to 9.0×10^{-2}

Falling and rising head permeability tests performed in the glacial drift in the spring of 1984 indicate that the range of permeabilities is from 1×10^{-2} to 9×10^{-4} cm/s for falling head tests and 1×10^{-3} to 8×10^{-4} cm/s for rising head tests (STS Consultants Ltd., 1984a).

Two pumping tests were conducted in the area north of Little Sand Lake. The locations of the test wells, which are designated as TW-1 and WW-2, are shown on Figure 2.3-1. The permeabilities, as calculated from the results, ranged from approximately 2.9×10^{-2} to 5.4×10^{-2} cm/s (6.1×10^{2} to 1.1×10^{3} gallons per day/square foot). Both of the pumping tests were conducted in outwash sand with some gravel. The storage coefficients calculated from the pumping tests ranged from 1.2×10^{-1} to 5.7×10^{-5}. The lower value (5.7×10^{-5}) was calculated for a deep zone within the drift and is indicative of confined or partially-confined conditions. The higher value (1.2×10^{-1}) is for a shallow zone within the drift and is indicative of water table conditions (Todd, 1959; Lohman et al., 1970). The existence of both water table and confined or partially confined conditions within the drift is a consequence of the stratification that exists within the profile and the variability of the permeability in the various strata.

A 24-day pumping test was performed by Golder Associates (1981b) during the summer of 1980. The test well, which was pumped at a constant rate of approximately 90 l/s (1,420 gallons/minute) is located approximately 1.6 km (1 mile) east of Little Sand Lake and midway between piezometers DMB-1 and DMB-2 (Figure 2.3-1). The response to pumping was monitored in 13 primary observation wells located within 457 m (1,500 feet) of the pumped wells and in 16 secondary observation wells located within 3,200 m (10,500 feet) from the pumped well. Permeability values were calculated or estimated from the results of the pumping test and ground water flow velocity data in the pumped well. These results, as presented by Golder Associates (1981b), are summarized below.

SUMMARY OF AQUIFER CHARACTERISTICS
(Golder Associates, 1981b)

SURFICIAL MATERIAL	PERMEABILITY HORIZONTAL (cm/s)	PERMEABILITY VERTICAL* (cm/s)	SPECIFIC STORAGE (cm^{-1})	SPECIFIC YIELD (%)
Glacial Till	9.4×10^{-5}	3.0×10^{-5}	1.5×10^{-7}	5.4
Stratified Drift (outwash)	1.3×10^{-2}	1.3×10^{-3}	1.5×10^{-7}	7.0

*The vertical permeabilities for the glacial till and the stratified drift (outwash) were estimated on the basis of the calculated vertical leakage factor during the pumping test and an assumed contrast of one order of magnitude between the vertical and horizontal permeabilities, respectively. A difference of one to several orders of magnitude between the vertical and horizontal permeabilities in stratified materials is consistent with general experience (Freeze and Cherry, 1979).

Measurements taken in the EX and WP series piezometers in the spring of 1984 indicate the presence of some vertical gradients within the glacial overburden (STS Consultants Ltd., 1984a). In general, the vertical gradients measured were small, both upward and downward (Table 2.3-8; Figures 2.3-5 through 2.3-7). The predominant ground water flow across the site is horizontal. The area northeast of Little Sand Lake is a major recharge area, based upon the measurement of downward vertical gradients in the till overlying the main glacial aquifer. No large upward vertical gradients were measured in the coarse and fine grained stratified drift underlying the till, indicating a predominantly horizontal flow. Upward gradients were measured in the till underlying the main glacial aquifer at EX-1, -4, -9, and -15, indicating recharge to the main glacial aquifer and substantiating the horizontal flow in it. It is likely that seasonal fluctuations in the ground water system will cause variations and possibly reversals of some of the smaller gradients presented in Table 2.3-8.

TABLE 2.3-8

SUMMARY OF VERTICAL GROUND WATER GRADIENTS
AT EX PIEZOMETERS AND WELL POINTS
(5/24/84)

EX PIEZOMETER	HEAD DIFFERENCE (m)	AVERAGE LENGTH BETWEEN GRAVEL PACKS (m)	MINIMUM LENGTH BETWEEN GRAVEL PACKS (m)	AVERAGE GRADIENT	MAXIMUM GRADIENT
1AL - 1AU	0.05	7.24	4.88	0.007	0.010
1AU - 1BL	0.00	18.59	16.46	none	none
1BL - 1BU	-0.16	8.96	5.49	-0.018	-0.029
2AL - 2AU	-0.19	24.99	22.85	-0.008	-0.008
2AU - 2BL	-0.17	10.92	9.45	-0.016	-0.018
3AL - 3AU	-0.05	10.36	8.23	-0.005	-0.006
3AU - 3BL	0.00	12.19	10.06	none	none
3BL - 3BU	0.01	9.14	7.01	none	none
3BU - 3CL	0.25	10.08	7.93	0.025	0.032
4AL - 4AU	0.13	7.01	4.72	0.019	0.027
4AU - 4BL	-0.12	8.84	6.86	-0.014	-0.018
4BL - 4BU	-0.06	7.77	5.64	-0.008	-0.011
4BU - 4CL	-0.44	5.21	1.83	-0.085	-0.240
5AL - 5AU	NS	-	-	-	-
5AU - 5BL	NS	-	-	-	-
5BL - 5CL	-0.53	12.53	9.14	-0.042	-0.058
6AL - 6AU	0.00	17.07	14.94	none	none
6AU - 6BL	-0.61	11.28	9.14	-0.054	-0.067
6BL - 6BU	0.26	17.36	14.63	0.015	0.018
7AL - 7BL	0.25	14.63	12.50	0.017	0.020
7BL - 7BU	0.47	11.58	9.60	0.041	0.049
7BU - 7CL	0.42	19.52	16.76	0.022	0.025
8AL - 8AU	0.53	17.98	15.85	0.030	0.033
8AU - 8BL	0.94	9.14	7.01	0.103	0.134
8BL - 8BU	-0.02	19.26	17.06	none	none
9AL - 9AU	0.65	9.75	7.62	0.067	0.085
9AU - 9BL	-0.01	17.07	14.93	none	none
9BL - 9BU	-0.09	19.24	14.63	-0.005	-0.006

Notes: 1) Positive value indicates upward gradient; negative value indicates downward gradient.
2) No significant gradient if head difference is $\leq$0.03 m.
3) NS = not stabilized.

EX PIEZOMETER	HEAD DIFFERENCE (m)	AVERAGE LENGTH BETWEEN GRAVEL PACKS (m)	MINIMUM LENGTH BETWEEN GRAVEL PACKS (m)	AVERAGE GRADIENT	MAXIMUM GRADIENT
10AL - 10AU	-0.07	15.09	12.80	-0.005	-0.006
10AU - 10BL	0.16	16.15	13.72	0.010	0.012
10BL - 10BU	-0.43	17.16	14.17	-0.025	-0.030
11AL - 11AU	0.00	13.11	10.36	none	none
11AU - 11BL	0.02	16.15	14.02	none	none
11BL - 11BU	-0.04	9.75	7.62	-0.004	-0.005
11BU - 11CL	-0.03	16.24	7.01	none	none
12AL - 12AU	-0.03	18.44	15.85	none	none
12AU - 12BL	0.07	15.09	12.50	0.005	0.006
12BL - 12BU	-0.11	22.42	16.76	-0.005	-0.007
13AL - 13BL	NS	-	-	-	-
13BL - 13BU	NS	-	-	-	-
13BU - 13CL	-0.10	11.74	8.23	-0.009	-0.012
13CL - 13DL	-0.02	10.48	7.93	none	none
14AL - 14AU	0.03	19.81	17.68	none	none
14AU - 14BL	0.01	13.11	10.97	none	none
14BL - 14BU	-0.05	16.55	11.58	-0.003	-0.004
15AL - 15AU	-0.24	31.32	28.80	-0.008	-0.008
15AU - 15BL	-0.02	22.64	19.20	none	none
16AL - 16AU	0.01	10.82	8.53	none	none
16AU - 16BL	-0.11	18.09	9.14	-0.006	-0.012
WP1L - WP1U	-0.23	-	7.31	-	-0.032
WP2L - WP2U	-0.20	-	7.19	-	-0.028
WP3L - WP3U	0.00	-	5.79	-	none
WP4L - WP4U	0.19	-	5.73	-	0.033
WP5L - WP5U	WP5L is flowing	-	-	-	-
WP6L - WP6U	-1.14	-	7.16	-	-0.159
WP7L - WP7U	0.06	-	7.31	-	0.008

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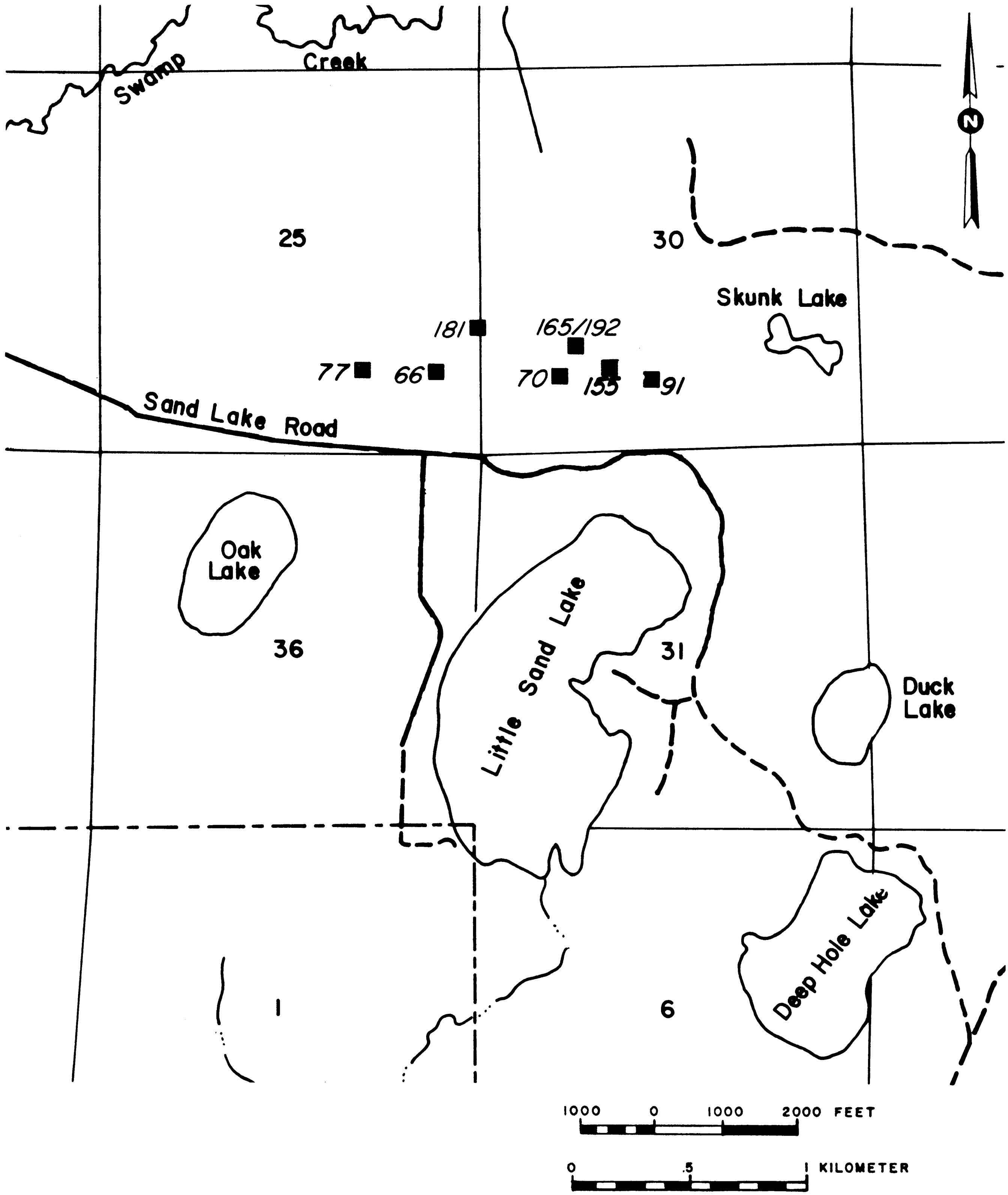
2.3.3.6 Bedrock

Ground water occurrence within the Precambrian bedrock is associated primarily with fractures and weathered zones near the subcrop of the bedrock. In general, these fractures and weathered zones diminish rapidly with depth. Because of the variability in degree of fracturing and weathering, it can be anticipated that the permeability of the bedrock will also vary spatially. A detailed discussion of bedrock weathering and bedrock permeability testing is presented in subsection 2.2.3.2 and in the report entitled "Bedrock Permeability" by Exxon Minerals Company (1984). As an example of bedrock permeability testing, a series of injection tests was conducted in deep exploration boreholes in zones isolated by packers. The locations of these test holes are shown on Figure 2.3-10. The permeability of selected zones in the bedrock as determined by these tests in selected zones ranged from 1×10^{-5} to 1×10^{-7} cm/s (0.2 to 0.002 gallons per day/square foot). The results of the tests are summarized in Table 2.3-9.

The potentiometric surface levels in the ore body exploration boreholes appear to be similar to those in the overlying glacial drift, suggesting the existence of hydraulic connection. The absence of large vertical gradients precludes major ground water movement from the overburden materials into the bedrock or vice versa. The potentiometric surface data suggest that there is no major vertical ground water movement within the environmental study area. Further documentation of these gradients is shown on Figures 2.3-5 through 2.3-7 and in the STS Consultants Ltd. (1984) report, "Hydrogeologic Study Update for the Crandon Project" and is discussed in the Exxon Minerals Company (1984) report, "Bedrock Permeability."



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LOCATIONS OF
DEEP BEDROCK BORINGS

DAMES & MOORE

FIGURE 2.3-10

TABLE 2.3-9

SUMMARY OF BEDROCK PERMEABILITIES[a]

EXXON HOLE NUMBER	INTERVAL TESTED[b] (feet)	PERMEABILITY (cm/s)
165	1600 - 2971	1.4×10^{-6}
	2920 - 2971	1.2×10^{-7}
	2297 - 2971	5.8×10^{-7}
155	161 - 3050	5.8×10^{-7}
	2710 - 2723	6.0×10^{-5}[c]
	2712 - 2725	6.3×10^{-5}[c]
	2202 - 2215	3.8×10^{-5}
	2102 - 3050	7.9×10^{-7}
	1372 - 3050	5.4×10^{-7}
	1042 - 3050	4.8×10^{-7}
	942 - 3050	3.9×10^{-7}
	842 - 3050	4.7×10^{-7}
	562 - 3050	4.3×10^{-7}
	362 - 3050	4.9×10^{-7}
77	602 - 1049	5.7×10^{-6}
66	228 - 1078	1.8×10^{-5}
	402 - 1078	9.0×10^{-6}
70	552 - 1334	8.6×10^{-6}
	302 - 1334	1.2×10^{-5}
91	179 - 1415	1.3×10^{-5}
	852 - 1415	1.9×10^{-5}

[a]Rock permeabilities determined using recovery tests.

[b]Some boreholes tested were not vertical; therefore, the interval tested may not correspond to the depth below ground surface.

[c]Some leakage around packers on these tests may have occurred because of open fractures.

Within the ore body, it is theoretically possible that some small amount of thermal and/or chemical mixing of the water could occur. However, based on the existing data, these exchanges are probably very slow (on the order of 1 m/century [Freeze and Cherry, 1979]), and any effects on the main ground water aquifer in the glacial material should not be measurable. As discussed in subsection 2.3.4, the ground water quality at depths within the bedrock is different from that within the upper portion of the bedrock. Therefore, the extent of possible mixing of ground water within the ore body and the main ground water aquifer is very minor.

2.3.3.7 Ground Water Use

The principal uses of ground water in Forest, Langlade, and Oneida counties are for municipal and private domestic water supplies. Generally, the region is sparsely populated. Industries in the three-county area presently require relatively small volumes of ground water, which in many cases are obtained from the nearest municipal system. Where municipal water supplies are not available, industrial users rely on ground water.

An inventory of water wells in the environmental study area indicates that of the 165 existing wells, 156 are used for domestic purposes and 9 for water supplies to various public buildings (Appendix 2.3G). Ground water is also withdrawn in the vicinity of Mole Lake for irrigation of a potato farm. The water well inventory is based on information provided by the Wisconsin DNR, USGS, and the local residents. Some wells within the environmental study area have not been included in the inventory because the pertinent information was not available from the Wisconsin DNR or the USGS, and/or the well owner was not available during the field survey. The

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LOCATIONS OF WATER WELLS IN THE ENVIRONMENTAL STUDY AREA

DAMES & MOORE

FIG. 2.3-11

2.3.4.1 Glacial Drift

The results of the ground water chemistry analyses for those piezometers and wells completed in the glacial drift are presented in Appendix 2.3C and a summary of these data is provided in Table 2.3-10. Also listed for comparison in Table 2.3-10 are the National Interim Primary Drinking Water Regulations (NIPDWR), the Proposed Secondary Drinking Water Standards (PSDWS), and the U.S. Environmental Protection Agency Quality Criteria for Domestic Water Supplies. A summary of ground water quality data for wells monitored by the USGS in the environmental study area is presented in Table 2.3-11. These wells were all completed in the glacial drift.

Ground water within the environmental study area is, in general, of good quality. Occasional reported values for cadmium, lead, nitrate, iron, and manganese exceeded the applicable drinking water and domestic water supply standards and criteria. A value of 0.015 mg/l for cadmium was reported for piezometer DMA-17 on July 5, 1977. All other reported values for cadmium were below the NIPDWR and U.S. EPA Water Quality criterion of 0.010 mg/l for domestic water supplies. A comparison of the single reported cadmium value with the reported values for all other samples from the same piezometer and the other piezometers indicates that cadmium, when present in ground water, is at concentrations close to the detection limit and the values obtained are within the expected error range of the analytical procedures.

Lead was reported from DMA-19 on September 29, 1981 in a concentration of 0.10 mg/l. Relative to lead values reported from DMA-19 at other times and to values reported from other piezometers, this value was unusually high. All other lead values were below the NIPDWR and U.S. EPA Water Quality criterion of 0.05 mg/l for domestic water supplies.

TABLE 2.3-10

SUMMARY OF GROUND WATER QUALITY FOR PRINCIPAL AQUIFERS IN THE ENVIRONMENTAL STUDY AREA

PARAMETER	UNITS	RANGE	MEAN (X̄)	STANDARD DEVIATION (S)	NUMBER OF SAMPLES	NIPDWR[a]	PSDWS[b]	EPA QUALITY CRITERIA FOR DOMESTIC WATER SUPPLIES[c]
Field temperature	°C	3.0 - 12.0	7.1	1.8[d]	220	-	-	-
Total laboratory alkalinity	mg/l[e]	14 - 453	123	50	234	-	-	-
Total field alkalinity	mg/l[e]	11 - 487	127	53	221	-	-	-
Specific conductance	µmhos/cm[f]	50 - 1,300	237	107	235	-	-	-
Field conductivity	µmhos/cm[f]	29 - 1,150	178	92	218	-	-	-
Laboratory pH	standard units	6.09 - 11.02	7.6	0.69	204	-	6.5-8.5	5-9
Field pH	standard units	5.5 - 12.2	7.7	1.0	222	-	6.5-8.5	5-9
Total hardness	mg/l[e]	16 - 452	125	53	236	-	-	-
Total dissolved solids	mg/l	14 - 836	166	84	235	-	500	250 $Cl+SO_4$
Chemical oxygen demand	mg/l	<1 - 365	<29	<56	143	-	-	-
Total phosphorus (P)	mg/l	<0.01 - 0.84	<0.06	<0.10	135	-	-	-
Anions								
Arsenic	mg/l	<0.001 - 0.004	<0.001	<0.001	236	0.05	-	0.05
Chloride	mg/l	<1 - 78	<4	<10	236	-	250	-
Cyanide, total	mg/l	<0.001 - 0.004	<0.001	<0.001	236	-	-	-
Fluoride	mg/l	<0.12 - 0.57	<0.20	<0.09	142	1.4-2.4[g]	-	-
Nitrate nitrogen (N)	mg/l	<0.01 - 11.0	<0.37	<1.04	235	10	-	-
Phosphate (PO_4)	mg/l	<0.01 - 0.31	<0.06	<0.06	101	-	-	-
Sulfate	mg/l	<1 - 86	<9	<9	232	-	250	-
Cations								
Aluminum	mg/l	<0.01 - 9.09	<0.53	<1.12	169	-	-	-
Barium	mg/l	<0.01 - 0.24	<0.02	<0.03	142	1	-	1
Cadmium	mg/l	<0.001 - 0.015	<0.002	<0.002	169	0.01	-	0.01
Calcium	mg/l	4.9 - 92.4	29.8	12.6	94	-	-	-
Chromium, total	mg/l	<0.001 - 0.021	<0.002	<0.003	169	0.05	-	0.05
Cobalt	mg/l	<0.01	<0.01	0	169	-	-	-
Copper	mg/l	<0.001 - 0.09	<0.007	<0.011	232	-	1	1.0
Iron	mg/l	<0.01 - 38.9	<1.74	<4.34	236	-	0.3	0.3
Lead	mg/l	<0.01 - 0.10	<0.01	<0.01	235	0.05	-	0.05
Magnesium	mg/l	0.279 - 29.6	12.00	5.12	169	-	-	-
Manganese	mg/l	<0.001 - 10.2	<0.423	<0.989	236	-	0.05	0.05
Mercury	mg/l	<0.0001 - 0.0010	<0.0001	<0.0001	169	0.002	-	0.002
Molybdenum	mg/l	<0.01 - 0.03	<0.01	<0.01	169	-	-	-
Nickel	mg/l	<0.01 - 0.04	<0.01	<0.01	169	-	-	-
Selenium	mg/l	<0.001 - 0.001	<0.001	0	142	0.01	-	0.01
Silver	mg/l	<0.001	<0.001	0	142	0.05	-	0.05
Zinc	mg/l	<0.001 - 2.60	<0.052	<0.214	235	-	5	5

Note: Dates of analyses presented in Table 2.3-11.

[a]National Interim Primary Drinking Water Regulations (U.S. EPA, 1976).

[b]Proposed Secondary Drinking Water Standards, 1979 (General Services Administration, 1979).

[c]U.S. EPA, 1979.

[d]Reflects seasonal temperature variation.

[e]All alkalinity and hardness values listed in text are as $CaCO_3$, although the "as $CaCO_3$" has been eliminated to make the text more readable.

[f]Varies with temperature (U.S. EPA, 1976).

[g]Geometric mean of $-\log[H^+]$.

TABLE 2.3-11

SUMMARY OF USGS GROUND WATER QUALITY DATA[a]
FOR WELLS IN THE ENVIRONMENTAL STUDY AREA

WATER WELL NUMBER[b]	LOCATION[c]	USGS WELL NUMBER	DATE OF ANALYSES	TOTAL LABORATORY ALKALINITY (mg/l $CaCO_3$)	CALCIUM (mg/l)	TOTAL HARDNESS (mg/l $CaCO_3$)	LABORATORY pH
80	35-12-23	36	7/23/77	120	38	137	8.3
80	35-12-23	96	7/23/77	120	34	137	8.3
77	35-12-26	98	7/19/77	94	51	214	7.9
75	35-12-27	99	7/18/77	128	24	111	7.0
72	35-12-27	105	5/04/65	137	31	111	6.8
70	35-12-27	107	7/21/77	128	24	94	8.1
60	35-12-27	115	7/20/77	86	17	77	7.1
56	35-12-27	117	7/20/77	77	27	128	6.5
-	35-12-28	120	7/19/77	128	34	128	8.1
59	35-12-27	122	7/21/77	94	38	171	7.7
63	35-12-27	124	7/19/77	103	21	94	7.9
-	35-12-28	126	7/20/77	103	45	180	7.7
-	35-12-28	129	7/21/77	94	24	111	7.2
148	35-12-28	132	7/22/77	110	28	110	-
9	35-12-34	133	10/21/77	111	27	120	8.1
92	35-12-26	135	7/26/77	146	41	154	7.5
-	35-12-26	137	7/25/77	51	10	60	-
93	35-12-34	139	7/28/77	137	31	128	8.0
-	35-12-33	140	7/25/77	120	41	163	6.8
98	35-12-25	142	7/25/77	137	41	154	7.3
101	35-12-36	143	7/25/77	128	34	137	6.5
120	35-12-36	146	7/26/77	128	41	154	6.8
136	35-13-31	149	7/25/77	146	38	146	7.3
-	35-12-23	157	7/27/77	154	41	171	7.4
-	35-12-27	176	7/20/77	128	27	120	6.5
53	35-12-22	180	10/18/77	98	25	110	-
-	35-12-28	181	10/18/77	12	30	110	-
86	35-12-27	183	10/19/77	25	6.3	26	-
96	35-12-35	185	10/18/77	57	14	63	-
91	35-12-26	187	10/19/77	79	22	96	-
-	35-12-33	188	10/19/77	75	19	89	-
-	35-12-21	191	10/18/77	150	34	160	-
102	35-12-36	201	10/19/77	80	22	85	-

[a]USGS, unpublished.

[b]Locations of water wells are shown on Figure 2.3-13.

[c]Township, range, section.

Nitrate in ground water samples typically occurred in concentrations of <1.0 mg/l, well below the 10 mg/l criterion as promulgated in the NIPDWR. However, this criterion was exceeded on April 19, 1979 at DMB-20 and on November 14, 1979 at WW-2 when nitrate was reported in concentrations of 10.98 mg/l and 11.0 mg/l, respectively.

Both iron and manganese concentrations were above the PSDWS and EPA domestic water supplies standards and criteria on several occasions (Table 2.3-10). Iron and manganese values at these concentrations in ground waters, however, are not uncommon, particularly where the waters are in contact with clastic material or rock strata of igneous origin (Hem, 1959). A solution of iron and manganese oxide and hydroxides and, in the case of iron, its sulfides are a probable source of the iron and manganese concentrations in ground water (Hem, 1959). Ferro-magnesium minerals such as biotite and hornblende were found in borehole samples.

Examination of the ground water quality data in combination with the main ground water aquifer potentiometric data (Figure 2.3-3) indicates that major differences exist within the environmental study area and that those differences are primarily associated with the location within the ground water recharge-discharge regime. For example, the water chemistry in piezometer DMB-20 is different from that reported for most other wells and piezometers completed in the glacial drift (Appendix 2.3C, Table C-16). DMB-20 is completed in a local aquifer above the main ground water table, as shown on Figure 2.3-3. The measured water levels in DMB-20 ranged from 7.6 to 9.1 m (25 to 30 feet) above the elevation of the main ground water table shown on Figure 2.3-3. The ground water samples from the local aquifer at DMB-20 had lower average alkalinity (31 mg/l), hardness (26 mg/l), pH (6.77), and calcium (7.3 mg/l) values than those reported for piezometers and wells completed in the main ground water aquifer. For example, TW-1, completed in the main ground water aquifer, had alkalinity, hardness, pH, and calcium values of 111 mg/l, 119 mg/l, 8.04, and 21.6 mg/l, respectively (Appendix 2.3C, Table C-29).

The ground water chemistry data of the main ground water aquifer support the interpretation of the ground water recharge-discharge regime presented previously in subsection 2.3.3. The mean laboratory alkalinity, calcium, and hardness concentrations for ground water within the main ground water aquifer are shown on Figures 2.3-12, 2.3-13, and 2.3-14, respectively. The concentrations of these water quality parameters, as determined from the established ground water monitoring piezometers, change spatially from the primary main ground water aquifer recharge area in the central portion of the environmental study area to the principal main ground water aquifer discharge areas located within the lower surface elevations (valley bottoms) along the major surface water drainages. The mean laboratory alkalinity, calcium, and hardness values are highest in the main ground water aquifer recharge areas; for example in the vicinity of Deep Hole, Little Sand, and Duck lakes; and lowest in the main ground water aquifer discharge areas; for example in the vicinity of Ground Hemlock, Mole, and Rolling Stone lakes (Figures 2.3-12, 2.3-13, and 2.3-14).

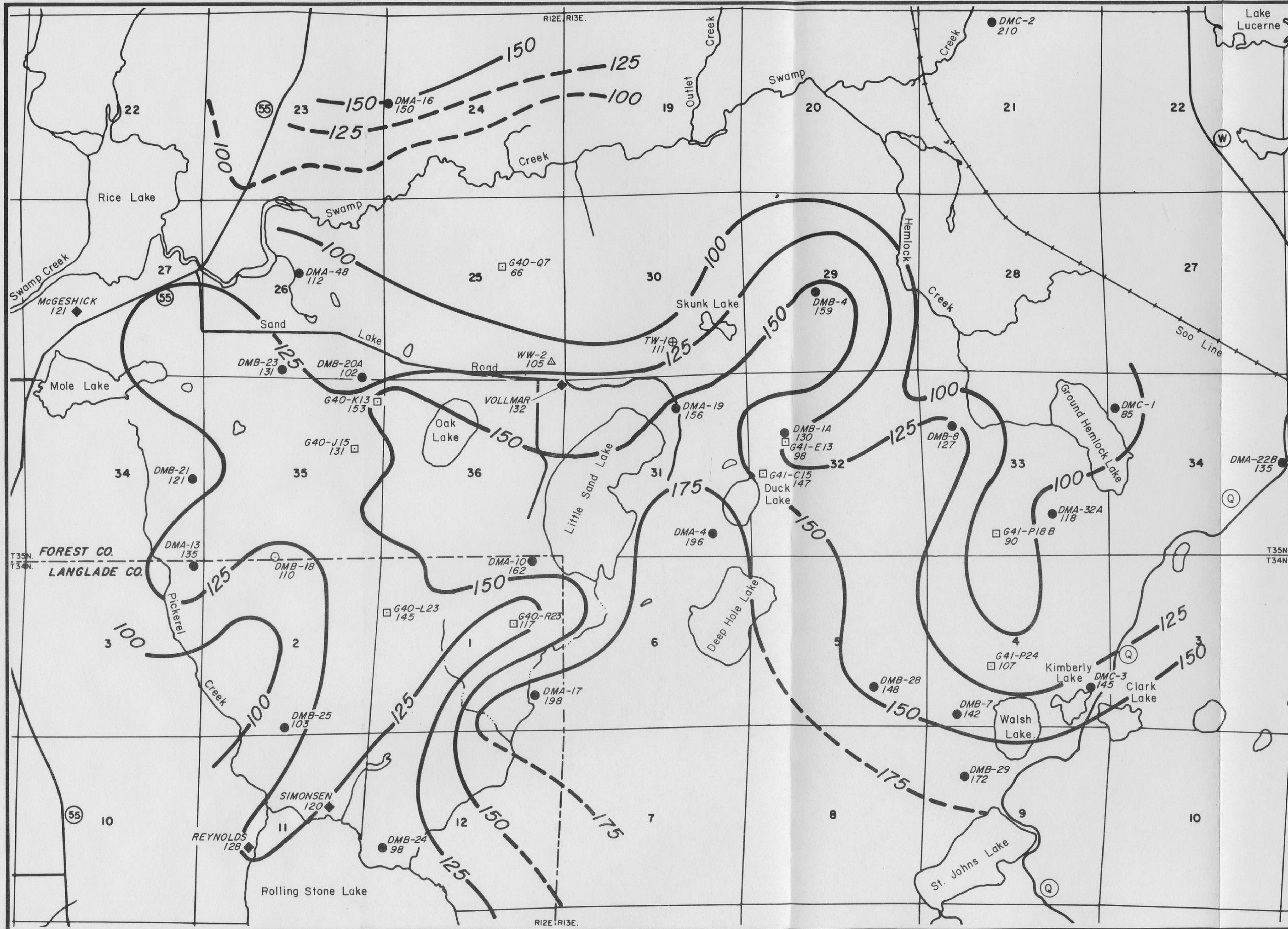
The water chemistry of the lakes and streams within the main ground water aquifer discharge areas is similar to and reflects the chemistry of that aquifer. For example, both the mean alkalinity and hardness of the aquifer in the vicinity of Ground Hemlock Lake was 100 mg/l (Figures 2.3-12 and 2.3-14), while the mean concentration of alkalinity and hardness measured in samples collected from Ground Hemlock Lake were 110 and 112 mg/l, respectively (Table 2.3-12).

Conversely, the lakes located in the main ground water aquifer recharge area, such as Deep Hole and Duck lakes, are situated aboved this aquifer (Figure 2.3-3). These lakes have much lower measured alkalinity and hardness than the lakes and streams in the main ground water aquifer discharge areas (Table 2.3-5).

The ground water-surface water relationships within the environmental study area are shown on Figure 2.3-15. Figure 2.3-15 shows the distribution of wetlands within the environmental study area and indicates those lakes that were identified as being within ground water recharge and discharge areas.

2.3.4.2 Bedrock

Results of selected water quality analyses for ground water samples obtained from deep exploration boreholes in bedrock are summarized in Table 2.3-13. The results for the bedrock water quality analyses are presented in Appendix 2.3D. The location of the deep boreholes that were tested is shown on Figures 2.3-16 and 2.3-17. The results of these analyses indicate different ground water qualities within the bedrock. Two "types" of bedrock ground water quality can be differentiated by comparing alkalinity, hardness, pH, and total dissolved solids values. These types generally can be differentiated by depth, although the exploration boreholes were not all vertical. Therefore, the interval sampled does not necessarily correspond to the depth below ground surface.



KEY:

125 APPROXIMATE LOCATION OF ISOPLETH (ISOPLETH INTERVAL = 25 mg/ℓ $CaCO_3$, DASHED WHERE INFERRED)

STREAM

55 BLACKTOP ROAD

127 MEAN LABORATORY ALKALINITY VALUES

BASE MAP REFERENCE:

PORTIONS OF THE FOLLOWING U.S.G.S. 7.5 MINUTE SERIES TOPOGRAPHIC QUADRANGLES:

CRANDON, WISCONSIN, 1965 — MOLE LAKE, WISCONSIN, 1973

LAKE LUCERNE, WISCONSIN, 1965 — ROBERTS LAKE, WISCONSIN, 1973

0 .5 1 MILE

1000 0 1000 3000 5000 FEET

0 .5 1 KILOMETER

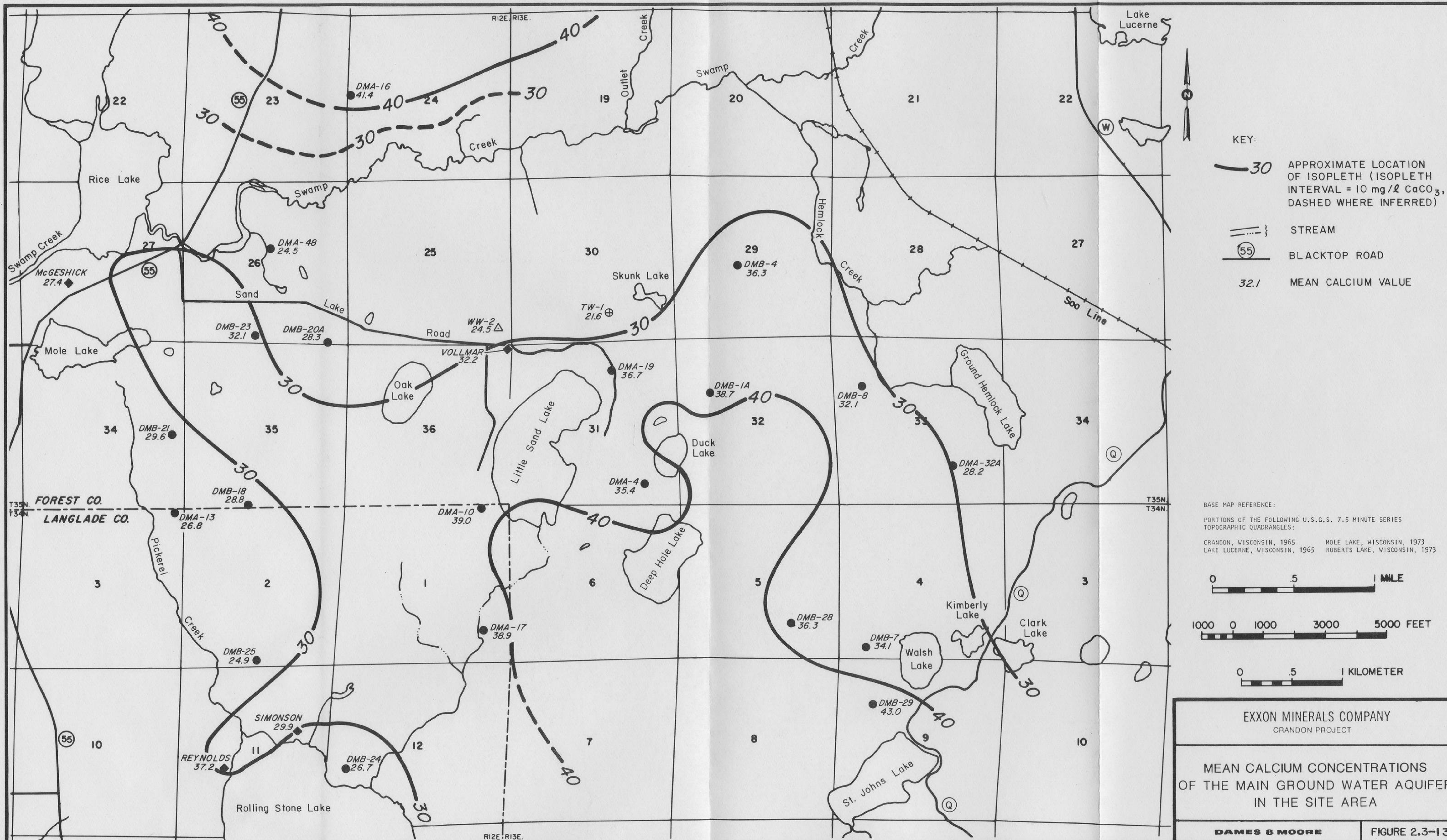
EXXON MINERALS COMPANY

CRANDON PROJECT

MEAN LABORATORY ALKALINITY OF THE MAIN GROUND WATER AQUIFER IN THE SITE AREA

DAMES & MOORE

FIGURE 2.3-12

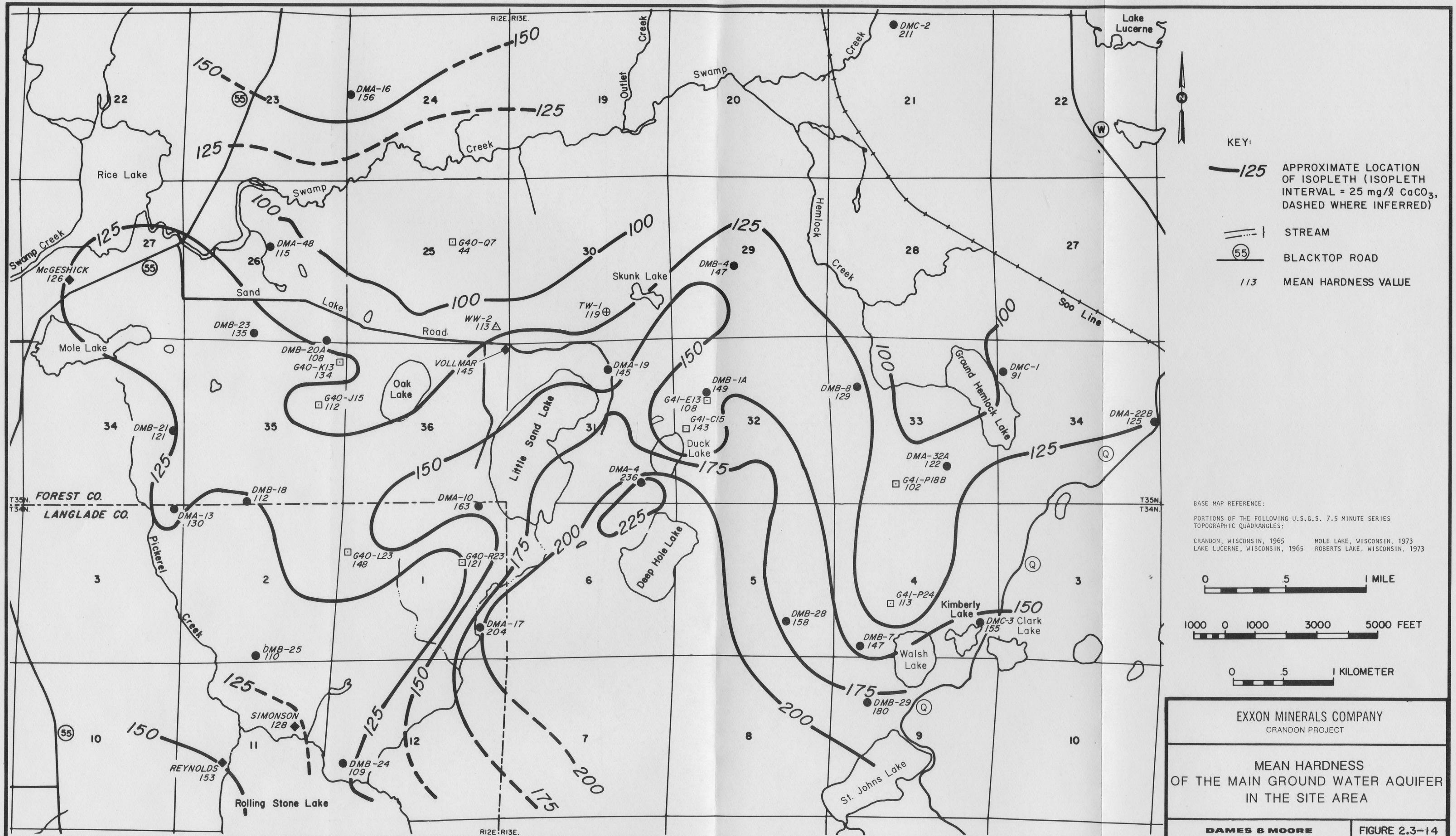


EXXON MINERALS COMPANY
CRANDON PROJECT

MEAN CALCIUM CONCENTRATIONS OF THE MAIN GROUND WATER AQUIFER IN THE SITE AREA

DAMES & MOORE

FIGURE 2.3-13



EXXON MINERALS COMPANY
CRANDON PROJECT

MEAN HARDNESS OF THE MAIN GROUND WATER AQUIFER IN THE SITE AREA

DAMES & MOORE

FIGURE 2.3-14

SUMMARY OF SURFACE WATER QUALITY DATA USED TO CHEMICALLY IDENTIFY GROUND WATER DISCHARGE AREAS IN THE ENVIRONMENTAL STUDY AREA

WATER BODY	SAMPLING STATION[a]	MEAN OF 1977-1978 VALUES (MEAN OF 1979-1980 VALUES) TOTAL LABORATORY ALKALINITY ($mg/l\ CaCO_3$)		TOTAL HARDNESS ($mg/l\ CaCO_3$)		FIELD pH		HARDNESS CLASSIFICATION[b,c]	pH CLASSIFICATION[c,d]	DNR HARDNESS CLASSIFICATION[e]	DNR pH CLASSIFICATION[e]
Hemlock Creek	A-1	101	(108)	107	(113)	7.4	(7.4)	moderately hard	neutral	hard	slightly basic
Hemlock Creek	A-2	105	-	115	-	7.2	-	moderately hard	neutral	hard	slightly basic
Metonga Creek	C	88	-	93	-	7.6	-	moderately hard	neutral	hard	slightly basic
Swamp Creek	B	103	-	110	-	7.4	-	moderately hard	neutral	medium hard	slightly basic
Swamp Creek	D	95	(96)	101	(97)	7.3	(7.4)	moderately hard	neutral	hard	slightly basic
Swamp Creek	E	94	(94)	99	(95)	7.3	(7.4)	moderately hard	neutral	hard	slightly basic
Swamp Creek	F[f]	98	-	108	-	7.1	-	moderately hard	neutral	hard	slightly basic
Swamp Creek	Q	88	-	110	-	7.4	-	moderately hard	neutral	hard	slightly basic
Swamp Creek	S	95	-	107	-	6.9	-	moderately hard	neutral	hard	slightly basic
Swamp Creek	V	81	-	95	-	6.8	-	moderately hard	neutral	medium hard	slightly basic
Creek 12-9	M-1	100	(94)	108	(94)	7.4	(7.6)	moderately hard	neutral	-	neutral
Creek 11-4	M-3	84	(96)	93	(102)	6.9	(7.3)	moderately hard	neutral	-	neutral
Upper Pickerel Creek	M-5	73	(80)	83	(82)	6.9	(7.2)	moderately hard	neutral	medium hard	slightly basic
Wolf River	Y	52	-	60	-	6.9	-	soft	neutral	medium hard	neutral
Wolf River	Z	63	-	73	-	7.0	-	soft	neutral	medium hard	neutral
Deep Hole Lake	L	<5	(5)	16	(15)	6.0	(6.2)	soft	neutral	very soft	acid
Duck Lake	K	<3	(19)	15	(33)	5.0	(6.1)	soft	slightly acidic	very soft	acid
Little Sand Lake	H	<2	(5)	12	(10)	5.4	(6.0)	soft	slightly acidic	very soft	slightly basic
Little Sand Lake	I	<2	-	10	-	5.4	-	soft	slightly acidic	very soft	slightly basic

Note: - Indicates no data.

[a]Locations of sampling stations are shown on Figure 2.4-2.

[b]Classification follows Sawyer and McCarty (1967): 0-75 $mg/l\ CaCO_3$ = soft; 75-150 $mg/l\ CaCO_3$ = moderately hard; 150-300 $mg/l\ CaCO_3$ = hard; 300+ $mg/l\ CaCO_3$ = very hard.

[c]Based on 1977-1978 data.

[d]Classification follows Steuck and Andrews (1976): 0-2 pH = very acidic; 2-4 pH = acidic; 4-6 pH = slightly acidic; 6-8 pH = neutral; 8-10 pH = slightly basic; 10-12 pH = basic; 12-14 pH = very basic.

[e]Steuck and Andrews, 1976; Steuck et al., 1977.

[f]Sampling station located in the Swamp Creek channel within Rice Lake.

[g]Sampling stations G-1 and GH-1 are 1 m (3.3 feet) below the water's surface and stations G-2 and GH-2 are below the metalimnion.

[h]Based on 1979-1980 data.

WATER BODY	SAMPLING STATION[a]	MEAN OF 1977-1978 VALUES (MEAN OF 1979-1980 VALUES): TOTAL LABORATORY ALKALINITY (mg/l $CaCO_3$)		TOTAL HARDNESS (mg/l $CaCO_3$)		FIELD pH		HARDNESS CLASSIFICATION[b,c]	pH CLASSIFICATION[c,d]	DNR HARDNESS CLASSIFICATION[e]	DNR pH CLASSIFICATION[e]
Mole Lake	O	26	-	31	-	7.2	-	soft	neutral	soft	neutral
Oak Lake	G-1[g]	<4	(6)	11	(14)	6.2	(6.5)	soft	neutral	very soft	slightly acid
Oak Lake	G-2[g]	<4	-	11	-	5.9	-	soft	slightly acidic	very soft	slightly acid
Rice Lake	N	<81	(69)	102	(106)	7.3	(7.5)	moderately hard	neutral	hard	basic
Rolling Stone Lake	M-2	83	-	91	-	7.7	-	moderately hard	neutral	medium hard	slightly basic
Rolling Stone Lake	M-4	87	-	93	-	7.7	-	moderately hard	neutral	medium hard	slightly basic
Skunk Lake	J	10	(8)	15	(13)	5.8	(5.7)	soft	slightly acidic	very soft	acid
St. Johns Lake	JL	-	(4)	-	(11)	-	(6.1)	soft[h]	neutral[h]	very soft	slightly acid
Walsh Lake	WL	-	(5)	-	(13)	-	(6.2)	soft[h]	neutral[h]	very soft	slightly acid
Ground Hemlock Lake	GH-1[g]	-	(110)	-	(112)	-	(8.2)	moderately hard[h]	slightly basic[h]	hard	basic
Ground Hemlock Lake	GH-2[g]	-	(129)	-	(128)	-	(7.7)	moderately hard[h]	neutral[h]	-	-
Lake Metonga	-	-		-		-		-	-	medium hard	slightly basic
Lake Lucerne	-	-		-		-		-	-	soft	slightly acid
Bishop Lake	-	-		-		-		-	-	medium hard	slightly basic
Kimberly Lake	-	-		-		-		-	-	very soft	slightly acid
Clark Lake	-	-		-		-		-	-	very soft	slightly acid
Jungle Lake	-	-		-		-		-	-	medium hard	basic
Cook Lake	-	-		-		-		-	-	very soft	slightly basic
Crawford Lake	-	-		-		-		-	-	very soft	slightly acid
Spring Lake	-	-		-		-		-	-	medium hard	slightly basic

KEY:
WETLANDS
DISCHARGE LAKES
RECHARGE LAKES
S-32
SPRING SEEP AND INTERMITTENT STREAM SURVEY STATION
STREAM
55
BLACKTOP ROAD
N
1 MILE
.5
0
1000 0 1000 3000 5000 7000 FEET
1 KILOMETER
Lake Metonga
Lake Lucerne
Rice Lake
Bishop Lake
Mole Lake
Oak Lake
Little Sand Lake
Skunk Lake
Duck Lake
Deep Hole Lake
Ground Hemlock Lake
Kimberly Lake
Clark Lake
Walsh Lake
Jungle Lake
St. Johns Lake
Rolling Stone Lake
Lily Lake
Swamp Creek
Outlet Creek
Hemlock Creek
Pickerel Creek
Lily River
Keith Siding Road
Sand Lake Road
Soo Line
FOREST CO.
LANGLADE CO.
T35N
T34N
R12E R13E
R13E R14E
BASE MAP REFERENCE:
PORTIONS OF THE FOLLOWING U.S.G.S. 7.5 MINUTE SERIES TOPOGRAPHIC QUADRANGLES:
NASHVILLE, WISCONSIN, 1965
CRANDON, WISCONSIN, 1965
LAKE LUCERNE, WISCONSIN, 1965
POST LAKE, WISCONSIN, 1973
MOLE LAKE, WISCONSIN, 1973
ROBERTS LAKE, WISCONSIN, 1973
EXXON MINERALS COMPANY
CRANDON PROJECT
GROUND WATER - SURFACE WATER RELATIONSHIPS IN THE ENVIRONMENTAL STUDY AREA
DAMES & MOORE
FIGURE 2.3-15

TABLE 2.3-13

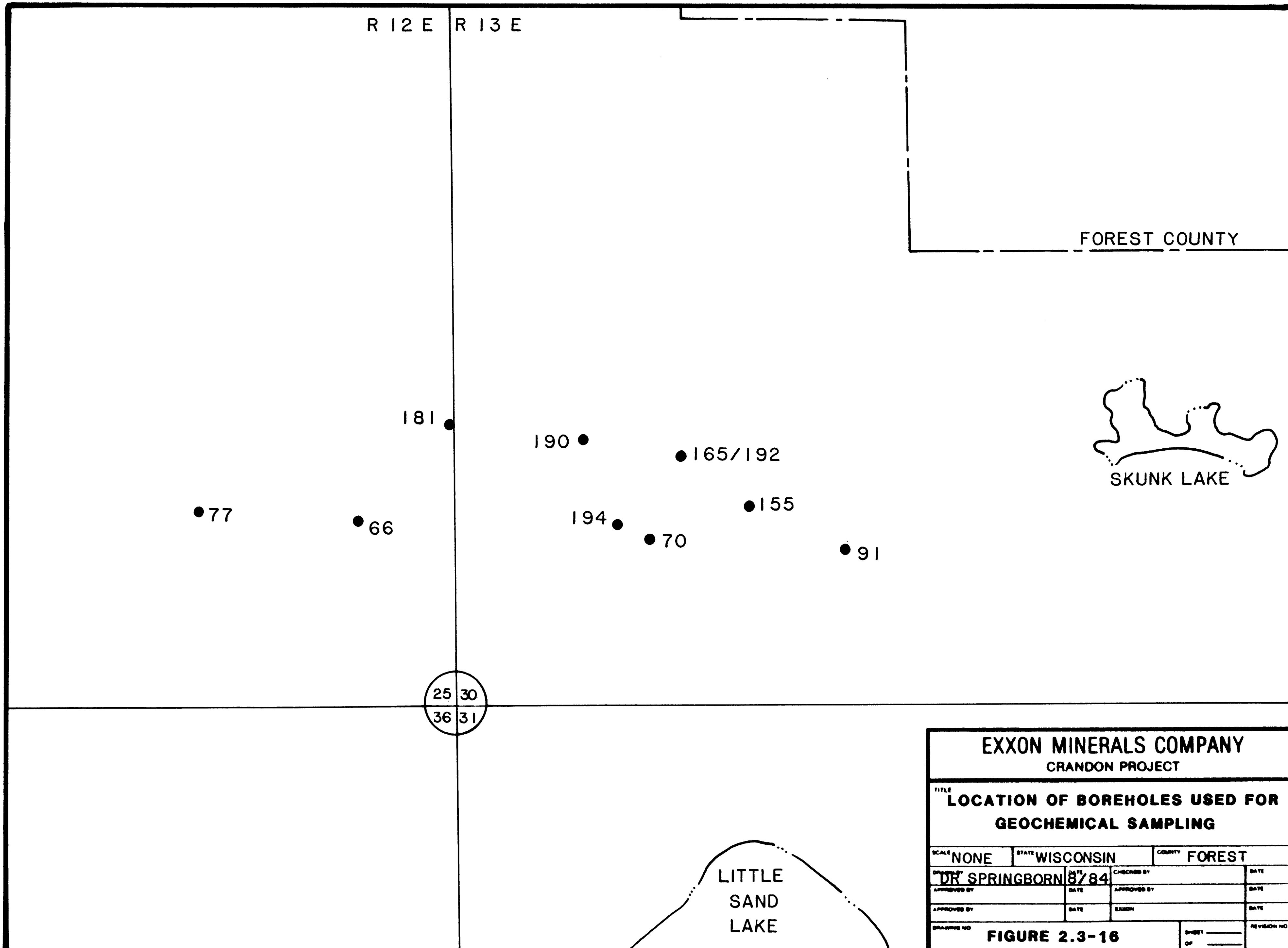
RESULTS OF CHEMICAL ANALYSES OF BEDROCK GROUND WATER SAMPLES

BOREHOLE NUMBER	ZONES (feet)	DATE-TIME COLLECTED	pH	TOTAL LABORATORY ALKALINITY (mg/l $CaCO_3$)	TOTAL HARDNESS (mg/l $CaCO_3$)	NONCARBONATE[a] HARDNESS (mg/l $CaCO_3$)	TOTAL DISSOLVED SOLIDS (mg/l)	SPECIFIC CONDUCTANCE (µmhos/cm)	CHLORIDE (mg/l)	MAGNESIUM (mg/l)	CALCIUM (mg/l)	SODIUM (mg/l)	SALINITY[b] (g/kg)
66	402 - 1078	03/02/78-2413	8.11	142	175	33	198	289	2	19.3	38.6	-	0.0036
70	552 - 1334	03/04/78-2245	7.98	160	194	34	170	312	8	23.4	39.1	-	0.0145
70[c]	552 - 1334	03/04/78-2245	7.99	160	194	34	178	310	8	23.4	39.2	-	0.0145
70	302 - 1334	03/05/78-0615	7.83	156	193	37	188	295	6	22.8	39.5	-	0.0108
77	602 - 1049	03/01/78-1940	7.75	134	170	36	170	298	20	20.5	34.6	-	0.0361
91	852 - 1415	03/06/78-0405	8.12	164	196	32	164	313	12	22.0	42.2	-	0.0217
155	362	02/28/78-1315	-	-	-	-	-	-	3700	-	-	-	6.68
155	562	02/28/78-1559	-	-	-	-	-	-	4200	-	-	-	7.59
155	842	02/27/78-1700	-	-	-	-	-	-	4000	-	-	-	7.23
155	942	02/27/78-1700	-	-	-	-	-	-	-	-	-	1670	-
155	942 - 3050	02/27/78-1700	7.27	80	1532	1452	6112	10000	3600	127	404	-	6.50
155	1042	02/26/78-2000	-	-	-	-	-	-	3300	-	-	-	5.96
155	1370	02/25/78-2010	-	-	-	-	-	-	2900	-	-	-	5.24
155	below 2102	02/25/78-0755	-	-	-	-	-	-	2550	-	-	-	4.61
155	2202 - 2215	02/23/78-2035	7.36	86	961	875	3524	6500	2200	75.0	261	-	3.97
155	2202 - 2215	02/23/78-2035	-	-	-	-	-	-	-	-	-	1060	-
155	2710	02/22/78-1540	-	-	-	-	-	-	2100	-	-	-	3.79
155	2712 - 2725	02/24/78-0835	-	-	-	-	-	-	2250	-	-	-	4.06
165	2300	02/19/78-2030	-	-	-	-	-	-	1900	-	-	-	3.43
165	2920	02/18/78-0128	-	-	-	-	-	-	-	-	-	1090	-
165	2920 - 2971	02/18/78-0128	5.89	12	1930	1918	5194	7200	2650	185	468	-	4.79
181	-	05/02/78-0600	6.97	48	3036[c]	2988	-	-	4850	221	850	1810	8.76
192	-	04/28/78-1030	6.99	112	3878[c]	3766	-	-	5100	298	1060	2450	9.21

[a]Values calculated using presented data.

[b]Salinity calculated using the relationship: S °/oo = 1.80655 Cl °/oo, where, S = salinity and Cl = chlorinity, both expressed as grams per kilogram of seawater, or parts per thousand (°/oo). Standard seawater has a salinity of 35 °/oo and a chlorinity of 19.38 °/oo.

[c]Quality assurance check sample analyses (duplicate).

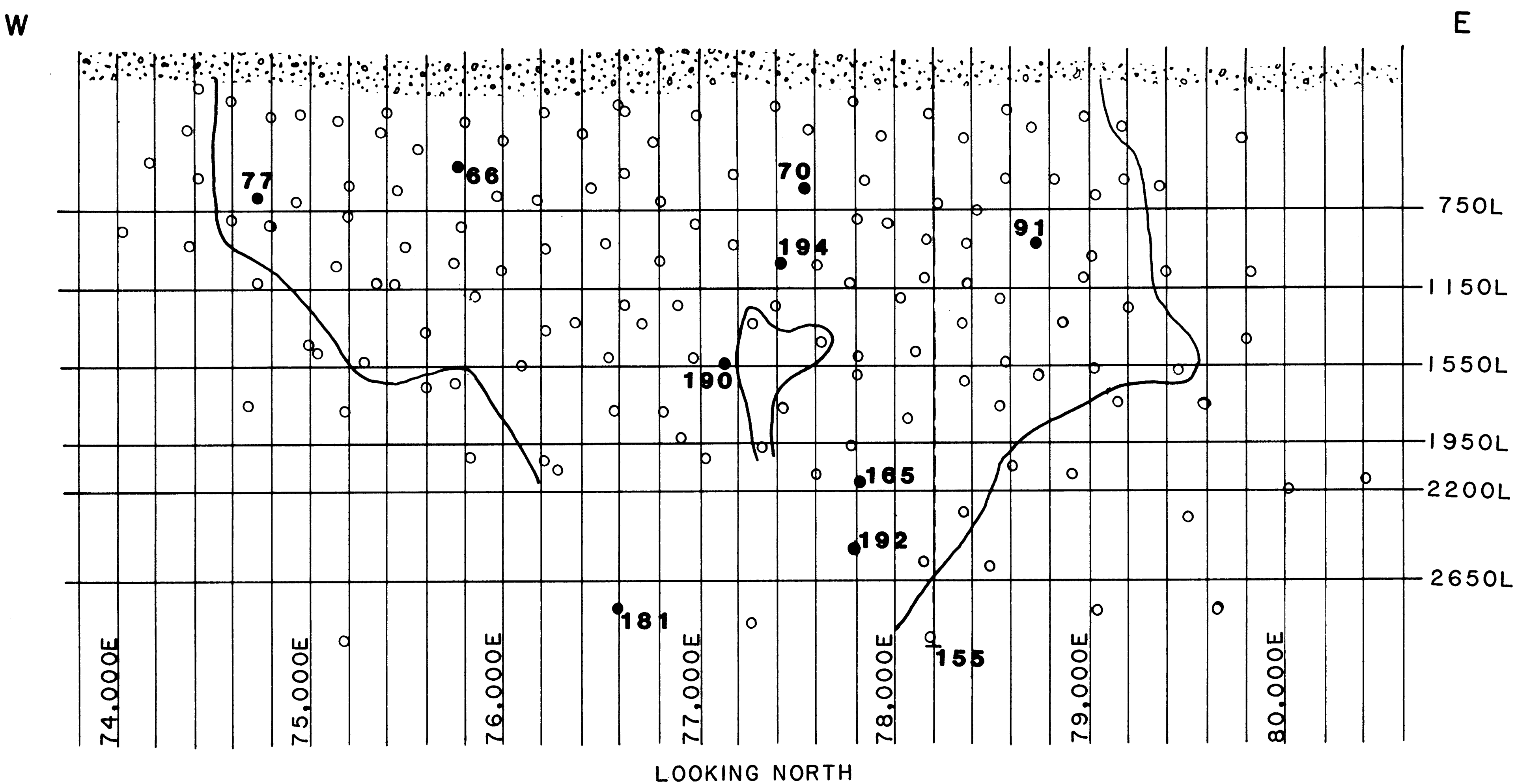


EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: LOCATION OF BOREHOLES USED FOR GEOCHEMICAL SAMPLING

SCALE: NONE	STATE: WISCONSIN	COUNTY: FOREST
DRAWN BY: DR SPRINGBORN	DATE: 8/84	CHECKED BY:

FIGURE 2.3-16



EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE **LOCATION OF BOREHOLES USED FOR GEOCHEMICAL SAMPLING**

SCALE NONE	STATE WISCONSIN	COUNTY FOREST
DRAWN BY DR SPRINGBORN	DATE 8/84	CHECKED BY	DATE
APPROVED BY	DATE	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE

DRAWING NO **FIGURE 2.3-17** SHEET OF REVISION NO

The reported alkalinity values for the upper bedrock strata ranged from 134 to 164 mg/l $CaCO_3$. This compares with a mean value of 127 mg/l $CaCO_3$ for laboratory alkalinity for the ground water samples obtained from the glacial drift. The alkalinity of the ground water obtained from the deeper zones within the bedrock was lower than that for the upper zone.

The highest pH values occurred in water samples from the upper strata, whereas the lower pH values were associated with the lower alkalinity values in ground water from the deeper bedrock strata. Above a depth of approximately 457 m (1,500 feet), the ground water quality characteristics are similar to those in the overlying glacial drift. This suggests interaction between ground water contained in the glacial drift and the ground water in the upper bedrock strata. The ground water chemistry, with increasing depth within the bedrock, was substantially different from that within the upper strata and the drift, suggesting limited ground water flow between the upper and the deeper bedrock zones.

Total dissolved solids and specific conductance were also closely related. Average values for these parameters for ground water from the upper bedrock strata were 178 mg/l and 303 μmhos/cm, respectively. These values reflect a slight increase over the average values found in ground water from the overlying glacial drift. These values were considerably higher in the lower bedrock strata (Table 2.3-13).

Chloride concentrations were lower in ground water from the upper bedrock than from the lower bedrock strata. Chloride values were used to calculate chlorinity which, in turn, was used to calculate salinity. Chlorinity is the weight of the halogenides (Cl^-, Br^-, and I^-) expressed as g of chlorine per kg. Since bromide (Br^-) and iodide (I^-) ions usually exist only in trace amounts in ground water (Hem, 1959), chlorinity was assumed to be equivalent to the chloride ion concentrations.

Calculated salinity values indicate an average salinity of 0.017 g/kg for ground water in the upper bedrock strata and 5.84 g/kg for ground water in the lower bedrock strata. As a point of comparison, the salinity of seawater is 35 g/kg (Rodier, 1975), which is 83.3 percent greater than the salinity of the ground water found in the lower bedrock strata.

A contradiction in the above trend occurred in samples collected from borehole 155; chloride and salinity values from the ground water analyzed from the upper portion (110 m [362 feet]) of the hole were similar to those found in ground water collected from the lower bedrock strata. These ground water samples were obtained with an air lift and the inconsistency can be attributed to mixing of the waters from the two depth zones. This is reflected in the intermediate alkalinity and pH values of these water samples.

2.3.5 Summary and Conclusions

The principal results and conclusions from the ground water investigations conducted in the environmental study area from July 1977 to July 1984 are presented below.

Ground Water Occurrence

1. The Crandon massive sulfide deposit is situated within a sequence of Precambrian volcanic rocks. The Precambrian basement complex is directly overlain by as much as 91 m (300 feet) of unconsolidated glacial drift consisting of interbedded and intermixed till and outwash deposits that are highly variable both spatially and with respect to depth within the section.

2. The principal ground water aquifers within the environmental study area are located within the unconsolidated glacial drift, which directly overlies the surface of the bedrock.

3. Ground water in the environmental study area exists mainly under water table conditions, although locally confined or partially confined conditions are present because of stratification within the glacial drift and the permeability contrast between the glacial till and outwash deposits.

4. Ground water in the Precambrian bedrock occurs mainly in fractured and weathered zones. These zones are in communication and quasi-equilibrium with ground water in the glacial drift as evidenced by the potentiometric surfaces in the glacial drift and bedrock systems.

Ground Water Recharge-Discharge Regime

1. The configuration of the water table or potentiometric surface within the environmental study area is, in general, a subdued reflection of the surface topography.

2. Ground water flow within the main ground water aquifer is principally horizontal and from upland to low-lying surface areas; that is, along the lower surface elevations and surface water drainages. The absence of large vertical hydraulic gradients within the glacial drift and Precambrian bedrock precludes major vertical ground water movement within the saturated zone.

3. Upland areas within the central portion of the environmental study area constitute the principal area of ground water recharge for the main ground water aquifer. Lakes located within these recharge areas, including Oak, Little Sand, Skunk, Duck, Deep Hole, Walsh, St. Johns, and Kimberly, are sources of ground water recharge. The surface water elevation in these lakes is above the main ground water table or potentiometric surface. Consequently, the potentiometric gradients and principal direction of ground water flow is downward to the water table.

4. Ground water movement in the bedrock is primarily limited to the weathered zone and the open fractures near the subcrop. Below this weathered zone, the bedrock is practically impermeable. Fractures are generally healed by subsequent mineralization or are very tight.

5. The principal areas of ground water discharge from the main ground water aquifer are along the lower surface elevations. Those lakes and streams located within these areas receive and are maintained by ground water discharge from the main ground water aquifer.

6. Surface water and ground water within the environmental study area are closely interrelated both with respect to occurrence and water quality. These interrelationships are illustrated on Figure 2.3-15, which identifies the principal wetlands, recharge and discharge lakes, and other surface water features within the environmental study area.

Ground Water Quality

1. Ground water quality within the glacial drift is good and, with the exception of occasional reported values for cadmium, iron, lead, nitrate, and manganese, meets applicable drinking water standards.

2. A change in quality occurs as ground water in the main ground water aquifer moves from recharge to discharge areas. Those lakes located within main ground water aquifer recharge areas (Deep Hole, Duck, Little Sand, Oak, Skunk, St. Johns, Kimberly, and Walsh) have lower alkalinity and hardness values than those located within main ground water aquifer discharge areas (Ground Hemlock, Mole, Rolling Stone, and Rice).

Ground Water Use

1. The principal uses of ground water in Forest, Langlade, and Oneida counties are for municipal and private domestic water supplies. Ground water is also used for irrigation in the vicinity of Mole Lake.

2. All of the existing ground water usage is obtained from the unconsolidated glacial drift overlying the surface of the Precambrian bedrock. There are no known water wells producing from bedrock.

2.3.6 References

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2.4 SURFACE WATER

The purpose of this investigation was to evaluate the quality and quantity of surface water resources existing in the environmental study area. The study area includes the Swamp Creek and Pickerel Creek drainage basins and that part of the Wolf River drainage between Swamp and Pickerel creeks.

This report includes a description and documentation of the data collection and analysis activities that were used in evaluating the surface water resources. Both the field observations and analytical activities have been modified since project inception. Judgments and assumptions guided the original data collection program from April 1977 through November 1980. As knowledge of the hydrologic system increased, as the environmental concerns focused, and as mine development plans progressed, data collection and analysis approaches were modified to meet changing needs. Water quality and hydrological data on Swamp Creek below Rice Lake were collected from April 1982 through December 1984 as part of a supplemental program (Ecological Analysts, Inc., 1983, 1984; EA Science and Technology, 1985). An interest in the surface water-ground water relationship of several lakes in the site area resulted in additional data collection and analysis in January 1985 (Dames & Moore, 1985). Several analytical efforts have been modified in response to suggestions for alternative assumptions or more comprehensive evaluations.

This report provides detailed descriptions of field data activities and analytical results. The appendices provide basic data and supporting information.

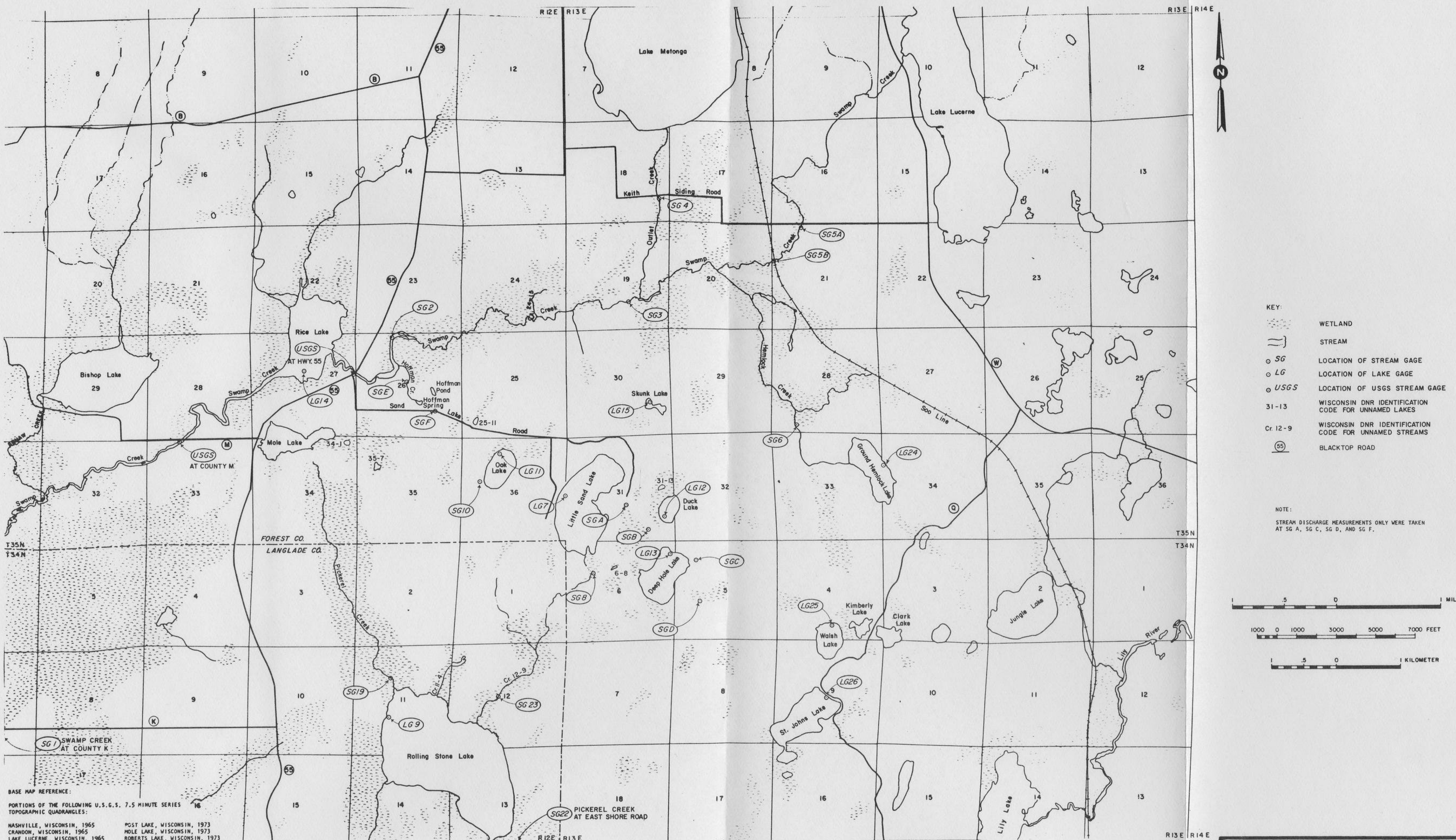
2.4.1 Field and Laboratory Methods

Studies of the surface water resources within the environmental study area were conducted discontinuously from April 1977 through November 1980. The basic rationale for the investigation was to document and describe the seasonal chemical and hydrologic characteristics in the existing water bodies and drainage systems within the environmental study area. These characteristics included lake levels, stream flow rates and the water and bottom sediment chemistry of both lakes and streams.

The existing water bodies and drainage systems within the area of the ore body were initially reviewed using available topographic maps. On the basis of this topographic review and a general knowledge of the location of the proposed mine, locations of the chemical and hydrologic sampling stations were preliminarily selected. Actual sampling stations were established after field reconnaissance for compatibility with the aquatic ecology stations and/or to delineate reasonably accessible locations.

The locations of the stream and lake gaging stations are shown on Figure 2.4-1 and listed in Table 2.4-1. The stream gaging stations were established for their location in the drainage basin (see Figure 2.4-5) and for accessibility. Staff gages at these stream stations were installed downstream of culverts at road crossings to avoid interference with debris collecting on the upstream side of the culverts. The lake gaging stations were selected for their proximity to the proposed site area and candidate mine waste disposal areas and for the potential influence from these facilities.

Stream sampling stations for water and bottom sediment chemistry are shown on Figure 2.4-2 and listed in Table 2.4-2. These stations were



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LOCATION OF
SURFACE WATER GAGING STATIONS
IN THE ENVIRONMENTAL STUDY AREA

DAMES & MOORE | FIGURE 2.4-1

TABLE 2.4-1

STREAM AND LAKE GAGING STATIONS
IN THE ENVIRONMENTAL STUDY AREA

GAGING STATION	LOCATION/NAME
Swamp Creek Drainage Basin	
SG 1	Swamp Creek at County K
SG 2	Swamp Creek above Highway 55
SG 3	Swamp Creek at Swampy Lane
SG 4	Outlet Creek at Keith Siding Road
SG 5A	Swamp Creek at Keith Siding Road
SG 5B	Swamp Creek at Railroad Bridge
SG 6	Hemlock Creek at Berry Lane
SG 10	Oak Lake Outflow immediately SW of Oak Lake
LG 11	Oak Lake
LG 14	Rice Lake
LG 24	Ground Hemlock Lake
SG E	Hoffman's Creek
SG F	Oak Lake Outflow at Sand Lake Road
Pickerel Creek Drainage Basin	
LG 7	Little Sand Lake
SG 8	Creek 12-9 immediately S of Little Sand Lake
LG 9	Rolling Stone Lake
LG 12	Duck Lake
LG 13	Deep Hole Lake
LG 15	Skunk Lake
SG 19	Pickerel Creek NW of Rolling Stone Lake
SG 22	Pickerel Creek at East Shore Road
SG 23	Creek 12-9 NW of Rolling Stone Lake
LG 25	Walsh Lake
LG 26	St. Johns Lake
SG A	Tributary to Little Sand Lake
SG B	Duck Lake Outflow at Sand Lake Road
SG C	Tributary to Deep Hole Lake
SG D	Tributary to Deep Hole Lake
Continuous Gaging Stations	
USGS at Hwy 55*	Swamp Creek at Highway 55
USGS at County M*	Swamp Creek at County M

*Located in Swamp Creek Drainage Basin.

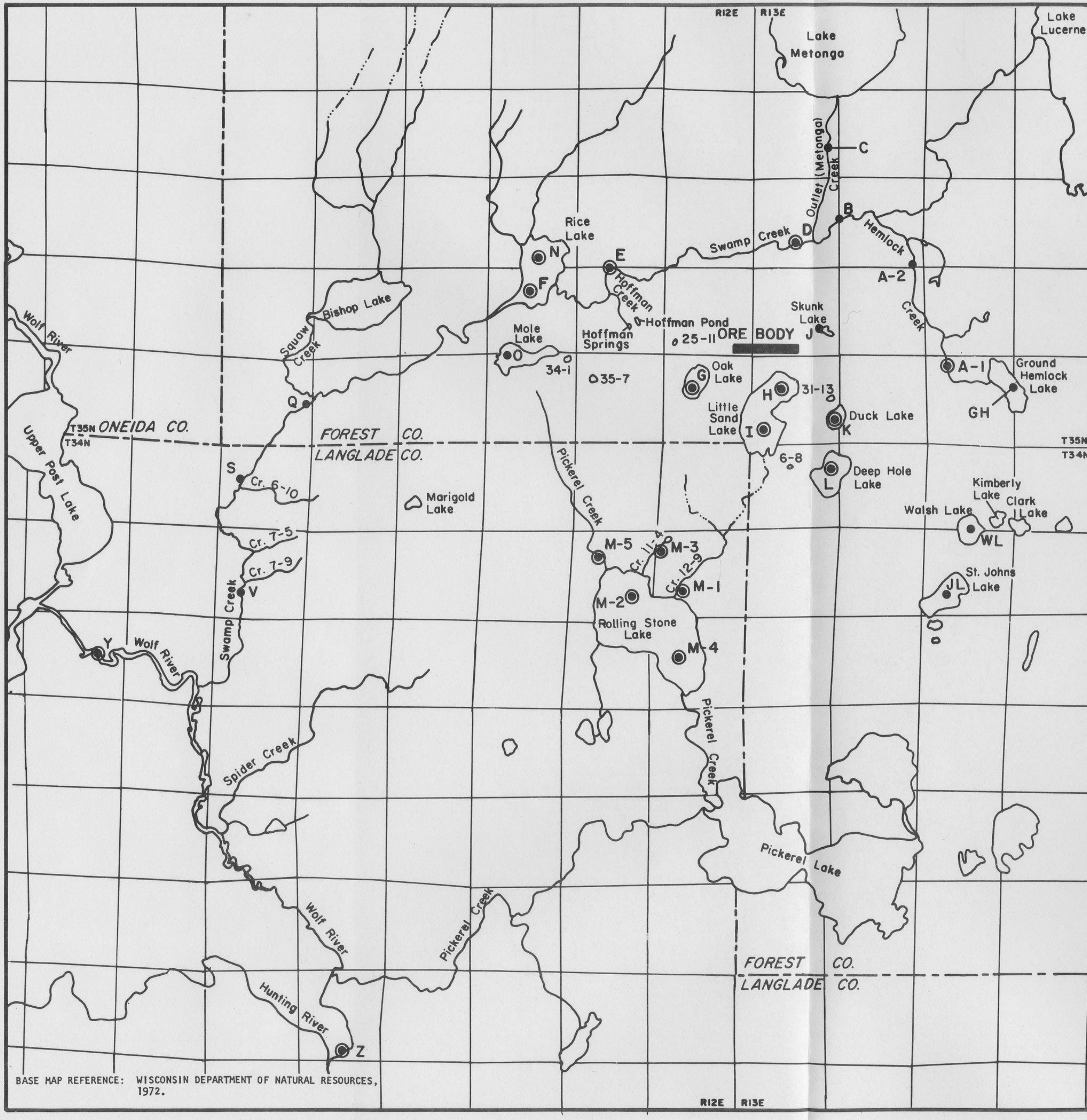
TABLE 2.4-2

SAMPLING STATIONS FOR WATER AND BOTTOM SEDIMENT CHEMISTRY IN THE ENVIRONMENTAL STUDY AREA

WATER BODY	1977-1978 WATER SAMPLING STATIONS	1979-1980 WATER SAMPLING STATIONS	1978 BOTTOM SEDIMENT SAMPLING STATIONS
Swamp Creek Drainage Basin			
Rice Lake	F, N	N	F, N
Hemlock Creek	A-1, A-2	A-1	A-1
Swamp Creek (upstream of Rice Lake)	B, D, E	D, E	D, E
Swamp Creek (downstream of Rice Lake)	Q, S, V		
Outlet (Metonga) Creek	C		
Ground Hemlock Lake		GH	
Oak Lake	G	G	G
Pickerel Creek Drainage Basin			
Rolling Stone Lake	M-2, M-4		M-2, M-4
Pickerel Creek	M-5	M-5	M-5
Creek 12-9[a]	M-1	M-1	M-1
Creek 11-4[a]	M-3	M-3	M-3
Little Sand Lake	H, I	H	H, I
Duck Lake	K	K	K
Deep Hole Lake	L	L	L
Skunk Lake	J	J	
Mole Lake	O		
Walsh Lake		WL	
St. Johns Lake		JL	
Wolf River[b]	Y, Z		Y,Z

[a]Wisconsin DNR identification code for unnamed streams.

[b]Although outside the designated 8-km (5-mile) radius, these stations are considered part of the environmental study area.



N

KEY:

STREAM

25-11 WISCONSIN DNR IDENTIFICATION CODE FOR UNNAMED LAKES

Cr. 11-4 WISCONSIN DNR IDENTIFICATION CODE FOR UNNAMED STREAMS

● WATER SAMPLING STATION

◉ WATER AND BOTTOM SEDIMENT CHEMISTRY SAMPLING STATION

1 .5 0 1 MILE

1 .5 0 1 KILOMETER

EXXON MINERALS COMPANY
CRANDON PROJECT

WATER AND BOTTOM SEDIMENT CHEMISTRY SAMPLING STATIONS

DAMES & MOORE

FIGURE 2.4-2

selected on the basis of the following rationale. For the Swamp Creek basin, six locations were selected on Swamp Creek to provide sampling areas upstream, adjacent to, and downstream from the general location of the ore body and potential mining activities. Station B was located approximately 2.4 km (1.5 miles) northeast of the ore body, and 0.8 km (0.5 mile) downstream from the confluence with Hemlock Creek. Station D was located 1.0 km (0.6 mile) downstream from Station B and 0.3 km (0.2 mile) downstream from the confluence with Outlet Creek. Station E was located 3.4 km (2.1 miles) downstream from Station D and approximately 1.4 km (0.9 mile) upstream from Rice Lake. Downstream from Rice Lake, three stations were established: Station Q, immediately below the confluence with Squaw Creek; Station S, approximately 2.3 km (1.4 miles) downstream from Station Q; and Station V, approximately 2.3 km (1.4 miles) upstream from the confluence with the Wolf River.

Sampling stations within the Swamp Creek basin were also established in Hemlock Creek (Stations A-1 and A-2), a major tributary to Swamp Creek upstream from the potential mine area. Station A-1 was located approximately 1.1 km (0.7 mile) downstream from Ground Hemlock Lake at Berry Lane, and Station A-2 approximately 1.3 km (0.8 mile) upstream from the confluence with Swamp Creek. A sampling station (C) was also established upstream from the potential mine area on Outlet Creek, a tributary to Swamp Creek. Sampling was conducted at Outlet Creek immediately upstream of Keith Siding Road, approximately 1.4 km (0.9 mile) upstream from the confluence with Swamp Creek.

For the Pickerel Creek basin, stations on Pickerel Creek (M-5), Creek 11-4 (M-3) and Creek 12-9 (M-1) were established to sample surface water systems that drain potential mine waste disposal areas. At Pickerel Creek, samples were collected from Station M-5, located approximately 0.2 km (0.1 mile) upstream from Rolling Stone Lake. Samples from Creek 12-9 were obtained from Station M-1, approximately 100 m (328 feet) upstream from Rolling Stone Lake. At Creek 11-4, samples were obtained from Station M-3, approximately 0.5 km (0.3 mile) upstream from Rolling Stone Lake.

Two stations on the Wolf River (Y and Z) were selected to permit sampling of this major aquatic system above and below the drainage from the environmental study area via Swamp and Pickerel creeks. Samples were collected at Station Y, located approximately 1.9 km (1.2 miles) upstream from the confluence with Swamp Creek, and Station Z, located approximately 1.4 km (0.9 mile) downstream from the confluence with Pickerel Creek. Although outside the designated 8-km (5-mile) radius, these stations are considered part of the environmental study area.

Sampling stations for water and bottom sediment chemistry were also established on lakes that were either adjacent to or in a location that could potentially receive drainage from the proposed site area or candidate mine waste disposal areas. Actual stations within each lake were selected for compatibility with aquatic ecology stations.

The number of locations sampled in the environmental study area and the intensity of sampling were adjusted during the investigation to address the environmental concerns associated with candidate areas for mine waste disposal facilities. The sampling schedule is presented in Tables 2.4-3 through 2.4-8.

Methods for measuring the lake levels and stream flows and the collection and analysis of samples for suspended sediments, bottom sediment (grain size and chemistry) and water chemistry are presented below. A

TABLE 2.4-3

SUMMARY OF SURFACE WATER DATA COLLECTION PROGRAM FOR STREAM GAGES IN THE ENVIRONMENTAL STUDY AREA

GAGE	LOCATION/NAME[a]	TOPOGRAPHIC DRAINAGE AREA (mile^2)	FREQUENCY OF STAFF GAGE READINGS	FREQUENCY OF SUSPENDED SEDIMENT SAMPLINGS	PERIOD OF RECORD[b]
Swamp Creek Drainage Basin					
SG 1	Swamp Creek at County K	70.5	Weekly	Biweekly	May 1977/Oct. 1978
SG 2	Swamp Creek above Highway 55	40.3	Weekly	Biweekly	Apr. 1977/Nov. 1980
SG 3	Swamp Creek at Swampy Lane	36.5	Weekly	Biweekly	Apr. 1977/Nov. 1980
SG 4	Outlet Creek at Keith Siding Road	11.2	Weekly	Monthly	May 1977/Nov. 1980
SG 5A	Swamp Creek at Keith Siding Road	13.9	Weekly	None	May 1977/Jul. 1977
SG 5B	Swamp Creek at Railroad Bridge	14.3	Weekly	Monthly	Jul. 1977/Nov. 1980
SG 6	Hemlock Creek	3.5	Weekly	Biweekly	May 1977/Nov. 1980
SG 10	Oak Lake Outflow	0.6	Monthly	Irregular	Apr. 1977/Apr. 1979
SG E	Hoffman's Creek	1.7	Irregular[c]	Irregular	Sep./Oct. 1978 & Apr. 1979
SG F	Oak Lake Outflow at Sand Lake Road	1.4	d	Irregular	Sep. 1978 & Apr. 1979
Pickerel Creek Drainage Basin					
SG 8	Creek 12-9	3.9	Weekly	Irregular	Apr. 1978/Apr. 1979
SG 19	Pickerel Creek NW of Rolling Stone Lake	2.5	Weekly	Monthly	Oct. 1977/Nov. 1980
SG 22	Pickerel Creek at East Shore Road	14.1	Weekly	Monthly	Oct. 1977/Nov. 1980
SG 23	Creek 12-9	6.0	Weekly	Irregular	Apr. 1978/Nov. 1980
SG A	Tributary to Little Sand Lake	2.2	d	Irregular	Apr. 1978 & Apr. 1979
SG B	Duck Lake Outflow	0.6	Weekly	Irregular	Jul. 1978/Apr. 1979
SG C	Tributary to Deep Hole Lake	0.2	d	None	Apr. 1978
SG D	Tributary to Deep Hole Lake	0.8	d	Irregular	Apr. 1978 & Apr. 1979
Continuous Gaging Stations					
USGS at Hwy 55	Swamp Creek at Highway 55	46.2	Continuous	None	Aug. 1977/Present
USGS at County M	Swamp Creek at County M	56.7	Continuous	None	Aug. 1977/Sep.1979

[a]Locations of the gaging stations are shown on Figure 2.4-1.

[b]Records are discontinuous; information was gathered during ice-free periods between April 1977 and November 1980. USGS records are continuous.

[c]Stream gage station was established during September 1978. Staff gage readings were recorded in April 1979 to monitor the effects of snowmelt runoff.

[d]Surface water discharge measurements only.

TABLE 2.4-4

SUMMARY OF SURFACE WATER DATA COLLECTION PROGRAM FOR LAKE GAGES IN THE ENVIRONMENTAL STUDY AREA

GAGE	LOCATION/NAME	FREQUENCY OF STAFF GAGE READINGS	PERIOD OF RECORD*
Swamp Creek Drainage Basin			
LG 11	Oak Lake	Monthly	Apr. 1977/Oct. 1980
LG 14	Rice Lake	Monthly	May 1977/Oct. 1980
LG 24	Ground Hemlock Lake	Monthly	Apr. 1980/Oct. 1980
Pickerel Creek Drainage Basin			
LG 7	Little Sand Lake	Monthly	Apr. 1977/Oct. 1980
LG 9	Rolling Stone Lake	Monthly	May 1977/Oct. 1980
LG 12	Duck Lake	Monthly	Apr. 1977/Oct. 1980
LG 13	Deep Hole Lake	Monthly	Jun. 1977/Oct. 1980
LG 15	Skunk Lake	Monthly	May 1977/Oct. 1980
LG 25	Walsh Lake	Monthly	Apr. 1980/Oct. 1980
LG 26	St. Johns Lake	Monthly	Apr. 1980/Oct. 1980

*Record is discontinuous; information was gathered during ice-free periods between April 1977 and October 1980.

TABLE 2.4-5

SCHEDULE OF SUSPENDED SEDIMENT SAMPLING
IN THE ENVIRONMENTAL STUDY AREA
OCTOBER 1977 THROUGH APRIL 1979

	1977							1978																			1979				
STREAM	OCT			NOV		DEC		MAR	APR			MAY		JUN		JUL			AUG					SEP			OCT	APR				
GAGE*	8/9	13	22	2	21	6	19	28/29	7	11	13-15	5/6	30	9	20	11	18	24/25	10	15	16	17	18	3/4	11/12	18	2	14	18	19	20	22
SG-1	X			X	X			X	X	X	X	X	X	X	X	X	X	X	X		X	X		X		X	X					
SG-2				X								X				X		X	X					X		X	X					
SG-3	X			X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X		X			
SG-4	X					X		X		X	X		X	X		X			X	X	X	X		X			X	X		X		
SG-5B	X				X		X	X		X		X	X					X			X				X	X		X				
SG-6	X			X	X		X	X		X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X		X		
SG-8																												X		X		
SG-10																												X			X	
SG-19			X							X	X	X		X		X	X		X	X	X	X		X			X		X	X		X
SG-22		X		X	X		X	X	X	X	X		X		X			X			X					X		X		X		X
SG-23											X	X	X	X	X	X		X	X	X	X		X	X	X	X	X	X		X		X
SG A											X																	X				
SG B											X							X	X	X	X			X	X	X	X					
SG D											X																			X		
SG E																											X		X			
SG F																													X			

TABLE 2.4-6

SCHEDULE OF WATER AND BOTTOM SEDIMENT CHEMISTRY SAMPLING IN THE SWAMP CREEK DRAINAGE BASIN MARCH 1977 THROUGH OCTOBER 1980

		1977									
WATER BODY	SAMPLE/STATION	MAR[a]	APR	MAY[a]	JUN	JUL	AUG[a]	SEP	OCT[a]	NOV	DEC
Rice Lake	Water Quality										
	F	X	-	X	X	X	X	X	X	X	X[b]
	N	X	-	X	X	X	X	X	X	X	-
	Sediment Chemistry[c]										
	F	-	-	-	-	-	-	-	-	-	-
	N	-	-	-	-	-	-	-	-	-	-
Hemlock Creek	Water Quality										
	A-1	X	X	X	X	X	X	X	X	X	X
	A-2	-	-	-	-	-	-	-	X	X	X
	Sediment Chemistry[c]										
	A-1	-	-	-	-	-	-	-	-	-	-
	Spring Metals Survey[d]										
	A-1	-	-	-	-	-	-	-	-	-	-
Swamp Creek	Water Quality										
	B	X	X	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X	X	X
	Q	-	-	-	-	-	-	-	X	X	-
	S	-	-	-	-	-	-	-	X	X	X
	V	-	-	-	-	-	-	-	X	X	X
	Sediment Chemistry[c]										
	D	-	-	-	-	-	-	-	-	-	-
	E	-	-	-	-	-	-	-	-	-	-
	Spring Metals Survey[d]										
	D	-	-	-	-	-	-	-	-	-	-
	E	-	-	-	-	-	-	-	-	-	-
	V	-	-	-	-	-	-	-	-	-	-
Outlet Creek	Water Quality										
	C	X	X	X	X	X	X	X	X	X	X
Ground Hemlock Lake	Water Quality										
	GH-1	-	-	-	-	-	-	-	-	-	-
	GH-2	-	-	-	-	-	-	-	-	-	-
Oak Lake	Water Quality										
	G-1	X	X	X	X	X	X	X	X	X	X
	G-2	-	-	-	X	X	X	X	X	X	X
	Sediment Chemistry[c]										
	G	-	-	-	-	-	-	-	-	-	-

Note - Indicates no samples collected.

[a]Water quality samples analyzed for the "seasonal" list of parameters are presented in Table 2.4-9. The parameters on the "monthly" list were analyzed for the other months.

[b]Because of thin or unsafe ice conditions, a contigency sample was collected as near the station as safely possible.

[c]Sediment chemistry samples were analyzed for those parameters listed in Table 2.4-9.

[d]Parameters analyzed from the samples collected for the spring metals survey are listed in Table 2.4-9.

TABLE 2.4-6 (continued)

WATER BODY	SAMPLE/STATION	1979 NOV[a]	DEC	1980 JAN	FEB[a]	MAR	APR	MAY[a]	JUN	JUL	AUG[a]	SEP	OCT
Rice Lake	Water Quality												
	F	–	–	–	–	–	–	–	–	–	–	–	–
	N	X[b]	–	–	X	–	–	X	–	–	X	–	–
	Sediment Chemistry[c]												
	F	–	–	–	–	–	–	–	–	–	–	–	–
	N	–	–	–	–	–	–	–	–	–	–	–	–
Hemlock Creek	Water Quality												
	A-1	X	–	–	X	–	–	X	–	–	X	–	–
	A-2	–	–	–	–	–	–	–	–	–	–	–	–
	Sediment Chemistry[c]												
	A-1	–	–	–	–	–	–	–	–	–	–	–	–
	Spring Metals Survey[d]												
	A-1	–	–	–	–	–	–	–	–	–	–	–	–
Swamp Creek	Water Quality												
	B	–	–	–	–	–	–	–	–	–	–	–	–
	D	X	–	–	X	–	–	X	–	–	X	–	–
	E	X	–	–	X	–	–	X	–	–	X	–	–
	Q	–	–	–	–	–	–	–	–	–	–	–	–
	S	–	–	–	–	–	–	–	–	–	–	–	–
	V	–	–	–	–	–	–	–	–	–	–	–	–
	Sediment Chemistry[c]												
	D	–	–	–	–	–	–	–	–	–	–	–	–
	E	–	–	–	–	–	–	–	–	–	–	–	–
	Spring Metals Survey[d]												
	D	–	–	–	–	–	–	–	–	–	–	–	–
	E	–	–	–	–	–	–	–	–	–	–	–	–
	V	–	–	–	–	–	–	–	–	–	–	–	–
Outlet Creek	Water Quality												
	C	–	–	–	–	–	–	–	–	–	–	–	–
Ground Hemlock Lake	Water Quality												
	GH-1	X[b]	X	X	X	X	X[b]	X	X	X	X	X	X
	GH-2	–	–	–	–	–	–	X	X	X	X	X	X
Oak Lake	Water Quality												
	G-1	X	–	–	X	–	–	X	–	–	X	–	–
	G-2	–	–	–	–	–	–	–	–	–	–	–	–
	Sediment Chemistry[c]												
	G	–	–	–	–	–	–	–	–	–	–	–	–

TABLE 2.4-6 (continued)

		1978									
WATER BODY	SAMPLE/STATION	JAN	FEB	MAR[a]	APR	MAY[a]	JUN	JUL	AUG[a]	SEP	OCT[a]
Rice Lake	Water Quality										
	F	X	X	X	-	-	-	-	-	-	-
	N	-	X	X	-	X	-	-	X	-	X
	Sediment Chemistry[c]										
	F	-	-	X	-	-	-	-	-	-	-
	N	-	-	X	-	-	-	-	-	-	-
Hemlock Creek	Water Quality										
	A-1	X	X	X	-	X	-	-	X	-	X
	A-2	X	X	X	-	-	-	-	-	-	-
	Sediment Chemistry[c]										
	A-1	-	-	X	-	-	-	-	-	-	-
	Spring Metals Survey[d]										
	A-1	-	-	-	X	-	-	-	-	-	-
Swamp Creek	Water Quality										
	B	X	X	X	-	-	-	-	-	-	-
	D	X	X	X	-	X	-	-	X	-	X
	E	X	X	X	-	X	-	-	X	-	X
	Q	-	-	-	-	-	-	-	-	-	-
	S	X	X	X	-	-	-	-	-	-	-
	V	X	X	X	X	X	-	-	X	X	-
	Sediment Chemistry[c]										
	D	-	-	X	-	-	-	-	-	-	-
	E	-	-	X	-	-	-	-	-	-	-
	Spring Metals Survey[d]										
	D	-	-	-	X	-	-	-	-	-	-
	E	-	-	-	X	-	-	-	-	-	-
	V	-	-	-	X	-	-	-	-	-	-
Outlet Creek	Water Quality										
	C	X	X	-	-	-	-	-	-	-	-
Ground Hemlock Lake	Water Quality										
	GH-1	-	-	-	-	-	-	-	-	-	-
	GH-2	-	-	-	-	-	-	-	-	-	-
Oak Lake	Water Quality										
	G-1	X	X	X	-	X	-	-	X	-	-
	G-2	X	X	X	-	X	-	-	X	-	-
	Sediment Chemistry[c]										
	G	-	-	X	-	-	-	-	-	-	-

TABLE 2.4-7

SCHEDULE OF WATER AND BOTTOM SEDIMENT CHEMISTRY SAMPLING
IN THE PICKEREL CREEK DRAINAGE BASIN
MARCH 1977 THROUGH OCTOBER 1980

WATER BODY	SAMPLE/STATION	1977									
		MAR[a]	APR	MAY[a]	JUN	JUL	AUG[a]	SEP	OCT[a]	NOV	DEC
Rolling Stone Lake	Water Quality										
	M-2	-	-	-	-	-	-	-	X	X	X
	M-4	-	-	-	-	-	-	-	X	X	X[b]
	Sediment Chemistry[c]										
	M-2	-	-	-	-	-	-	-	-	-	-
	M-4	-	-	-	-	-	-	-	-	-	-
Pickerel Creek	Water Quality										
	M-5	-	-	-	-	-	-	-	X	X	X
	Sediment Chemistry[c]										
	M-5	-	-	-	-	-	-	-	-	-	-
	Spring Metals Survey[d]										
	M-5	-	-	-	-	-	-	-	-	-	-
Creek 12-9	Water Quality										
	M-1	X	X	X	X	X	X	X	X	X	X
	Sediment Chemistry[c]										
	M-1	-	-	-	-	-	-	-	-	-	-
	Spring Metals Survey[d]										
	M-1	-	-	-	-	-	-	-	-	-	-
Creek 11-4	Water Quality										
	M-3	-	-	-	-	-	-	-	X	X	X
	Sediment Chemistry[c]										
	M-3	-	-	-	-	-	-	-	-	-	-
	Spring Metals Survey[d]										
	M-3	-	-	-	-	-	-	-	-	-	-
Little Sand Lake	Water Quality										
	H	X	X	X	X	X	X	X	X	X	X[b]
	I	X	X	X	X	X	X	X	X	X	X[b]
	Sediment Chemistry[c]										
	H	-	-	-	-	-	-	-	-	-	-
	I	-	-	-	-	-	-	-	-	-	-
Duck Lake	Water Quality										
	K	X	X	X	X	X	X	X	X	X	X
	Sediment Chemistry[c]										
	K	-	-	-	-	-	-	-	-	-	-
Deep Hole Lake	Water Quality										
	L	X	X	X	X	X	X	X	X	X	X[b]
	Sediment Chemistry[c]										
	L	-	-	-	-	-	-	-	-	-	-
Skunk Lake	Water Quality										
	J	X	X[b]	X	X	X	X	X	X	X	X
Mole Lake	Water Quality										
	O	-	-	X	X	X	X	X	X	X	X[b]
Walsh Lake	Water Quality										
	WL	-	-	-	-	-	-	-	-	-	-
St. Johns Lake	Water Quality										
	JL	-	-	-	-	-	-	-	-	-	-

Note - Indicates no samples collected.

[a]Water quality samples analyzed for the "seasonal" list of parameters are presented in Table 2.4-9. The parameters on the "monthly" list were analyzed for the other months.

[b]Because of thin or unsafe ice conditions, a contingency sample was collected as near the station as safely possible.

[c]Sediment chemistry samples were analyzed for those parameters listed in Table 2.4-9.

[d]Parameters analyzed from the samples collected for the spring metals survey are listed in Table 2.4-9.

TABLE 2.4-7 (continued)

WATER BODY	SAMPLE/STATION	1978 JAN	FEB	MAR[a]	APR	MAY[a]	JUN	JUL	AUG[a]	SEP	OCT[a]
Rolling Stone Lake	Water Quality										
	M-2	X	X	X	X	X	X	X	X	X	-
	M-4	X	X	X	X	X	X	X	X	X	-
	Sediment Chemistry[c]										
	M-2	-	-	X	-	-	-	-	-	-	-
	M-4	-	-	X	-	-	-	-	-	-	-
Pickerel Creek	Water Quality										
	M-5	X	X	X	X	X	X	X	X	X	-
	Sediment Chemistry[c]										
	M-5	-	-	X	-	-	-	-	-	-	-
	Spring Metals Survey[d]										
	M-5	-	-	-	X	-	-	-	-	-	-
Creek 12-9	Water Quality										
	M-1	X	X	X	X	X	X	X	X	X	-
	Sediment Chemistry[c]										
	M-1	-	-	X	-	-	-	-	-	-	-
	Spring Metals Survey[d]										
	M-1	-	-	-	X	-	-	-	-	-	-
Creek 11-4	Water Quality										
	M-3	X	X	X	X	X	X	X	X	X	-
	Sediment Chemistry[c]										
	M-3	-	-	X	-	-	-	-	-	-	-
	Spring Metals Survey[d]										
	M-3	-	-	-	X	-	-	-	-	-	-
Little Sand Lake	Water Quality										
	H	X	X	X	X	X	-	-	X	-	-
	I	X	X	X	X	X	-	-	X	-	-
	Sediment Chemistry[c]										
	H	-	-	X	-	-	-	-	-	-	-
	I	-	-	X	-	-	-	-	-	-	-
Duck Lake	Water Quality										
	K	X	X	X	X	X	X	X	X	X	X
	Sediment Chemistry[c]										
	K	-	-	X	-	-	-	-	-	-	-
Deep Hole Lake	Water Quality										
	L	X	X	X	X	X	X	X	X	X	X
	Sediment Chemistry[c]										
	L	-	-	X	-	-	-	-	-	-	-
Skunk Lake	Water Quality										
	J	X	X	X	-	-	-	-	-	-	-
Mole Lake	Water Quality										
	O	X	X	X	X	-	-	-	-	-	-
Walsh Lake	Water Quality										
	WL	-	-	-	-	-	-	-	-	-	-
St. Johns Lake	Water Quality										
	JL	-	-	-	-	-	-	-	-	-	-

TABLE 2.4-7 (continued)

WATER BODY	SAMPLE/STATION	1979 NOV[a]	DEC	1980 JAN	FEB[a]	MAR	APR	MAY[a]	JUN	JUL	AUG[a]	SEP	OCT
Rolling Stone Lake	Water Quality												
	M-2	-	-	-	-	-	-	-	-	-	-	-	-
	M-4	-	-	-	-	-	-	-	-	-	-	-	-
	Sediment Chemistry[c]												
	M-2	-	-	-	-	-	-	-	-	-	-	-	-
	M-4	-	-	-	-	-	-	-	-	-	-	-	-
Pickerel Creek	Water Quality												
	M-5	X	-	-	X	-	-	X	-	-	X	-	-
	Sediment Chemistry[c]												
	M-5	-	-	-	-	-	-	-	-	-	-	-	-
	Spring Metals Survey[d]												
	M-5	-	-	-	-	-	-	-	-	-	-	-	-
Creek 12-9	Water Quality												
	M-1	X	-	-	X	-	-	X	-	-	X	-	-
	Sediment Chemistry[c]												
	M-1	-	-	-	-	-	-	-	-	-	-	-	-
	Spring Metals Survey[d]												
	M-1	-	-	-	-	-	-	-	-	-	-	-	-
Creek 11-4	Water Quality												
	M-3	X	-	-	X	-	-	X	-	-	X	-	-
	Sediment Chemistry[c]												
	M-3	-	-	-	-	-	-	-	-	-	-	-	-
	Spring Metals Survey[d]												
	M-3	-	-	-	-	-	-	-	-	-	-	-	-
Little Sand Lake	Water Quality												
	H	X[b]	-	-	X	-	-	X	-	-	X	-	-
	I	-	-	-	-	-	-	-	-	-	-	-	-
	Sediment Chemistry[c]												
	H	-	-	-	-	-	-	-	-	-	-	-	-
	I	-	-	-	-	-	-	-	-	-	-	-	-
Duck Lake	Water Quality												
	K	X[b]	-	-	X	-	-	X	-	-	X	-	-
	Sediment Chemistry[c]												
	K	-	-	-	-	-	-	-	-	-	-	-	-
Deep Hole Lake	Water Quality												
	L	X[b]	-	-	X	-	-	X	-	-	X	-	-
	Sediment Chemistry[c]												
	L	-	-	-	-	-	-	-	-	-	-	-	-
Skunk Lake	Water Quality												
	J	X[b]	-	-	X	-	-	X	-	-	X	-	-
Mole Lake	Water Quality												
	O	-	-	-	-	-	-	-	-	-	-	-	-
Walsh Lake	Water Quality												
	WL	X[b]	X	X	X	X	X[b]	X	X	X	X	X	X
St. Johns Lake	Water Quality												
	JL	X[b]	X	X	X	X	X	X	X	X	X	X	X

TABLE 2.4-8

SCHEDULE OF WATER AND BOTTOM SEDIMENT CHEMISTRY SAMPLING
IN THE WOLF RIVER
OCTOBER 1977 THROUGH OCTOBER 1978

		1977			1978									
WATER BODY	SAMPLE/STATION	OCT[a]	NOV	DEC	JAN	FEB	MAR[a]	APR	MAY[a]	JUN	JUL	AUG[a]	SEP	OCT[a]
Wolf River	Water Quality													
	Y	X	X	X	X	X	X	X	X	X	X	X	X	X
	Z	X	X	X	X	X	X	X	X	X	X	X	X	X
	Sediment Chemistry[b]													
	Y	-	-	-	-	-	X	-	-	-	-	-	-	-
	Z	-	-	-	-	-	X	-	-	-	-	-	-	-
	Spring Metals Survey[c]													
	Y	-	-	-	-	-	-	X	-	-	-	-	-	-
	Z	-	-	-	-	-	-	X	-	-	-	-	-	-

Note - Indicates no samples collected.

[a]Water quality samples analyzed for the "seasonal" list of parameters are presented in Table 2.4-9. The parameters on the "monthly" list were analyzed for the other months.

[b]Sediment chemistry samples were analyzed for those parameters listed in Table 2.4-9.

[c]Parameters analyzed from the samples collected for the spring metals survey are listed in Table 2.4-9.

description of the quality control program, which consisted of field and laboratory procedures and data analyses for the surface water investigation, is also presented.

2.4.1.1 Lake Levels

During ice free periods, water level measurements were made at 10 lake gaging stations (Figure 2.4-1). Water levels were recorded on a monthly basis from April 1977 to October 1978, in April 1979, and monthly from April to October 1980 (Table 2.4-3). Occasionally, more frequent measurements were made to monitor the effects of increases or decreases in precipitation. Data from these measurements are presented in Appendix 2.4B.

Water levels were measured by means of staff gages located and constructed in accordance with USGS procedures (Buchanan and Somers, 1968). The gages consisted of a section of enameled iron 101.6 mm (4 inches) wide, 1.0 m (3.4 feet) long, and graduated every 3.0 mm (0.01 foot). These sections were attached to a steel fence post firmly driven into the lake bed. For each staff gage, surveyors established local benchmarks and determined the elevation of the 0.00 datum above the USGS mean sea level datum. Staff gages were resurveyed in the spring of each year to correct for movement because of ice damage as discussed below. Water levels were read directly from the staff gage and measurement units corrected to feet above mean sea level.

During January 1985, a special investigation produced short-term but detailed field observations on Little Sand, Oak, Duck, and Skunk lakes. In addition to frequent and precise lake water surface elevations, many climatic, stream flow, ground water, and lake seepage variables were observed as a basis for a definitive lake water balance analysis. These data and the analytical results are presented in a separate report (Dames & Moore, 1985).

2.4.1.2 Stream Flow Rates

Stream flow rates are a major aspect of the temporal and areal variations in surface water systems studied. Stream stages and flow rates were observed in the field at representative sites over discontinuous time periods from April 1977 to November 1980. These data were originally intended only to characterize the seasonal variations in flow rates and the areal variations in low flow magnitudes. Ongoing and related environmental investigations, along with developing mining designs, subsequently indicated the desirability of more comprehensive and reliable stream flow evaluation than originally planned. Consequently, some of the stream flow rate data have been revised.

Manual observations of water levels at staff gages were used to establish stream flow rate records. The relation between stream discharge and water level was established through concurrent flow and staff observations, and this "rating curve" allowed conversion of staff readings to discharge rates. The following paragraphs describe the techniques of field data collection, the original analytical process, and the revised analyses.

During ice-free periods, scheduled water level measurements were made at 12 staff gage stations (Table 2.4-4). Stream levels were generally recorded on a weekly basis from April 1977 to October 1979, during April 1979, and from April to November 1980 (Table 2.4-4). Occasionally, more frequent measurements were made to monitor the effects of precipitation on stream flow rates.

Observations at SG 5A were discontinued in July 1977 because of difficulties encountered while making discharge measurements. This station was replaced by SG 5B, which was located approximately 0.6 km (0.4 mile) downstream (Figure 2.4-1). Staff Gage 23 was installed on Creek 12-9 in April 1978 and read thereafter as part of the stream flow program. The sites referenced as Miscellaneous A through F (Table 2.4-1; Figure 2.4-1) were temporary stations established to describe water movement characteristics in subbasins of the Swamp Creek and Pickerel Creek drainage basins. Data from these measurements are presented in Appendix 2.4A.

Stream levels were measured by means of staff gages located and constructed in accordance with USGS procedures (Buchanan and Somers, 1968). The same type of gage was used to measure lake and stream levels. Each gage was attached to either a stationary structure such as a bridge, or to a steel fence post driven firmly into the stream bed. Surveyors established local benchmarks and determined the elevations of the 0.00 datum above mean sea level for each stream gage. Water levels were read directly from the staff gage and measurement units were corrected to feet above mean sea level.

Staff gages were resurveyed in the spring of each year to correct for movement caused by ice damage. The change in gage datum (survey elevation) due to the freeze and thaw cycle during the winter had little effect on the accuracy of stage-discharge determinations; the average change in gage datum was 3.0 cm (0.10 foot) for the eight gages being monitored. This small change in elevation was corrected in the spring at the start of ice-free data collection.

Stream water discharge was determined as a rate of flow by making observations of the stream water level on a staff gage at a specific stream location. The staff gages were calibrated by current meter discharge measurements. The methods used for stream water discharge measurements and for calibration of the staff gages are described in the following paragraphs.

Stream discharges were measured 99 times at the 18 project stream gaging stations listed in Table 2.4-4. In addition, discharge measurements were made at the two USGS gaging stations. Stream discharge is defined as the rate of flow of water and any intermixed sediment or other solids, and is usually expressed in cubic feet per second or cubic meters per second. At most locations, discharges were measured according to standard USGS procedures (Buchanan and Somers, 1969) using the USGS mid-section method of measuring stream velocities and calculating discharges. A cross section was established near each stream gage for the measurement of stream discharges. The cross section was divided into approximately 20 verticals for measuring discharge by segments across the stream. Measurements of stream velocity were made at sixth-tenths of the depth below the surface in each imaginary vertical line dividing the stream. Velocity measurements were made with a Scientific Instruments Pygmy Current Meter No. 1210P, which is accurate to the nearest 0.03 m/s (0.1 foot per second). Stream discharge was then calculated on the assumption that the velocity measured at each vertical represents the mean velocity in a partial rectangular area (Buchanan and Somers, 1969). This partial area extended laterally from the center of one segment to the center of the next, and vertically from the water surface to the stream bottom.

For the calculation of stream discharge values, the cross section is defined by depths at verticals 1, 2, 3, 4,...N. At each vertical, the measured velocity and depth are used to calculate the discharge for the partial section at vertical N as:

$$q_x = v_x \left[\frac{b_{(x+1)} - b_{(x-1)}}{2}\right] d_x$$

where:

q_x = discharge through partial area x;

v_x = mean velocity at vertical x;

$b_{(x-1)}$ = distance from initial point to preceding vertical;

$b_{(x+1)}$ = distance from initial point to the next vertical; and

d_x = depth of water at vertical x.

The total stream discharge (Q) equals the sum of the discharges for all the partial sections (Buchanan and Somers, 1969).

$$Q = \sum_{x=1}^{N} q_x$$

During periods of high stream flow when wading the stream to obtain velocity measurements would be dangerous or where no suitable stream cross section could be located, a modified method of measuring and calculating discharges at culverts was used. On 19 occasions, at eight gaging locations, SG 1, SG 5A, SG 10, SG 19, SG B, SG C, SG D, and SG E, discharges were measured using the following method at culverts underneath bridges near the gaging station. The basic assumptions of this method are the same as those for the USGS mid-section method (Buchanan and Somers, 1969). At culverts, the cross section was subdivided into several small square partial areas. Velocity measurements were made in the center of each of these partial areas to establish an average velocity for that partial area. The discharge for each partial area was then determined by multiplying the average velocity times the area of the partial area. The sum of the discharges of the partial areas was equivalent to the stream discharge.

Rating curves defining the relation between flow rates and staff gage heights were developed to establish discharge rates at 12 staff gage sites, as shown in Appendix 2.4A, Figure A-1. At the remaining six stream gaging stations, SG 5A, SG A, SG C, SG D, SG E, and SG F, rating curves were not constructed because infrequent measurement of stream discharges did not provide a sufficient data base. Staff Gages A, B, C, D, E, and F were established as temporary gages to characterize drainage subbasins during storm events and periods of high surface water runoff. SG 5A was replaced with SG 5B early in the study. Summaries of the rating curve analyses for the staff gages are presented in Appendix 2.4K. At SG 1, SG 5B, and SG 6, separate ratings were defined for two different time periods, and for SG 6, SG 19, and SG 22, shifting control adjustments were utilized to adjust for channel changes.

Staff gages occasionally were read at levels above or below stages measured to define the rating curves. Discharge determinations for these readings, therefore, are less accurate than for intermediate measured stages. In early drafts, discharge values were not provided for these extreme stage readings, but because this omission inhibits definition of low flow characteristics, the constraint was relaxed in a subsequent analysis after agency comments (see Appendix 2.4L), and discharges were evaluated for extreme readings but were flagged to indicate values of lower reliability.

No discharges were measured at times of ice cover when rating curves are unlikely to define appropriate discharge values. In the original stream flow rate analysis, the effects of ice cover were assumed to be small, and discharges were determined directly from the staff gage readings and rating curve. During a subsequent analysis (described in Appendix 2.4L), discharges during periods of ice cover were determined by hydrographic comparison with complete flow rate records for the USGS gages on Swamp Creek above Rice Lake at Highway 55 and Swamp Creek below Rice Lake at County Highway M.

Stream flow rate data are presented in Appendix 2.4A, Tables A-1 through A-15. In these tables, gage datum refers to the elevation, in feet above mean sea level, of 0.00 on the staff gage. The upper and lower reliability limits of the rating curves were arbitrarily set to be approximately 10 percent higher or lower than the highest and lowest measured discharges.

Stream flow rate records collected by the USGS were also used in the stream water discharge analysis, including those from two recently established stations. In August of 1977, the USGS began collecting stream water discharge data at two locations on Swamp Creek: one upstream of Rice Lake (referred to as USGS at Highway 55) and one downstream of Rice Lake (referred to as USGS at County Highway M) (Figure 2.4-1). These stations were equipped with continuous water level recorders. The 1977 to 1980 data collected at these two USGS stations are presented in Appendix 2.4C. USGS flow rate records for 1982 and 1983 at County Highway M are presented in Ecological Analysts, Inc. (1983, 1984).

Hydrographs showing the variations of stream discharge over time were prepared from USGS records at two continuous gaging stations and are presented in Appendix 2.4J, Figures J-9 through J-11. For visual comparison, similar hydrographs at the same scales were prepared for each of the project staff gages that were read at least on a weekly schedule. These hydrographs are presented in Appendix 2.4J, Figures J-1 through J-8. These hydrographs are based upon a linear interpolation between observed discharge values, and they indicate discharge rates only within the established confidence level of the rating curves and show discharges as determined by direct application of the rating curve during ice periods. Despite these limitations on the precision of the hydrographs, they provide a reasonable basis for graphical comparisons of areal variations in flow rates and for judging the temporal similarities and differences in stream flow patterns. Hydrographs were not prepared for the stream staff gages that were monitored less frequently than weekly. Data from the less frequently recorded stream staff gages were used in defining the hydrologic characteristics of the site area and were not intended for use in developing hydrographs. Lake level hydrographs (lake level versus time) were also plotted and are presented in subsection 2.4.3.

As mine development plans progressed and as related environmental studies became available, more reliable and precise stream flow rate information was required at selected staff gage sites. In a reanalysis after agency comments, available flow rate data were used to redefine hydrographs for nine staff gage sites (SG 1, SG 2, SG 5B, SG 6, SG 8, SG 19, SG 22, SG 23, and SG B). No hydrographs were redefined for sites SG 3 and SG 4 because they were considered unnecessary for the desired water balance studies (see Appendix 2.4L), and no hydrograph was redefined for SG 9 because insufficient data were available for a meaningful analysis. Hydrographic comparison techniques (Carter and Davidian, 1965; Rantz, 1983) were used to define the discharges during periods of ice cover and during days of no staff gage readings.

Estimates of the average monthly and annual flow rates for the period of staff gage observations were obtained from the redefined hydrographs. In addition, the techniques of hydrograph separation (Riggs, 1963; Linsley et al., 1975) provided estimates of monthly and annual base flow rates, the contribution of ground water or other stored water to stream flows. The defined average and base flow values are presented in Appendix 2.4L, and average and base flow values for the 1978 water year (October 1977 through September 1978) are provided in subsection 2.4.4.1 (see Table 2.4-19).

USGS personnel (Krug, 1984) have provided independently determined estimates of the low flow characteristics for several sites in the project study area. These characteristics are the 7-day average flow rate expected to be reached as a minimum of no more frequently than once per 2 years, on the average (Q7,2), and no more frequently than once per 10 years, on the average (Q7,10). Stated in another way, there is a 50 percent chance that the lowest 7-day average flow rate in any year will be less than Q7,2 and one chance in 10 that the minimum 7-day average flow in any year will be less than Q7,10.

Values of Q7,2 and Q7,10 were determined by correlating a few base flow measurements at the project gaging sites with concurrent flow rates on the Wolf River at Langlade. The long-term record at Langlade had been analyzed to define the likelihood of experiencing low flow rates, and the correlation between the concurrent flows at the project gaging sites allowed transfer of the probabilities. Flow measurements by USGS personnel on or about October 2, 1984, when used in relations defined by Holstrom (1980), indicated that the estimates of Q7,2 and Q7,10 calculated by Krug (1984) are reasonable. These estimates are presented in subsection 2.4.4.1 (see Table 2.4-19).

Values of Q7,10 would be expected to be similar to or smaller than the minimum observed flow rates during the 3-year observation period unless the gaging period occurred during a drought. At four sites listed in Table 2.4-19, the Q7,10 exceeds the observed minimum. These low gaged values possibly record some unique, temporary or man-made stream flow aberration, but more likely they indicate the imprecision of values being compared. Both the estimated Q7,10 and observed minimum include a degree of uncertainty. The Q7,10 is based on the assumption that concurrent flow rates at the Wolf River gage and the project gaging sites have common likelihoods of occurrence (duration points), and that flow rates are precisely defined. For minimum flow rates at the staff gage sites, it was assumed that stage-discharge ratings were defined reliably. Review of the ratings in use at the four sites when the minimum was determined indicates that at two sites (SG 4 and SG 22), the stage was below the lowest defined point on the rating. At the other two sites (SG 6 and SG 19), shifting control adjustments were in use, suggesting unstable rating definition. However, the magnitude of differences between Q7,10 and observed minimum is small -- 0.017 m^3/s (0.6 cubic foot/second) or less.

2.4.1.3 Suspended and Bottom Sediment Sampling

Suspended sediment sampling was conducted concurrently with the stream water discharges and lake level measurements during the field monitoring program. The location and frequency of suspended sediment sampling are given in Table 2.4-4. A total of 173 suspended sediment samples were collected from 16 stream gaging locations from October 1977 to April 1979 (Table 2.4-5). Sampling stations were established at the cross sections used to measure stream discharge so that suspended sediment transport rates could be determined. The samples collected were analyzed to determine total suspended solids and volatile suspended solids. The results of these analyses are presented in Appendix 2.4D.

Suspended sediment samples were collected according to USGS procedures, following the Equal Transit Rate (ETR) Method (Guy and Norman, 1970). A DH-48 depth-integrating suspended sediment sampler was used.

In the ETR method, depth integrated suspended sediment samples are taken at equally spaced verticals across the stream cross section. The cross-sectional area of the stream was established in the same manner used to determine stream discharge. At each vertical, the sampler is lowered to the streambed and returned to the surface at a constant rate (ETR). The suspended sediment sample obtained by the ETR method at each vertical is proportional to the amount of flow through the respective partial area. The equal spacing between verticals across the stream and the equal transit rate, both upward and downward, of the sampler yield a sample proportional to the stream flow.

Suspended sediment samples collected in the field were sent to Aqualab Inc., Streamwood, Illinois, for analysis. The suspended sediment samples were analyzed for total suspended solids by glass fiber filtration and volatile suspended solids by the gravimetric method (American Public Health Association et al., 1976).

In addition to suspended sediment sampling, stream bottom sediment samples were collected for physical characterization once at each of four locations in order to provide a general characterization of the nature of the sediment. These locations (SG 3, SG 4, SG 6, and SG 22) included the common streambed types found in the environmental study area: sand, sand and gravel, and organic bottom material.

A USGS Type BMH-53 hand-held piston-type bed material sampler was used (Guy and Norman, 1970). This sampler collects a column of material, 50.8 mm (2 inches) in diameter and 203.2 mm (8 inches) long with a minimum of distortion. The samples were analyzed in the Dames & Moore soils laboratory in Park Ridge, Illinois for grain-size distribution using the standard sieve method in accordance with American Society for Testing and Materials (ASTM) Standard Methods for Particle Size Analysis of Soils (American Society for Testing and Materials, 1977). For a complete description of the procedure, the reader is referred to ASTM Part 19 Standard Methods D-422, Particle Size Analyses of Soils.

2.4.1.4 Water and Bottom Sediment Chemistry

The surface water quality investigation was designed initially to provide data for 15 water bodies. Water samples were collected monthly from February 1977 through October 1978 as indicated in Tables 2.4-6 through 2.4-8. Subsequently, from November 1979 through October 1980, 11 of the previously sampled stations were sampled seasonally and three additional water bodies (Ground Hemlock, St. Johns, and Walsh lakes) were sampled monthly. At various times thin or unsafe ice conditions made the collection of lake water samples hazardous. On these occasions (Tables 2.4-6 through 2.4-8), a contingency sample was collected as near the station as safely possible.

Supplemental water samples were collected in April 1978 at nine stream sampling stations to evaluate the influence of spring runoff on several chemical parameters (Tables 2.4-6 through 2.4-8). The streams sampled were Hemlock Creek (Station A-1), Swamp Creek (Stations D, E, and V), Creek 11-4 (Station M-3), Creek 12-9 (Station M-1), Pickerel Creek (Station M-5), and the Wolf River (Stations Y and Z).

Water samples were collected at lake stations approximately 1 m (3.3 feet) below the water surface and at stream stations at a subsurface depth of approximately 0.2 m (0.7 foot). As evidenced by temperature and dissolved oxygen profile data (Appendix 2.4H, Tables H-6 and H-9), both Oak and Ground Hemlock lakes exhibited well defined seasonal vertical stratification. Therefore, additional water samples were collected from depths of 5 to 7 m (16 to 23 feet) to monitor possible stratification.

Water samples for chemical analysis were collected at lake stations with a 2.2-, 6.2-, or 8.2-liter PVC Van Dorn-type water bottle. Samples for bacteriological analysis were collected with a Gemware-JZ Bacteriological Water Sampler equipped with two evacuated, sterilized 0.5-liter glass reagent bottles. At the stream stations, water samples were collected by "hand-dipping" with a 1-liter plastic bottle for chemical analysis and a sterilized 0.250-liter plastic container for bacteriological analysis. To prevent contamination of the sample, the container was opened and closed underwater.

The water chemistry parameters analyzed are listed in Table 2.4-9. The parameters on the "seasonal" list were analyzed during March, May, August, and October in 1977 and 1978, and during November 1979, February, May and August 1980. The parameters on the "monthly" list were analyzed during the intervening months according to the water chemistry program.

Procedures and detection limits, and sample containers and methods of preservation of all water chemistry parameters are listed in Tables 2.4-10 and 2.4-11, respectively.

Immediately after collection, all water chemistry samples were placed on ice in an insulated container and shipped to the laboratory via air freight on the day of collection. Water chemistry analyses were performed by Aqualab, Inc. The holding time for each parameter prior to analysis was in accordance with U.S. EPA (1974) methods.

TABLE 2.4-9

WATER AND BOTTOM SEDIMENT CHEMISTRY LABORATORY PARAMETERS

	WATER ANALYSES			
PARAMETER	SEASONAL	MONTHLY	SPRING RUNOFF	SEDIMENT ANALYSIS
Total laboratory alkalinity	X	X		
Total hardness	X	X		
Total solids	X	X	X	X
Total volatile solids	X		X	X
Total dissolved solids	X	X	X	
Total suspended solids	X	X	X	
Total volatile suspended solids	X		X	
Color, true	X			
Ammonia nitrogen (N)	X			
Nitrate nitrogen (N)	X			
Nitrite nitrogen (N)	X			
Organic nitrogen (N)	X			
Total phosphorus (P)	X			
Dissolved orthophosphate (P)	X			
Chloride	X	X		
Sulfide	X	X		X
Sulfur, total	X	X		X
Sulfate	X	X		X
Cyanide, total	X	X		
Phenols	X	X		X
Surfactants	X			
Biochemical oxygen demand 5-day	X			
Chemical oxygen demand	X			
Fecal streptococcus	X			
Fecal coliform	X			
Freon extractables	X	X		X
Arsenic*	X	X	X	X
Aluminum*	X		X	
Cadmium*	X	X	X	X
Chromium*-III	X		X	
Chromium*-VI	X		X	
Chromium, total*				X
Cobalt*	X		X	
Copper*	X	X	X	X
Iron*	X	X	X	X
Lead*	X	X	X	X
Manganese*	X	X	X	X
Mercury*	X	X	X	X
Molybdenum*	X		X	
Nickel*	X		X	
Zinc*	X	X	X	X

*Trace metals were determined as total metal present, except during spring runoff 1978 when dissolved and total metals were determined.

TABLE 2.4-10

PROCEDURE SUMMARY AND DETECTION LIMITS FOR WATER CHEMISTRY PARAMETERS

PARAMETER	REPORTED AS	METHOD	REFERENCES (PAGE NUMBERS) U.S. EPA 1974	APHA et al. 1976	DETECTION LIMIT
Total laboratory alkalinity	$CaCO_3$	Titrametric to pH 4.5 end point	3	278	1 mg/ℓ
Total hardness	$CaCO_3$	EDTA titration or sum of Ca and Mg as their carbonates	68	202	1 mg/ℓ
Total solids	-	Total residue dried at 103° - 105°C	270	91	1 mg/ℓ
Total volatile solids	-	Total volatile and fixed residue at 550°C	272	95	1 mg/ℓ
Total dissolved solids	-	Total filterable residue dried at 180°C.	266	92	1 mg/ℓ
Total suspended solids	-	Total nonfilterable residue dried at 103° - 105°C	268	94	1 mg/ℓ
Total volatile suspended solids	-	Volatile and fixed matter in nonfilterable residue and in solid and semi-solid samples	-	96	1 mg/ℓ
Color, true	Pt-Co	Spectrophotometric	39	66	1 color unit
Ammonia nitrogen	N	Distillation followed by Nesslerization	159	410,412	0.01 mg/ℓ
Nitrate nitrogen	N	Cadmium reduction	201	423	0.05 mg/ℓ
Nitrite nitrogen	N	Diazotization	215	434	0.01 mg/ℓ
Organic nitrogen	N	Kjeldahl minus ammonia	175,159	437	0.01 mg/ℓ
Total phosphorus	P	Persulfate digestion followed by ascorbic acid reduction	249	481	0.01 mg/ℓ
Dissolved orthophosphaste	P	Ascorbic acid reduction	249	481	0.01 mg/ℓ
Chloride	Cl	Mercuric nitrate	29	304	1 mg/ℓ
Sulfide	S	Methylene blue	-	503	0.01 mg/ℓ
Sulfate	SO_4	Turbidimetric	277	496	1 mg/ℓ
Sulfur, total	S	Acid cook, analyze for sulfate, sum with sulfide	-	-	0.01 mg/ℓ
Cyanide, total	CN	Distillation followed by barbituric acid	40	361	0.001 mg/ℓ
Phenols	-	Distillation followed by 4 AAP	241	582	0.001 mg/ℓ
Surfactants	MBAS	Methylene blue extraction	157	600	0.01 mg/ℓ
Biochemical oxygen demand	BOD_5	Electrode	-	543	1 mg/ℓ
Chemical oxygen demand	COD	Dichromate reflux	20	550	1 mg/ℓ
Fecal streptococcus	organisms per 100 ml	Membrane filter	-	937	1 org/mℓ
Fecal coliform	organisms per 100 ml	Membrane filter	-	944	1 org/mℓ
Freon extractables	Freon extractables	Partition - gravimetric	229	515	1 mg/ℓ
Metals*, total	element	Acid digestion followed by atomic absorption spectroscopy	78	147	
Aluminum					0.01 mg/ℓ
Arsenic					0.001 mg/ℓ
Cadmium					0.001 mg/ℓ
Chromium - III					0.001 mg/ℓ
Chromium - VI					0.01 mg/ℓ
Chromium, total					0.0001 mg/ℓ
Cobalt					0.01 mg/ℓ
Copper					0.001 mg/ℓ
Iron					0.01 mg/ℓ
Lead					0.01 mg/ℓ
Manganese					0.001 mg/ℓ
Mercury					0.0001 mg/ℓ
Molybdenum					0.01 mg/ℓ
Nickel					0.01 mg/ℓ
Zinc					0.001 mg/ℓ

*The methods for determination of dissolved metals consists of filtration through a 0.45 μ filter followed by atomic absorption spectroscopy.

TABLE 2.4-11

WATER SAMPLE CONTAINERS AND PRESERVATIVES FOR LISTED PARAMETERS

PARAMETER	CONTAINER*	PRESERVATIVE
Total laboratory alkalinity	P,G	Cool, 4°C
Total hardness	P,G	Cool, 4°C
Total solids	P,G	Cool, 4°C
Total volatile solids	P,G	Cool, 4°C
Total dissolved solids	P,G	Cool, 4°C
Total suspended solids	P,G	Cool, 4°C
Total volatile suspended solids	P,G	Cool, 4°C
Color, true	P,G	Cool, 4°C
Ammonia nitrogen (N)	P,G	Cool, 4°C; H_2SO_4 to pH<2
Nitrite nitrogen (N)	P,G	Cool, 4°C
Nitrate nitrogen (N)	P,G	Cool, 4°C; H_2SO_4 to pH<2
Organic nitrogen (N)	P,G	Cool, 4°C; H_2SO_4 to pH<2
Total phosphorus (P)	P,G	Cool, 4°C
Dissolved orthophosphate (P)	P,G	Filter on Site; Cool, 4°C
Chloride	P,G	None required
Sulfide	P,G	2 ml Zinc Acetate
Sulfur, total	P,G	Cool, 4°C
Sulfate	P,G	Cool, 4°C
Cyanide, total	P,G	Cool, 4°C; NaOH to pH 12
Phenols	G	Cool, 4°C; H_3PO_4 to pH<4; 1.0 g $CuSO_4$/
Surfactants	P,G	Cool, 4°C
Biochemical oxygen demand-5 day	P,G	Cool, 4°C
Chemical oxygen demand	P,G	H_2SO_4 to pH<2
Fecal streptococcus	P,G (Sterilized)	Cool, 4°C
Fecal coliform	P,G (Sterilized)	Cool, 4°C
Freon extractables	G	Cool, 4°C H_2SO_4 or HCl to pH<2
Arsenic	P,G	HNO_3 to pH<2
Aluminum	P,G	HNO_3 to pH<2
Cadmium	P,G	HNO_3 to pH<2
Chromium III	P,G	HNO_3 to pH<2
Chromium VI	P,G	HNO_3 to pH<2
Chromium, total	P,G	HNO_3 to pH<2
Cobalt	P,G	HNO_3 to pH<2
Copper	P,G	HNO_3 to pH<2
Iron	P,G	HNO_3 to pH<2
Lead	P,G	HNO_3 to pH<2
Manganese	P,G	HNO_3 to pH<2
Mercury	P,G	HNO_3 to pH<2
Molybdenum	P,G	HNO_3 to pH<2
Nickel	P,G	HNO_3 to pH<2
Zinc	P,G	HNO_3 to pH<2

*P - plastic
G - glass

A description of field conditions was recorded during all field surveys. This description included: collection time, weather and water conditions, and stream or lake depth. Field measurements for water temperature, pH, turbidity, transparency, conductivity, and dissolved oxygen concentration were recorded for lake and stream stations (Appendix 2.4F). With the exception of transparency, vertical profiles for these parameters and for oxygen saturation were recorded for lake stations (Appendix 2.4H, Tables H-4 through H-14). Vertical profile measurements were obtained at subsurface and at 1-m (3.3-foot) intervals thereafter. In-situ measurements were obtained of dissolved oxygen (YSI Model No. 54), conductivity (YSI Model No. 33), water temperature (temperature mode of YSI Model No. 54 or 33) and transparency (Secchi disc). Turbidity (Hach Model No. 2100 A) and pH (Markson Model No. 85) were measured on site for samples collected during water chemistry collections.

Where discussed in the text, conductivity is expressed as specific conductance (measured at 25°C). Specific conductance values were converted from field conductivity and temperature measurements (Appendices 2.4F, 2.4G, and 2.4H), utilizing the conversion curve (based on a 0.01M KCl solution) presented in Standard Methods for Examination of Water and Waste Water (American Public Health Association et al., 1971).

Arithmetic means were calculated for all parameters (which for pH is the negative log of the geometric mean of the H^+ ion concentration). Concentrations reported below the limit of detection were signified by the "less than" sign (<). These values were considered to be at the level of detection for calculation of the mean and the mean was reported as a "less than" value if the average was the "detection limit." In these cases, the mean lies between the reported numerical value and a minimum value that could be calculated assuming all "less than" values were some concentration between the level of detection and 0. Occasionally, the concentration of a parameter may be reported as a "greater than" value, signified by a "greater than" sign (>). The value was used in calculation of the mean and was reported as "greater than." In these cases, the mean lies above the reported numerical value.

The water quality parameters are discussed to generally describe the water bodies. The water bodies also are classified in relation to hardness, pH and color based on the categories presented in Table 2.4-12.

The water chemistry data are presented according to sampling station and time in Appendix 2.4F, Tables F-1 through F-29. In Appendix 2.4G, Tables G-1 through G-29, the means and ranges for the parameters analyzed at each station are presented. Supplementary water quality data such as the April 1978 survey, Stations Q, S, and A-2, and lake profiles are presented in Appendix 2.4H, Tables H-1 through H-14. Additional water quality data collected on Swamp Creek below Rice Lake during 1982 and 1983 are presented in Ecological Analysts, Inc. (1983, 1984).

Bottom sediment samples were collected from 12 water bodies (Table 2.4-2) during March 1978 with a 15.2- x 15.2-cm (6- x 6-inch) Ekman grab sampler. Sediment material to be used for chemical analyses was removed from the center of the sampler to minimize contact with the outer walls of the sampling device. Material to be analyzed was then placed in externally marked, acid-rinsed plastic containers. Each sample container was immediately placed on ice in an insulated container and shipped via air freight on the day of collection to the laboratory for analysis. Samples were frozen upon

TABLE 2.4-12

HARDNESS, pH, AND COLOR CLASSIFICATION SYSTEM

HARDNESS[a] (mg/ as $CaCO_3$)	pH[b] (standard units)	COLOR[c] (color units)
0 - 75 = soft	0 - 2 = very acidic	0 - 20 = clear
75 - 150 = moderately hard	2 - 4 = acidic	20 - 50 = light brown
150 - 300 = hard	4 - 6 = slightly acidic	50 - 100 = medium brown
300+ = very hard	6 - 8 = neutral	100+ = dark brown
	8 - 10 = slightly basic	
	10 - 12 = basic	
	12 - 14 = very basic	

[a]Sawyer and McCarty, 1967.

[b]This classification is based on narrative text used by Steuck and Andrews (1976).

[c]This classification system was developed specifically for this study.

receipt at the laboratory and remained frozen until analysis. Analyses were conducted within 1 month of receipt of the samples.

The sediment samples were analyzed for the parameters listed in Table 2.4-9. The results of the analyses are presented in Appendix 2.4E. The data from sediment samples collected in August and October 1977 have not been utilized in the description of environmental conditions. The quality control program led to the questioning of several of the reported concentrations. Subsequent investigation in the laboratory demonstrated a lack of reproducibility, suggesting inadequate homogenization during sample preparation. Three alternate sample preparation procedures were evaluated in the laboratory and compared on the basis of reproducibility of analytical results. The methodology for sample homogenization and analysis, which was developed and subsequently utilized for sediment samples collected from 12 water bodies in the environmental study area during March 1978, is presented in the following paragraphs.

Sediment samples were screened through a stainless steel sieve, 2-mm (0.079-inch) mesh size, by rubbing with a rubber stopper, when necessary. Large pieces of extraneous material, such as stones and twigs, were removed. The sieved material was then homogenized by blending with an Osterizer blender for 2 minutes at high speed (Great Lakes Region Committee on Analytical Methods [GLRCAM], 1969).

Several portions of the wet, sieved, and blended sample were weighed. The size of the aliquot depended upon the concentration range anticipated for the parameter to be measured and the known sensitivity of the applicable analytical technique. All aliquots were weighed simultaneously to reduce potential errors resulting from possible decomposition and/or dehydration. This was essential since all final results were reported as dry weight and were calculated on the basis of the percent of total solids measured for each sample.

The parameters analyzed, the size and number of aliquots used for analysis, and the analytical methods used for sediment samples are presented in Table 2.4-13.

2.4.1.5 Quality Control

Quality control procedures were utilized by field and office personnel during the surface water resources investigation as a means of assuring that the study was completed according to currently accepted standards and methods.

Field Procedures - All field activities were conducted by trained Dames & Moore personnel. In addition to recording field activities on daily memos, the resulting data were recorded on special preprepared forms designed for each activity.

Calibration of the dissolved oxygen, pH, and turbidity meters was performed daily by the field crew prior to initiation of measurements using standard methods of calibration described below.

The pH electrode was standardized using the appropriate pH buffers according to manufacturer's specifications. Fresh buffers were periodically obtained throughout the study. The turbidity meter was calibrated using the calibration standards supplied by the manufacturer. The dissolved oxygen meter was calibrated using the barometric pressure and temperature per the manufacturer's directions.

TABLE 2.4-13

ALIQUOT SIZE, NUMBER OF ALIQUOTS, AND ANALYTICAL METHODS FOR SEDIMENT CHEMISTRY ANALYSIS

PARAMETER	ALIQUOT SIZE (Number of aliquots)	ANALYTICAL METHOD	REFERENCES - PAGE NUMBERS GLRCAM, 1969	U.S. EPA, 1974	APHA AND OTHERS, 1976
Total solids Total volatile solids Iron Manganese Zinc Cadmium Copper Chromium, total Lead	20 g (1)	Total Solids-Dry Sample overnight at 103°-105°C Total Volatile Solids-Weight loss of dry weight sample after ignition in a muffle furnace at 600°C for 1 hour Metals - Dissolve ash sample after total volatile solids determination in minimum quantity of concentrated HCl and deionized water. Filter sample and neutralize with NH_4OH and adjust to standard volume, followed by atomic adsorption spectrophotometric analysis	Total Solids - p. 85 Total Volatile Solids - p. 85		Metals - p. 148
Arsenic	1 g (2)	Atomic Absorption Spectrophotometric Analysis utilizing the gaseous hydridegeneration method			p. 159
Mercury	5 g (2)	Cold Vapor (Flameless) Atomic Absorption Spectrophotometric Analysis after Sample Digestion		p. 118	
Phenols	25 g (1)	Chloroform extraction			p. 577
Freon extractables	20 g (1)	Freon extraction of oil and grease			p. 519
Sulfide	5 g (1)	Distillation into zinc acetate solution followed by methylene blue colorimetric determination			p. 503
Sulfate	5 g (1)	Leach sample with deionized water, filter and analyze turbidimetrically			p. 496
Sulfur, total	5 g (1)	Determined turbidimetrically as sulfate after rigorous digestion to oxidize all sulfur compounds to sulfate			p. 496

Analytical Quality Control - Chemical analyses for water, bottom sediment, and suspended sediment samples were conducted by Aqualab, Inc. Monitoring of analytical performance was accomplished by the analysis of duplicate ("split") samples. This procedure is discussed in further detail in subsection 2.3.1.8. All laboratory analyses completed by Aqualab, Inc. were subject to review and verification procedures.

As part of the quality control program for the present study, samples were split at intervals specified by the DNR or as part of in-house quality control. Samples were split in the field for separate analysis by Aqualab, Inc. and the DNR. The Aqualab laboratory facilities were also audited by Dames & Moore, DNR, and Exxon personnel regarding laboratory analysis records and compliance with procedures outlined in the Quality Assurance Manual.

Grain-size analyses for bottom sediment samples were performed in accordance with ASTM methods. All laboratory equipment was calibrated in accordance with Dames & Moore standard soils laboratory procedures. The soils laboratory is inspected and audited at least annually by Dames & Moore quality assurance personnel.

Data Analyses - All data were rechecked by a Dames & Moore employee other than the original investigator. This review included checking of calculations where applicable and was recorded by the signing and dating of the document reviewed.

All data that were transcribed onto computer code forms were checked for accuracy by a second individual who made corrections where needed and signed and dated the coding forms.

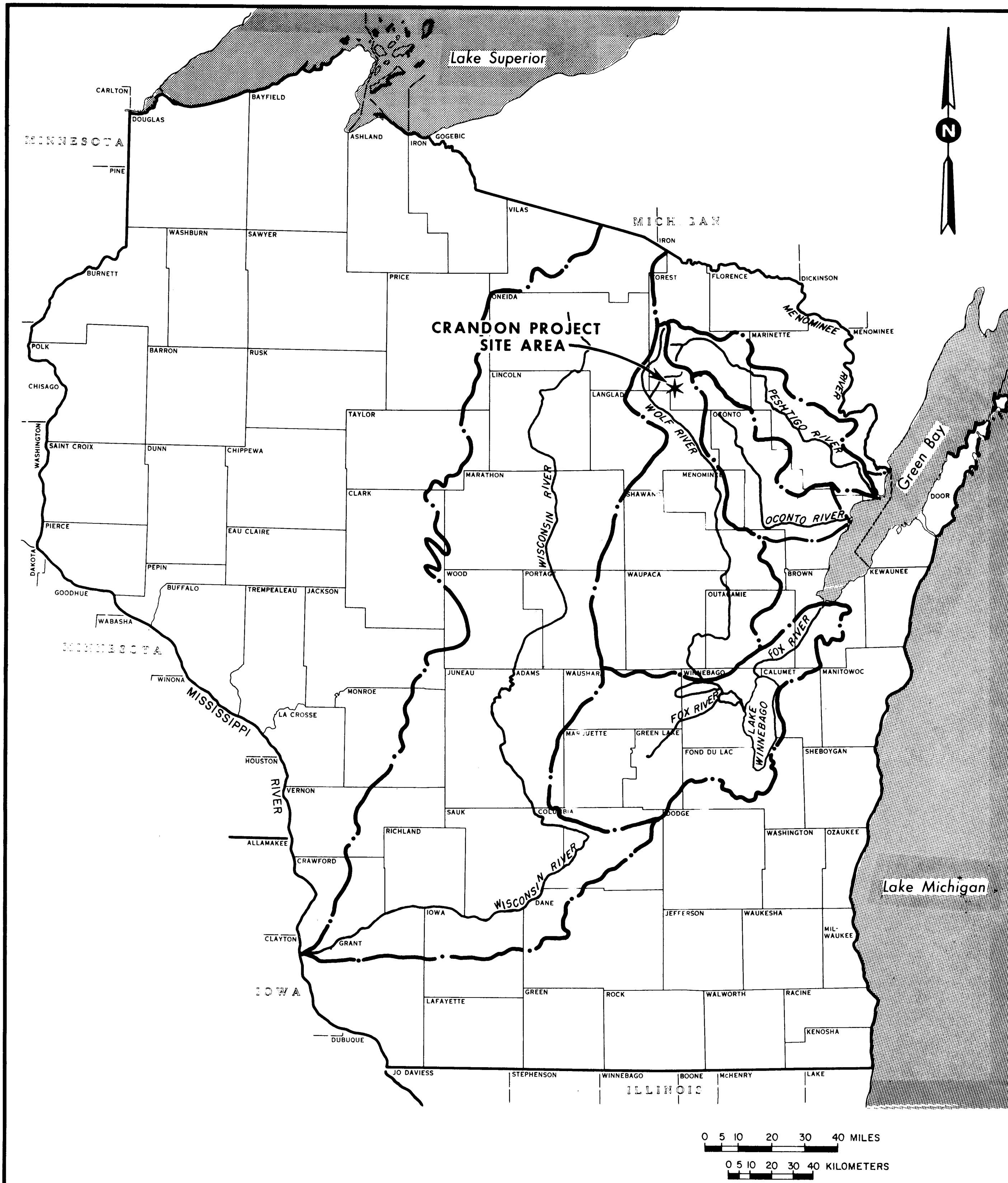
The transmittal of these materials to the keypunch and computer service was documented. The completed computer printouts underwent a final documented review upon return from the computer services to check for misspellings and incorrect data calculations. Calculations were performed with a formally verified computer program.

2.4.2 Regional Hydrologic Characterizations

2.4.2.1 Drainage Basins

The regional study area lies within the area of northeast Wisconsin that is drained by the Wisconsin, Wolf, Fox, Peshtigo, Oconto, and Menominee rivers. The environmental study area is entirely within the northern headwaters of the Wolf River drainage basin as shown on Figure 2.4-3. The Wolf River originates approximately 32 km (20 miles) northwest of the site area and flows south to Lake Poygan in Winnebago County (Wisconsin DNR, 1977), which is approximately 161 km (100 miles) south of the environmental study area. The Fox River drains the Lake Poygan-Winnebago system in a northeasterly direction to Green Bay. The Wolf River basin is bordered on the west by the Wisconsin River basin. The Wisconsin River flows south and then west to the Mississippi River. To the north and east of the Wolf River basin, drainage is provided by the Menominee, Peshtigo, and Oconto rivers, which all flow southeast to Green Bay.

In the upper Wolf River basin, the relatively slow-flowing streams frequently pass through lakes and wetlands. Stream gradients were determined from topographic maps and are generally in the range of 1.5 to 1.9 m/km (7.7 to 10 feet/mile).



KEY:

DRAINAGE BASIN BOUNDARY

EXXON MINERALS COMPANY
CRANDON PROJECT

MAJOR DRAINAGE BASINS
IN NORTHEASTERN WISCONSIN

DAMES & MOORE | FIGURE 2.4-3

2.4.2.2 Regional Precipitation

Average annual precipitation in the regional study area is 781.6 mm (30.77 inches) (Black, 1978) (see section 2.1, Meteorology and Air Quality). Precipitation is greatest during late spring and early summer and least during mid-winter when it generally occurs as snow. The mean annual accumulation of snow is 1,270 mm (50 inches) (Conger, 1971). Precipitation records measured at the Nicolet College weather station at Rhinelander, Wisconsin, the nearest long-term data record, are assumed to be representative of the region. Rhinelander is approximately 45 km (28 miles) northwest of the site area. Average monthly precipitation values for the period 1908 through 1977 inclusive are given in Table 2.4-14. On the average, the wettest month is June with almost 15 percent of the annual precipitation and the driest is February with only 3.3 percent.

2.4.2.3 Regional Runoff

Total annual surface water runoff in the drainage basins in the regional study area ranges from 279 mm (11 inches) to 330 mm (13 inches) (Hindall, 1976). For the Wolf River basin the annual stream discharges range from 254 mm (10 inches) to 330 mm (13 inches) of surface water runoff per year (Hindall, 1976).

The nearest long-term stream gaging station to the site area is the USGS station on the Wolf River at Langlade (Figure 2.4-4). The surface drainage area upstream from this gage encompasses 1,191 km^2 (460 $miles^2$) and includes the site area. Mean annual discharge at the Langlade station for the period 1966-1978 is approximately 13.2 m^3/s (466 cubic feet/second)

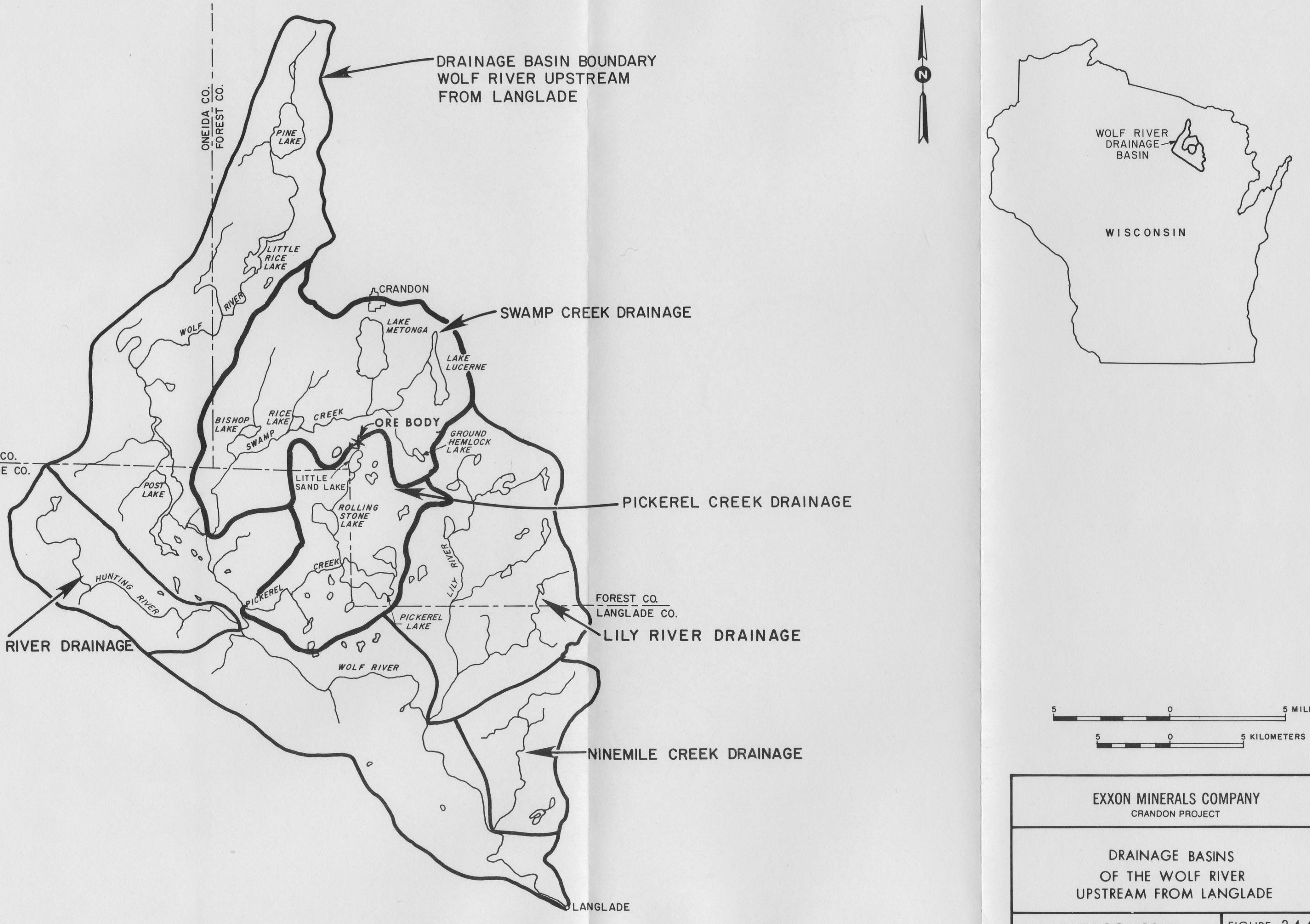
TABLE 2.4-14

AVERAGE MONTHLY PRECIPITATION AT
NICOLET COLLEGE, RHINELANDER, WISCONSIN
1908 THROUGH 1977[a]

MONTH	AVERAGE PRECIPITATION (mm)[b]	PERCENT OF ANNUAL PRECIPITATION
October	59.4	7.6
November	47.8	6.1
December	28.2	3.6
January	26.9	3.4
February	25.4	3.3
March	38.4	4.9
April	59.4	7.6
May	85.3	10.9
June	115.6	14.8
July	97.3	12.4
August	102.6	13.1
September	95.2	12.2
Total	781.6	100

[a]Black, 1978.

[b]25.4 mm = 1 inch.



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CRANDON PROJECT

DRAINAGE BASINS
OF THE WOLF RIVER
UPSTREAM FROM LANGLADE

DAMES & MOORE

FIGURE 2.4-4

(USGS, 1979). This discharge rate corresponds to an average surface water runoff depth of 352 mm (13.87 inches) from the surface drainage area of the Wolf River measured by this gage. Monthly stream flow data for the Wolf River at Langlade are given in Table 2.4-15. The highest average monthly stream runoff of 56.4 mm (2.22 inches) occurs during April when snowmelt runoff is highest. January and February are the months of lowest stream runoff, with 20.6 mm (0.81 inch) and 17.5 mm (0.69 inch), respectively, because most precipitation is retained on the ground surface as snow and ice.

Review of the Wolf River stream discharge data (Table 2.4-15) indicates that the 1977 water year had the lowest surface water flow measured during the 13-year period of record. The annual total surface water runoff for this year was 246 mm (9.67 inches) compared to the average annual total surface water runoff of 352 mm (13.87 inches) (USGS, 1979). The 1979 water year was the second wettest recorded during the period of record with an annual total runoff of 405 mm (15.93 inches) (USGS, 1979).

2.4.2.4 Regional Evapotranspiration

Evapotranspiration is defined as the movement of water through vegetation and from a free surface to the atmosphere. Evapotranspiration (E) is generally computed as the difference between precipitation (P) and stream discharge (Q), assuming that there is no net flux of ground water from the regional area (Freeze and Cherry, 1979), and that the amount of water held in storage in both the ground water (S_G) and surface water (S_S) reservoirs remains constant. That is, the average annual amount of ground water that flows from the aquifer is equal to the amount of recharge to the aquifer within the designated watershed or drainage basin, regardless of porosity/

TABLE 2.4-15

USGS MONTHLY STREAM DISCHARGE RECORD FOR THE
WOLF RIVER AT LANGLADE, WISCONSIN
USGS STATION NUMBER 04074950

WATER YEAR	MEAN MONTHLY STREAM DISCHARGE (cfs) OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL TOTAL (inches of runoff)
1965-1966	-	-	-	-	-	-	685	540	365	240	280	231	—
1966-1967	317	288	295	284	265	300	1,319	515	507	518	362	395	13.18
1967-1968	423	386	344	279	263	448	643	642	911	874	473	813	16.03
1968-1969	518	447	466	548	440	463	964	606	541	436	270	260	14.65
1969-1970	340	351	320	281	262	339	426	533	469	228	206	298	9.97
1970-1971	380	683	476	369	348	401	1,142	572	421	283	224	256	13.64
1971-1972	569	437	421	364	297	361	896	887	322	300	632	618	15.07
1972-1973	723	612	359	397	351	1,227	1,100	1,312	649	369	384	483	19.66
1973-1974	386	447	311	315	301	445	712	463	457	265	436	455	12.28
1974-1975	331	465	345	312	287	356	885	785	493	290	266	483	13.02
1975-1976	295	430	518	241	292	698	1,330	713	344	229	254	216	13.71
1976-1977	196	204	226	193	223	589	775	339	263	255	228	445	9.67
1977-1978	505	441	384	305	258	294	693	494	460	592	526	538	13.53
1978-1979	441	349	321	311	334	671	1,219	933	727	470	362	336	15.93
Max. Month	723	683	518	548	440	1,227	1,330	1,312	911	874	632	813	—
Max. Day	1,330	1,040	880	660	540	2,200	1,770	1,780	1,510	1,380	1,030	1,400	—
Min. Month	196	204	226	193	223	294	426	339	263	228	206	216	—
Min. Day	185	164	166	190	200	235	250	248	226	166	156	166	—

MEAN MONTHLY STREAM DISCHARGE

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL TOTAL
(cfs)	417	426	368	323	302	507	914	667	495	382	350	416	—
Inches of Runoff	1.04	1.03	0.92	0.81	0.69	1.27	2.22	1.67	1.20	0.96	0.88	1.01	13.87

Notes: Location: see Figure 2.4-4.
Drainage Area, 1191 km^2 (460 square miles).
Period of Record: March 1966 to September 1979, discontinued after September 1979.
To convert to m^3/s, multiply cfs by 0.02832.
— Indicates no data.

Source: USGS, 1979.

permeability of the aquifer(s), and that the average annual amount of surface water lost from storage in the surface water system (i.e., in lakes and ponds) is replaced by precipitation. These assumptions have been proven to be generally accurate by empirical studies. Thus, this concept is expressed in the equation (Freeze and Cherry, 1979, p. 205):

$$P = Q + E + \Delta S_S + \Delta S_G$$

where $\Delta S_S = \Delta S_G = 0$ for a given drainage basin. Therefore, the general equation for evapotranspiration becomes:

$$E = P - Q$$

Each unit of this equation has several components that can be evaluated in detail for a specific stream flow rate analysis; however, for a general description of a regional system, such as that described in this subsection, the general equation is sufficient. On this basis, average annual evapotranspiration for the Wolf River surface drainage basin measured by the USGS station at Langlade is approximately 429 mm (16.9 inches).

2.4.2.5 Surface Water Use

In Wisconsin, permits for diversion of surface water are required for irrigation or agricultural purposes. Water law in Wisconsin is essentially riparian, which means that water rights are acquired with the land adjacent to surface waters.

In the Wolf River basin in Forest and Langlade counties, there are three diversions of surface water for irrigation registered with the DNR (Table 2.4-16), all of which are outside the environmental study area. There

TABLE 2.4-16

IRRIGATION DIVERSION PERMITS FOR THE WOLF RIVER DRAINAGE BASIN IN FOREST AND LANGLADE COUNTIES

	PERMITTEE	STREAM	COUNTY	LOCATION SECTION	TWP.	RANGE	MAXIMUM RATE (cfs)	DOCKET NUMBER
1.	Dale Jackson[a]	Hunting River	Langlade	5, 6	33N	12E	2.22	2-WP-1075
2.	William Koehler & John Witman	Lily River	Langlade	11, 14, 15	33N	13E	2.22	2-WP-1076
3.	Diercks & Sons[a]	Wolf River	Langlade	4, 5	31N	14E	2.00	2-WP-1078
				33	32N	14E		
4.	Diercks & Sons[a]	Evergreen River	Langlade	31, 32	31N	14E	2.00	2-WP-1078
5.	Bert Jackson[a]	Hunting River	Langlade	6	33N	12E	1.33	2-WP-1082
				31	34N	12E		
6.	Bula Potato Farms	Wolf River	Langlade	12, 13	34N	11E	2.00	2-WP-1092
7.	Bula Potato Farms	Pollack Creek	Langlade	3, 4, 10	34N	11E	1.50	2-WP-1120
8.	David & Edward Bula[b]	Swamp Creek	Forest	33	35N	12E	2.22	76-NC-125

Source: Rafen, 1978.

[a]Permits in effect pending court review of DNR revocation order.

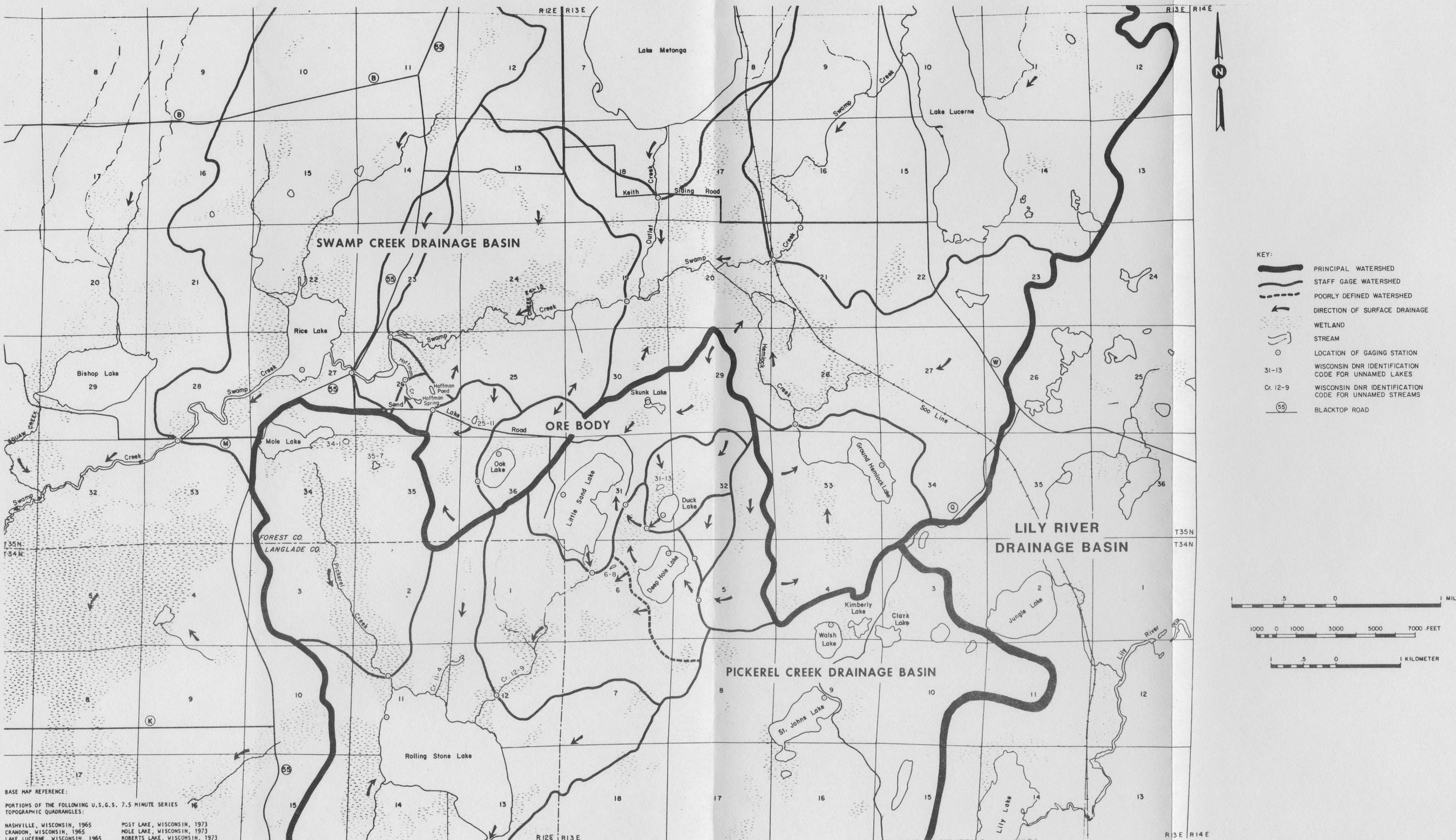
[b]Permit applied for.

are no known diversions of surface water for domestic or industrial use in Forest or Langlade counties, although such diversions may exist on the lower Wolf River.

2.4.3 Hydrologic Characteristics of the Environmental Study Area

The environmental study area is entirely within the Wolf River drainage basin. This drainage basin is part of a larger basin (the Fox River) and consists of numerous smaller basins (Figure 2.4-4). Ground surface topography defines watersheds (usually depicted by lines delineating locations where water flows perpendicular from the lines) and drainage basins are separated by watersheds. Therefore, for any particular point of interest, a drainage basin can be determined based on the surrounding topography. Hence, the Wolf River drainage basin actually consists of many smaller drainage basins. From a practical standpoint, only a limited number of drainage basins so delineated are of interest, and commonly, not until drainage basins reach a sufficient size to have a defined stream providing a drainage path do they become recognized. In the case of the environmental study area, the ore body lies near a watershed dividing the Swamp Creek basin and the Pickerel Creek basin (as defined by determining watershed lines from the respective downstream points of interest) as shown on Figure 2.4-5. The environmental study area is characterized by forested land, lakes, wetland areas and perennial streams providing drainage paths.

The topographic features of the environmental study area are a reflection of its glacial origin. The drainage basins are underlain by glacial drift including sand and gravel. This material allows water to move under the ground and stores water percolating from the surface.



EXXON MINERALS COMPANY
CRANDON PROJECT

SURFACE WATER DRAINAGE BASINS
IN THE ENVIRONMENTAL STUDY AREA

DAMES & MOORE

FIGURE 2.4-5

The wetlands and the forested lands are described in detail under Terrestrial Ecology (section 2.6) and the topographic features, geology, and glacial drift are described in section 2.2, Geology. Ground water characteristics are presented in section 2.3, Ground Water.

Flooding on streams is characterized by a brief time period of higher water levels, greater surface areas covered by water, higher stream velocities, and greater turbulence than under "non-flood" conditions. Flooding on lakes is characterized by higher water levels and a greater surface area covered by water. Moreover, a lake, because of its greater surface area, spreads surface water runoff evenly over a greater area at a smaller increase in water level for a longer period of time; however, a stream is more dynamic, concentrating the water to a stream channel at greater increases in water level for a short period of time and conveying it quickly downstream. Greater hazards are normally associated with stream flooding because of its dynamic force and greater increases in water level. During the period of study the maximum lake levels and stream flows were recorded in the third week of April 1979 (Appendix 2.4I).

The analysis of the water storage and flow dampening effects of wetlands on the hydrologic system is a complex process and is often difficult to quantify. Basically, the wetlands act as a retarding agent to surface water drainage, which, in turn, serves as a source of delayed yield to ground water aquifers and to surface runoff from rainfall and tends to dampen the flash flood effects of precipitation events.

The hydrographs show the seasonal stream discharge that occurred over the period of record (Appendix 2.4J). Annual stream discharge patterns vary from year to year, depending upon the annual precipitation. Although some of the peak values were beyond the rating curves for the stream gage, their hydrographs appropriately show the seasonal pattern of stream flows in the study areas.

The regional study area lies within a physiographic province known as the Northern Highlands (Hindall, 1976), which encompasses all or part of 16 Wisconsin counties. Average annual sediment yields from the Northern Highlands region, based on USGS records, are generally less than 3.5 t/km^2 (10 $tons/mile^2$), and average annual values recorded at 12 stations in the Northern Highlands ranged from 1.1 to 11 t/km^2 (3.1 to 31 $tons/mile^2$) (Hindall, 1976). This annual sediment yield of 3.5 t/km^2 (10 $tons/mile^2$) is from a region with an annual average surface water runoff of 330 mm (13 inches) over the area and produces an average suspended sediment concentration of approximately 11 mg/l. This suspended sediment concentration is used herein as a standard for comparison to surface water sediment yields within the regional study area.

The lakes of the Swamp Creek and Pickerel Creek drainage basins that were studied in this investigation are characterized as one of three basic lake types presented by Steuck and Andrews (1976):

> Drainage lakes have their main water source from stream drainage. These lakes have at least one inlet and an outlet.
>
> Seepage lakes have no inlets and no outlets or only an intermittent inlet and outlet. The water level is maintained by the ground water table and basin seal.
>
> Spring lakes seldom have an inlet, but always have an outlet of relatively substantial water flow. Water supply is dependent upon ground water inflow rather than surface drainage.

Based on discussions presented in section 2.3 (Ground Water), it is evident that the seepage lakes studied are "perched" above the main ground water table (i.e., the lake surface elevation is above the elevation of the main ground water table) with water levels apparently maintained by a basin seal. Ground water is recharged by seepage from these lakes through the basin seal. Similarly, the drainage lakes and spring lakes studied receive main ground water aquifer discharge (see Figure 2.3-17).

A listing of lakes studied and a comparison of lake level elevations are shown in Table 2.4-17. Ordinary high water mark elevations, determined and surveyed by the DNR in July 1983, are also included in the table for comparative purposes. The ordinary high water mark is the point on the bank or shore up to which the presence and action of the water is so continuous as to leave a distinct mark, either by erosion, destruction of terrestrial vegetation, or other easily recognized characteristic.

During January 1985, detailed field study of Little Sand, Duck, Oak, and Skunk lakes provided data for comprehensive water balance analyses. Data and analytical results are provided in Dames & Moore (1985).

2.4.4 Swamp Creek Drainage Basin

A portion of the environmental study area lies within the Swamp Creek drainage basin as shown on Figures 2.4-4 and 2.4-5. The Swamp Creek drainage basin is located in the north-central portion of the Wolf River drainage basin as shown on Figure 2.4-4. Headwater streams of the Swamp Creek drainage basin include upper Swamp Creek originating from Lake Lucerne, Hemlock Creek originating from Ground Hemlock Lake, Outlet Creek originating from Lake Metonga, and Hoffman Creek originating from Hoffman Springs. Surface water drainage flows to the southwest via Swamp Creek to its confluence with the Wolf River. Water bodies included in the discussion of

TABLE 2.4-17

COMPARISON OF LAKE ELEVATION[a] VARIATIONS

GAGE	LOCATION/NAME	MAXIMUM ELEVATION	MINIMUM ELEVATION	VARIATION	PERIOD OF RECORD[b]
Swamp Creek Drainage Basin					
LG 11	Oak Lake	1,634.21	1,632.11	2.10	4-14-77 to 10-11-80
LG 14	Rice Lake	1,535.16+	1,532.98	2.18+	5-26-77 to 10-11-78
LG 24	Ground Hemlock Lake	1,579.10	1,578.52	0.58	4-12-80 to 10-16-80
Pickerel Creek Drainage Basin					
LG 7	Little Sand Lake	1,592.96	1,590.82	2.14	4-14-77 to 10-11-78
LG 9	Rolling Stone Lake	1,535.84	1,534.95	0.89	5-17-77 to 10-11-78
LG 12	Duck Lake	1,612.25+	1,610.23	2.02+[c]	4-27-77 to 10-16-80
LG 13	Deep Hole Lake	1,607.10+	1,604.96	2.14+	6-09-77 to 10-11-80
LG 15	Skunk Lake	1,598.26	1,596.48	1.78	5-09-77 to 10-11-80
LG 25	Walsh Lake	1,600.00	1,599.21	0.79	4-12-80 to 10-16-80
LG 26	St. Johns Lake	1,590.70	1,590.10	0.60	4-12-80 to 10-11-80

[a]Elevation expressed as feet above mean sea level.

[b]Record is discontinuous: information was gathered during ice-free periods between April 1977 and October 1980.

[c]This value reflects the influence of the main ground water aquifer pump test, when 0.090 to 0.091 m^3/s (1,420 to 1,440 gallons/minute) of ground water were pumped into Duck Lake from June 27, 1980 through July 21, 1980 (Golder Associates, 1981).

the Swamp Creek drainage basin are Rice Lake; Hemlock, Swamp, Outlet, and Hoffman creeks; Hoffman Springs; Ground Hemlock Lake; and Oak Lake.

2.4.4.1 Drainage Lakes and Associated Streams

Rice Lake - Rice Lake is a drainage lake located approximately 4.3 km (2.7 miles) northwest of the ore body (Figure 2.4-5). It has a total area of 84.2 ha (208 acres) and a maximum depth of 1.8 m (6 feet). Over much of the lake, depths are typically 1.2 m (4 feet) or less. The shoreline vegetation consists of conifer, shrub, and marsh wetland. The predominant lake substrate is muck (Table 2.4-18). The lake has five inlets, the largest being Swamp Creek, which is navigable by small craft. The outlet, lower Swamp Creek, is navigable by small craft and flows to the Wolf River. The lake is entirely within the Swamp Creek drainage basin.

A staff gage (LG 14) was established in Rice Lake to measure surface water levels (Figure 2.4-1). Appendix 2.4B, Table B-6 provides a record of gage readings at this location, and Appendix 2.4I, Figures I-1 and I-2 show a continuous plot of these points. The lake gage fluctuated in response to the ground water inflow, incident precipitation, and the flow pattern of its primary water supply, Swamp Creek (Appendix 2.4C, Table C-1). During the period of study a 0.66-m (2.18-foot) water level fluctuation was observed. The highest water level during the study period occurred on April 21, 1979 during the 1979 high snowmelt runoff period; however, no reading was taken because the gage was submerged. A measured high water level of 467.89 m (1,535.16 feet) MSL was recorded in October 1977. The lowest water level of 467.25 m (1,532.98 feet) MSL occurred on July 12, 1980.

TABLE 2.4-18

SUMMARY OF CHARACTERISTICS FOR THE SWAMP CREEK DRAINAGE BASIN IN THE ENVIRONMENTAL STUDY AREA[a]

SEEPAGE WATER CATEGORY/ WATER BODY	DISTANCE AND DIRECTION FROM OREBODY km (mi)	DRAINAGE BASIN AREA km^2 (mi^2)	LENGTH km (mi)	AVERAGE WIDTH m (ft)	AVERAGE DEPTH m (ft)	MAXIMUM DEPTH m (ft)	SURFACE AREA ha (acres)	GRADIENT[b] m/km (ft/mi)	ADJOINING WETLANDS ha (acres)	PREDOMINANT SHORELINE VEGETATION[c]	SUBSTRATE CLASSIFICATION
Drainage Lake and Associated Streams											
Rice Lake	4.3 (2.7) Northwest	--[d]	--	--	--	1.8 (6)	84.2 (208)	—	91.1 (225)	Sedge Meadow (Emergent wetland)	muck
Hemlock Creek	2.6 (1.6) East	11 (4.3)	3.9 (2.4)	4.3 (14)	0.3 (1.0)	--	1.7 (4.1)	0.5 (2.5)	72.8 (180)	Wet-mesic or Wet Northern Forest	muck, sand, gravel
Swamp Creek	1.6 (1.0) North	391.9 (151.3)	24.9 (15.5)	7.0 (23.1)	0.3 (1.0)	--	17.6 (8.1)	1.5 (8.1)	1,408 (3,479)	Wet-mesic or Wet Northern Forest	muck, sand gravel and rubble
Outlet Creek	1.9 (1.2) North	29.5 (11.4)	2.9 (1.8)	4.0 (13)	0.3 (1.0)	--	1.1 (2.8)	2.8 (15)	210 (520)	Dry-mesic or Mesic Northern Hardwoods and Wet-mesic or Wet Northern Forest	sand, gravel, muck
Hoffman Creek	2.9 (1.8) West	4.4 (1.7)[e]	0.8 (0.5)	2.4 (8.0)	0.2 (0.5)	—	0.2 (0.5)	1.5 (8.1)	8.1 (20)	Wet-mesic or Wet Northern Forest	sand, gravel muck
Spring Lake											
Ground Hemlock Lake	3.9 (2.4) East	--	--	--	--	13 (42)	36 (88)	--	3.2 (8)	Dry-mesic or Mesic Northern Hardwoods	sand, gravel muck, rubble boulders
Seepage Lake											
Oak Lake	1.4 (0.9) Southwest	--	--	—	--	14 (47)	21 (51)	—	6.1 (15)	Dry-mesic or Mesic Northern Hardwoods	muck, sand, gravel

[a]Steuck and Andrews, 1976; Steuck et al., 1977; Andrews and Threinen, 1966.

[b]Calculated from topographic maps.

[c]See Terrestrial Ecology, section 2.6.

[d]Not applicable.

[e]Calculated from data generated in current study.

Samples for water chemistry analyses were collected at two locations in Rice Lake: Station N, centrally situated in the lake at a depth of approximately 0.9 m (3 feet), and Station F, located in the southern portion of the lake within the channel of Swamp Creek that meanders through Rice Lake (Figure 2.4-2). The depth at Station F was approximately 1.1 m (3.6 feet). Water chemistry samples were collected monthly at both locations from March 1977 through March 1978. Additional samples were collected at Station N in May, August, and October 1978. Unsafe ice conditions were common on this lake in the winter; consequently, no samples were collected from either station in April 1977 and from Station N in December 1977 and January 1978. The data for the months sampled are presented in Appendix 2.4F, Table F-6. The maximum, minimum, and mean values for the parameters measured are presented in Appendix 2.4G, Table G-6.

Water chemistry data indicated that Rice Lake was a moderately hard, light brown-stained, neutral pH lake. Mean values for hardness, alkalinity, and specific conductance were 102 and 108 mg/l $CaCO_3$, <81 and 98 mg/l $CaCO_3$, and 197 and 194 µmhos/cm at Stations N and F, respectively. Mean pH values calculated for Stations N and F were 7.3 and 7.1, respectively. Secchi disc transparency was consistently recorded at or near the bottom at both sampling locations. Mean true color determined for Stations N and F was <40 and <24 color units, respectively.

Low dissolved oxygen concentrations were occasionally recorded at both stations in the winter and summer (Appendix 2.4H, Table H-10). Dissolved oxygen concentrations below 5.0 mg/l were found at Station N in March, July, and September 1977. Similarly, concentrations below 5.0 mg/l were found in July, August, and September 1977 and January 1978 at Station F.

Depth profiles of water chemistry parameters such as temperature, dissolved oxygen, pH, and conductivity indicate that Rice Lake at these sampling locations was generally well mixed (Appendix 2.4H, Table H-10).

Concentrations of metals measured in Rice Lake were either below detection limits or at very low levels. Mercury values were consistently below the detection limit of 0.1 μg/l at both stations, with the exception of a concentration of 0.1 μg/l reported for Station N in November 1977. Iron was detected in all samples from Rice Lake. Except for January 1978, in which a concentration of 4.34 mg/l was detected at Station F, concentrations ranged from 0.12 to 0.60 mg/l (mean: 0.27 mg/l) at Station F and from 0.10 to 0.35 mg/l (mean: 0.20 mg/l) at Station N. The anomalously high iron concentration in the water sample collected from Station F in January 1978 also had the highest suspended solids concentration, 28 mg/l, and therefore may reflect inadequate filtration and/or the presence of colloidal (unfilterable) iron oxides. Lead was below detection limits at both stations on Rice Lake on all sampling dates except July 1977 when a concentration of 0.03 mg/l was recorded at Station N.

Station N was sampled seasonally during 1979-1980. The results reported from these analyses generally were similar to those of 1977-1978 and are presented in Appendix 2.4F, Table F-21 and Appendix 2.4G, Table G-21. However, neither lead nor mercury was measured in the 1979-1980 samples. Also, lower levels of nitrate and organic nitrogen (mean: both <0.05 mg/l) and dissolved and total solids (mean 117 mg/l and 124 mg/l, respectively) were reported in the 1979-1980 analytical results.

Bottom sediments were collected in March 1978 for chemical analyses at Stations F and N. The analytical results are presented in Appendix 2.4E, Table E-1. The concentrations of the parameters measured were low.

A comparison between Table 2.4-23 ("Bottom Sediment Chemistry Summary") and Appendix 2.4E, Table E-4 ("Comparison of Selected Metal Concentrations on Bottom Sediment from the Environmental Study Area with Reported Concentrations for Background Levels or Nonindustrial Use Areas") indicates that mean concentration of metals in bottom sediments from the environmental study area are within the ranges of reported background levels.

Hemlock Creek - Hemlock Creek is a perennial stream that originates from the northwest shore of Ground Hemlock Lake, approximately 4.0 km (2.5 miles) southeast of the ore body, and flows 3.9 km (2.4 miles) north to its confluence with Swamp Creek (Figure 2.4-5). This stream is adjoined by 72.8 ha (180 acres) of wetlands, has a drainage area of 11 km^2 (4.3 $miles^2$), a total surface area of 1.7 ha (4.1 acres), an average width of 4.3 m (14 feet), and an average depth of 0.3 m (1 foot) (Table 2.4-9). The channel is well defined and flows through a wooded, flat drainage basin. Hemlock Creek has two unnamed tributaries that flow into the creek from the adjacent wetlands to the east.

A stream gage was established on Hemlock Creek (SG 6), and its location is shown on Figure 2.4-1. Gage readings at this location are given in Appendix 2.4A, Table A-7, and a summary of available average monthly flow rates is provided in Appendix 2.4L. The flat, well vegetated drainage basin causes surface water runoff to be detained and results in relatively flat, broad-based stream hydrographs (Appendix 2.4J, Figures J-3 and J-4). The maximum surface water flow rate observed at SG 6 was 0.88 m^3/s (30.9 cubic feet/second), and the minimum flow rate observed was 0.02 m^3/s (0.8 cubic feet/second). Higher and lower surface water flow rates probably occurred between times of gage observations. In any year, the minimum 7-day average flow rate of Hemlock Creek has a 50 percent chance of being less than 0.057 m^3/s (2.0 cubic feet/second) and a 10 percent chance of being less than 0.040 m^3/s (1.4 cubic feet/second) (Table 2.4-19).

Samples for water chemistry analyses were collected from two locations on Hemlock Creek: Station A-1, located approximately 1.1 km (0.7 mile) downstream from Ground Hemlock Lake, and Station A-2, located approximately 1.3 km (0.8 mile) upstream of the confluence with Swamp Creek (Figure 2.4-2). Samples were collected monthly at Station A-1 from March 1977 through March 1978 and in May, August, and October 1978. Samples were also collected monthly at Station A-2 from October 1977 through March 1978. The data for Station A-1 are presented in Appendix 2.4F, Table F-11. Maximum, minimum, and mean values for the parameters measured at this station are presented in Appendix 2.4G, Table G-11. Water chemistry data for Station A-2 are presented in Appendix 2.4H, Table H-2.

Water chemistry data indicated that Hemlock Creek was a moderately hard, neutral pH stream. Mean values recorded for hardness, alkalinity, and specific conductance at Stations A-1 and A-2 were 107 and 115 mg/l as $CaCO_3$, 101 and 109 mg/l as $CaCO_3$, and 199 and 242 µmhos/cm, respectively. Mean pH values were 7.4 and 7.2 standard units at A-1 and A-2, respectively. True color values for both stations ranged from <1 to 60 color units. The concentration of dissolved oxygen in Hemlock Creek was below 5 mg/l during June 1977 at Station A-1 (3.2 mg/l oxygen, 32 percent saturation at 13.5°C),

TABLE 2.4-19

SUMMARY OF STREAM DISCHARGES
IN THE ENVIRONMENTAL STUDY AREA

STREAM GAGING LOCATION	1978 WATER YEAR AVERAGE FLOW	1978 WATER YEAR AVERAGE BASE FLOW	MAXIMUM RECORDED DISCHARGE[a]	MINIMUM RECORDED DISCHARGE[a]	ESTIMATED Q7,2[b,c]	ESTIMATED Q7,10[b]
Wolf River (at Langlade-USGS)	n/c	n/c	1,840.	175.	--	--
Swamp Creek						
SG 1	74.4	50.1	274.	25.3	24.	18.
USGS Below Rice Lake @ Hwy M	47.9	n/c	209.	17.	19.	15.
USGS Above Rice Lake @ Hwy 55	33.5	23.6	151.	8.	11.	8.
SG 2	29.0	22.8	95.4	15.5	n/c	n/c
SG 3	n/c	n/c	138.	10.3	6.7	4.7
SG 5B	5.1	3.6	30.7	2.1	n/c	n/c
Hoffman Creek (SG E and SG F)	n/c	n/c	11.9	0.4	n/c	n/c
Outlet Creek (SG 4)	n/c	n/c	206.	<0.1	0.8	0.6
Hemlock Creek (SG 6)	3.6	2.3	30.9	0.8	2.0	1.4
Duck Lake Outlet (SG B)	n/c	n/c	10.3	0.1	0.	0.
Pickerel Creek						
SG 22	13.9	9.8	77.0	4.3	6.5	4.7
SG 19	3.0	1.8	23.4	0.1	0.6	0.4
Creek 12-9						
SG 23	n/c	n/c	42.2	1.2	1.5	1.1
SG 8	0.7	0.55	10.1	0.4	0.	0.

Notes: All values in cubic feet per second.
n/c = not calculated.

[a]During periods of record prior to November 1980.

[b]Source: Krug (1984).

[c]The Q7,2 values will be used as the base flow rate in projecting potential project impacts in Chapter 4.

but all other measurements at both stations were approximately 5 mg/1, or 50 percent oxygen saturation.

Metals analyzed were either below detection limits or were found in low concentrations. Only mercury was detected in March and December 1977 at Station A-1 in concentrations of 0.2 and 0.1 µg/1, respectively, and in December 1977 at Station A-2 at a concentration of 0.1 µg/1.

Station A-1 also was sampled seasonally during 1979-1980. The results reported were very similar to those reported at Station A-1 during 1977-1978 (Appendix 2.4F, Table F-27 and Appendix 2.4G, Table G-27). However, during 1979-1980 no mercury was detected and much lower levels of organic nitrogen were found.

In March 1978, bottom sediment was collected (using a single Ekman grab sampler) at Station A-1 for chemical analysis. The analytical results are presented in Appendix 2.4E, Table E-1.

Chromium was highest of all metals measured in this one-time sampling of the Swamp Creek drainage basin with a concentration of 66.2 ppm (dry weight). Chromium is a widely distributed element in soils. Indigenous concentrations have been reported to range from 5 to 3000 ppm with a mean of 100 ppm (Bowen, 1966), although most soils have concentrations less than 1000 ppm (Brown and Deuel, 1980). The chromium concentration measured in the sediments of Hemlock Creek at Station A-1 (66.2 ppm) was one of several relatively high values measured in the Swamp Creek and Pickerel Creek drainage basins (concentrations of 180.8, 57.9, and 92.1 ppm were measured at Stations D, E, and M-1, respectively).

Bottom sediment and suspended solids samples were also collected for physical characterization. Bottom sediment sampling was accomplished in

April 1978 at SG 6 and the results (showing a well-graded sand with some fine organics) are presented in Appendix 2.4D, Figure D-1. Suspended sediment samples were collected at SG 6 as indicated on Table 2.4-1, and the results are presented in Appendix 2.4D, Table D-6. The average total suspended solids was 5.6 mg/l indicating that Hemlock Creek was essentially free of suspended sediments. The volatile portion of the suspended solids, serving as an indicator of the organic content of sediment carried by Hemlock Creek, averaged 3.3 mg/l.

Swamp Creek - Swamp Creek is a perennial stream that originates at Lake Lucerne, approximately 7.2 km (4.5 miles) northeast of the ore body and joins the Wolf River approximately 12.6 km (7.8 miles) southwest of the ore body (Figure 2.4-2). Swamp Creek has a drainage area of 391.9 km^2 (151.3 $miles^2$), a total surface area of 17.6 ha (43.5 acres) and a total length of 24.9 km (15.5 miles) when measured to its confluence with the Wolf River (Table 2.4-18). Wooded land, wetlands, and undeveloped lands dominate in the watershed, and approximately 10 percent of the area is used for agricultural purposes. The channel is well defined and flows through a relatively flat drainage basin. Swamp Creek flows west along the northern edge of the site area, through Rice Lake and a broad wetland to its confluence with the Wolf River (Figure 2.4-2). Its major tributaries in the environmental study area are Hemlock, Hoffman, and Outlet creeks, each of which is discussed individually in this section.

An additional unnamed tributary to Swamp Creek, designated Creek 24-15, is located in Sections 13 and 24, T35N, R12E. The confluence of Creek 24-15 with Swamp Creek is located approximately 457 m (1500 feet) downstream from the proposed access road crossing. Three tributaries, Creeks 24-4, 24-13, and 24-14, contribute flow to Creek 24-15. No stream gage measurements have been taken in this stream system during these studies. Steuck (1981) described Creek 24-15 as a medium hard water trout stream (Class IB) with slightly alkaline, light brown water. In August 1983, a beaver dam was observed on Creek 24-15 approximately 61 m (200 feet) upstream from the confluence with Swamp Creek. Other major tributaries to Swamp Creek not included in this investigation are Squaw Creek and Creeks 6-10, 7-5, and 7-9.

During the study period, two USGS stream gages and five other stream gages were established to monitor stream flow rates on Swamp Creek (Figure 2.4-1). Records of gage readings and flow rate summaries for these locations are presented in Appendices 2.4A, 2.4C, and 2.4L. Table 2.4-19 lists some descriptive flow rate characteristics for gaged sites along Swamp Creek and major tributaries.

The flat, well vegetated drainage basin results in relatively flat, broad hydrographs (Appendix 2.4J, Figures J-1 through J-4, and J-9 through J-11). A maximum flow rate of 5.92 m^3/s (209 cubic feet/second) was recorded on April 22, 1979 at County Highway M and reflects the large snowmelt runoff of spring 1979. A minimum flow rate of 0.48 m^3/s (17 cubic feet/second) was recorded on August 2, 1977 at County Highway M.

Samples for water chemistry analysis were collected from six locations on Swamp Creek (Figure 2.4-2). Station B was located approximately 2.4 km (1.5 miles) northeast of the ore body, and approximately 0.8 km (0.5 mile) downstream from the confluence with Hemlock Creek. Station D was located 1.0 km (0.6 mile) downstream from Station B and 0.3 km (0.2 mile) below the confluence with Outlet Creek, and Station E was located 3.4 km

(2.1 miles) downstream from Station D and approximately 1.4 km (0.9 mile) upstream from Rice Lake. Station D was located in a riffle section of Swamp Creek containing boulders, rubble, and gravel and coarse sand substrate. The other stations were located on reaches of the creek with typically slower current velocities and predominantly less coarse substrates. Downstream from Rice Lake, three stations were established: Station Q, immediately below the confluence with Squaw Creek; Station S, approximately 2.3 km (1.4 miles) downstream from Station Q; and Station V, approximately 2.3 km (1.4 miles) upstream from the confluence with the Wolf River.

Stations B, D, and E were sampled monthly from March 1977 through March 1979. Samples were also collected at Stations D and E in May, August and October 1978. Station Q was sampled only in October and November 1977; Station S was sampled monthly from October 1977 through March 1978; and samples from Station V were collected monthly from October 1977 through September 1978. The data from Stations B, D, E, and V are presented in Appendix 2.4F, Table F-14. The maximum, minimum, and mean values for the parameters measured are presented in Appendix 2.4G, Table G-14. Since the water chemistry sampling at Stations Q and S was of shorter duration, the data for these stations are presented as supplementary water chemistry data in Appendix 2.4H, Table H-3.

From April 1982 through December 1983, monthly water quality samples were collected at sampling stations in Swamp Creek between County Highways K and M. The results of these analyses are presented in Ecological Analysts, Inc. (1983, 1984).

The water chemistry data indicated that Swamp Creek was a moderately hard, neutral pH stream. Mean values for hardness, alkalinity, and specific conductance at the six sampling stations ranged from 95 to 110 mg/l $CaCO_3$, 81 to 103 mg/l $CaCO_3$ and 156 to 212 µmhos/cm, respectively. Mean pH values ranged from 6.8 to 7.4. Mean true color determinations varied from light brown above Rice Lake (range: <1 to 80 color units) to medium brown downstream from the lake (range: 10 to 200 color units).

Dissolved oxygen was measured in concentrations below 5.0 mg/l at Station B in March 1977, at Station S in February and March 1978, and at Station V in February, March, July, and August 1978.

Metals measured in Swamp Creek were found either in low concentration or below detection limits. Detectable levels of mercury (0.1 µg/l) were recorded in March and July 1977 at Station B and in March and December 1977 at Station D. Mercury was not detected elsewhere in Swamp Creek.

Stations D and E also were sampled during 1979-1980. Data for this sampling period are presented in Appendix 2.4F, Table F-29 and in Appendix 2.4G, Table G-29. All parameters measured were within the mean concentrations from the previous samplings. Further, nitrate and organic nitrogen and total and dissolved solids were found in lower levels in 1979-1980 than in previous studies.

Fecal streptococcus and fecal coliform bacteria counts in Swamp Creek above Rice Lake were consistently higher than those below Rice Lake. Fecal coliform bacteria were more numerous in water samples from Station E in August 1980 (>250 organisms/100 ml) than from any other station at any other time.

As part of a water quality study performed by the Northeastern Wisconsin Regional Planning Commission (1970), water samples were collected from a station on Swamp Creek, which coincides with Station V of this study.

The commission collected samples seasonally from January 1968 through May 1969. Mean values from this study and the Commission Study were similar for alkalinity (81 vs. 78), chloride (<3 vs. 2.2), sulfates (<5 vs. 7.8), total phosphorus (<0.03 vs. 0.04 mg/l), nitrate nitrogen (<0.21 vs. 0.14 mg/l) and pH (6.8 vs. 7.4), indicating that little change has occurred in water chemistry in Swamp Creek at Station V since 1968.

The U.S. Geological Survey began collecting water samples for chemical analysis from Swamp Creek in August 1977 at three stations. One station was located at Station D, another was located approximately 0.5 km (0.3 mile) upstream from Rice Lake at State Highway 55, and the third was located approximately 1.8 km (1.1 miles) downstream from Rice Lake at County Highway M. These data are presented in Ecological Analysts, Inc. (1983, 1984).

Although some chemical parameters were detected in higher concentrations by the USGS, generally, water chemistry values from these stations were similar to those reported for Swamp Creek during the current studies (USGS, 1978; 1979; 1980; 1981). Among those parameters reported at higher levels by the USGS were aluminum (0.3 mg/l) and zinc (0.3 mg/l). The highest values reported from Swamp Creek during this study for aluminum and zinc were 0.08 and 0.023 mg/l, respectively.

Bottom sediments were collected for chemical analysis in March 1978 at both Stations D and E on Swamp Creek. The results are presented in Appendix 2.4E, Table E-1. The concentration of chromium was 180.8 and 57.9 ppm at Stations D and E, respectively, cadmium at Station D was 4.4 ppm, and arsenic at Station E was 6.3 ppm. Also, compared with the results from other stations in this study, iron (19,894 ppm), manganese (3,696 ppm), phenol

(42.45 ppm), and sulfate (8,655 ppm) were all very high at Station D. Other parameters at both stations were not found in unusually high concentrations on this date.

Chemical analyses on stream sediment samples in the Swamp Creek drainage basin in March 1978 indicate a mean of 43.5 ppm with a standard deviation of 21.4 ppm for chromium, exclusive of Station D. The single reported value of 180.8 ppm for Station L is 6 standard deviations from the above mean of the chromium values reported for the Swamp Creek drainage basin. The chromium value for Station D is anomalously high compared to other analyzed concentrations during the sampling period and appears to be unrepresentative of the sediments for the drainage basins. The results of more recent chemical analyses (May of 1982 and 1983) of sediment samples collected at four stations on Swamp Creek downstream from County Highway M are presented in Ecological Analysts, Inc. (1983, 1984). The total chromium concentrations measured were lower than those reported in 1978 and had less statistical variance.

Bottom sediment was sampled in April 1978, at SG 3 on Swamp Creek, and the results showing a well-graded sand are presented in Appendix 2.4D, Figure D-1. Suspended sediment samples were collected at SG 1, SG 2, SG 3, and SG 5B as indicated on Table 2.4-1 and the results are also presented in Appendix 2.4D, Tables D-1 through D-3 and D-5. The average total suspended solids was 4.5 mg/l, which is less than the average 11 mg/l for the Northern Highlands region (Hindall, 1976), indicating that Swamp Creek was essentially free of suspended sediments. The volatile portion of the suspended solids, serving as an indicator of the organic content of sediment carried by Swamp Creek, averaged <2.6 mg/l.

Outlet (Metonga) Creek - Outlet Creek originates approximately 4.5 km (2.8 miles) north of the ore body at the south shore of Lake Metonga and flows southward 2.9 km (1.8 miles) to its confluence with Swamp Creek (Figure 2.4-5). The creek has a drainage area of 29.5 km^2 (11.4 $miles^2$), is adjoined by 210 ha (520 acres) of wetlands, has a total surface area of 1.1 ha (2.8 acres), and an average width and depth of 4 m (13 feet) and 0.3 m (1 foot), respectively (Table 2.4-18). It has a well defined channel with water flowing through a relatively flat drainage basin and has no major tributaries.

A stream gage was established on Outlet Creek (SG 4) (Figure 2.4-1) and the record of gage readings at this location is presented in Appendix 2.4A, Table A-4. Staff gage observations indicate that Outlet Creek flow rates may have ranged between 0.002 m^3/s (0.1 cubic foot/second) and 5.8 m^3/s (206 cubic feet/second), although these extremes are well outside the defined range of the stage-discharge relation.

In any year, the minimum 7-day average flow rate is estimated to have a 50 percent chance of being less than 0.023 m^3/s (0.8 cubic foot/second) and a 10 percent chance of being less than 0.017 m^3/s (0.6 cubic foot/second).

Samples for water chemistry analysis were collected monthly from March 1977 through March 1978 from Station C on Outlet Creek. This station was located immediately upstream of Keith Siding Road and was approximately 1.4 km (0.9 mile) upstream from the confluence of Outlet and Swamp creeks (Figure 2.4-2). The data for the months sampled are presented in Appendix 2.4F, Table F-12. The maximum, minimum, and mean values for the parameters are presented in Appendix 2.4G, Table G-12.

Water chemistry information indicated that Outlet Creek was a moderately hard, neutral pH stream. Mean values recorded for hardness, alkalinity, and specific conductance were 93 mg/l as $CaCO_3$, 88 mg/l as $CaCO_3$, and 194 µmhos/cm, respectively. Mean pH was 7.6. True color values ranged from <1 to 20 color units. Dissolved oxygen concentrations measured during the study were consistently high, ranging from 9.1 to 16.0 mg/l with a mean of 12.1 mg/l.

Metals measured in samples from Outlet Creek generally were reported either as below detection limits or in low concentrations. In November 1977, the concentration of mercury was 0.2 µg/l; however, during all other months, mercury was below the detection limit (<0.1 µg/l).

Bottom sediment sampling for physical characterization was undertaken in April 1978 at SG 4 and the results indicated the presence of a well-graded sand (Appendix 2.4D, Figure D-1). Suspended sediment samples at SG 4 were collected as indicated in Table 2.4-1 and the results are presented in Appendix 2.4D, Table D-4. The average total suspended solids was 5.6 mg/l, which is considerably less than the average 11 mg/l reported for the Northern Highlands region (Hindall, 1976). The volatile portion of the total suspended solids averaged <2.7 mg/l.

Hoffman Creek and Springs - Hoffman Creek originates from Hoffman Spring Pond, which is located approximately 2.9 km (1.8 miles) west of the ore body. It has a drainage area of 4.4 km^2 (1.7 $miles^2$) and flows north approximately 0.8 km (0.5 mile) to its confluence with Swamp Creek (Figure 2.4-5). This stream has a total surface area of 0.2 ha (0.5 acre), and its watershed is predominantly wetland, wooded, and undeveloped land (Table 2.4-18). It is a stream with a poorly defined channel that derives its water flow from a large, poorly drained wetland area above Hoffman Spring Pond. Oak Lake discharges intermittently to this wetland and, thus, to Hoffman Creek. Hoffman Creek has no major tributaries.

Two stream gages were established in the Hoffman Creek drainage system (SG E and SG F) for this study (Figure 2.4-1). The record of gage readings at these locations is presented in Appendix 2.4A, Tables A-13 and A-15. Regular readings were not recorded at either gage; however, at SG E downstream of Hoffman Spring Pond, a measured discharge of 0.34 m^3/s (11.9 cubic feet/second) was recorded on April 18, 1979. Also at SG E, a flow rate of 0.02 m^3/s (0.4 cubic foot/second) was recorded on September 28, 1978. No estimate of base flow is provided for Hoffman Creek due to the few measurements collected and the ill-defined drainage area above the gage.

In mid-April 1978, when discharges in most streams in the site area were approaching their annual maxima, there was no measurable water flow at the culvert under Sand Lake Road downgradient of Oak Lake. However, in April 1979, a flow rate of 0.22 m^3/s (7.9 cubic feet/second) was measured at this culvert. Moreover, in 1978, Hoffman Spring, which is located in the channel upstream from SG E (Figure 2.4-1), had no visible surface inflow during the period; however, a discharge of approximately 0.03 m^3/s (1 cubic foot/second) was observed at the outlet of the pond at SG E. This pond and the immediate surroundings, therefore, appear to be a ground water discharge area.

Suspended sediment samples were collected once at SG F and twice at SG E and the results are presented in Appendix 2.4D, Table D-11. The average total suspended solids measured at these two gages was 5.7 mg/l, which is less than the average 11 mg/l for the Northern Highlands region (Hindall, 1976). The volatile portion of the suspended solids averaged 3.0 mg/l.

2.4.4.2 Spring Lakes

Ground Hemlock Lake - Ground Hemlock Lake is a spring lake (Steuck and Andrews, 1976) located 3.9 km (2.4 miles) east of the ore body (Figure 2.4-5). It has a total surface area of 36 ha (88 acres) and a maximum depth of 13 m (42 feet). The predominant lake substrate is sand, gravel, marl, and muck (Table 2.4-18). The lake has no defined inlets and is the headwaters of Hemlock Creek.

The shoreline vegetation is predominantly upland hardwoods with the remainder a coniferous wetland. The effects of associated wetlands on lake levels of spring lakes vary, depending on hydrologic characteristics of the wetland. In a spring-fed lake such as Ground Hemlock Lake, the primary source of water supply to the lake is ground water. If the wetland associated with the lake is also ground water fed, then the level of water in both should fluctuate about the same, although there would be a delayed yield of water to the lake from the wetland that would tend to stabilize the lake level. If, however, the wetlands are perched, as many in the environmental study area are, then the wetland discharge to the lake could also have a stabilizing effect on the level of the lake.

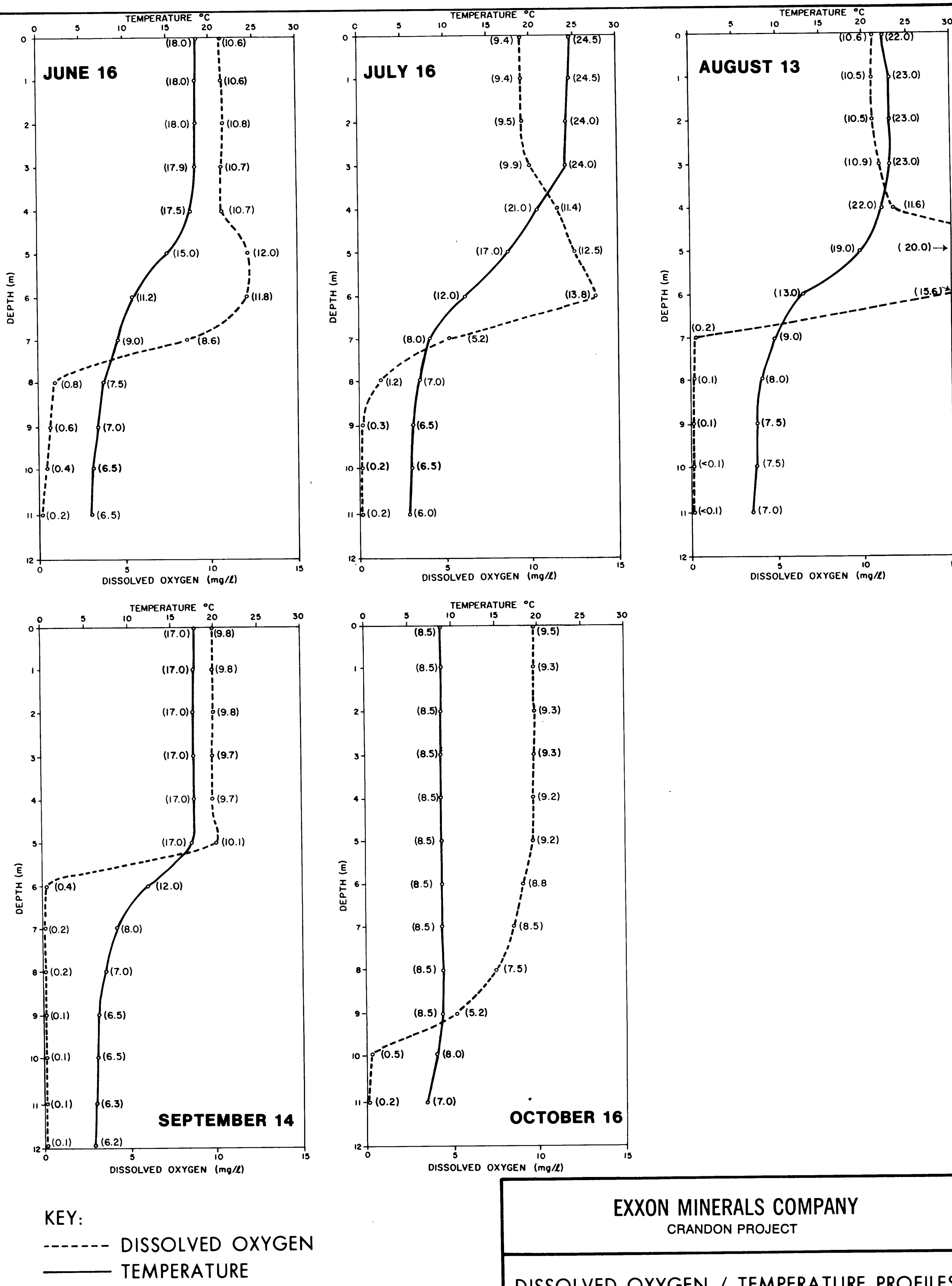
Surface water levels in Ground Hemlock Lake were measured at LG 24 (Figure 2.4-1). Appendix 2.4B, Table B-8 provides a record of gage readings at this location and Figure I-2 of Appendix 2.4I shows a continuous plot of these points. Lake levels fluctuated in response to ground water inflow, incident precipitation, and local runoff from rainfall. During the period of study, a 0.18-m (0.58-foot) water level fluctuation was observed, reflecting a fairly constant water level (see Table 2.4-17). The high water level of

481.31 m (1,579.10 feet) MSL during the study period occurred on May 13, 1980, whereas the low lake level reading of 481.13 m (1,578.52 feet) MSL was recorded on July 16, 1980.

The water chemistry sampling station in Ground Hemlock Lake was centrally located at approximately the 11-m (36.1-foot) depth contour (Figure 2.4-2). Samples were collected at this location from two separate levels: 1 m (3.3 feet) (GH-1) and 6 to 10 m (19.7 to 32.8 feet) (GH-2). Samples at GH-2 were always collected in the hypolimnion, when present. Water chemistry collections for Ground Hemlock Lake continued monthly from November 1979 through October 1980 and from May 1979 through October 1980 at GH-1 and GH-2, respectively. The results of the analyses of the water samples are presented in Appendix 2.4F, Table F-18. Maximum, minimum, and mean values are presented in Appendix 2.4G, Table G-18.

The results of the water chemistry data indicated that Ground Hemlock Lake was a moderately hard, clear, neutral to slightly basic pH lake. Mean values for hardness, alkalinity, and specific conductance were 112 and 128 mg/l as $CaCO_3$, 110 and 129 mg/l as $CaCO_3$, and 213 and 257 µmhos/cm at GH-1 and GH-2, respectively. Mean hardness and pH values indicated that the deeper waters were somewhat harder and more acidic (GH-2: 128 mg/l as $CaCO_3$ and pH 7.7) than the near surface waters (GH-1: 112 mg/l as $CaCO_3$ and pH 8.2). Secchi disc transparency ranged from 1.1 to 3.8 m (3.6 to 12.5 feet) throughout the study. Mean true color measured at GH-1 and GH-2 was <12 and <15 color units, respectively.

Temperature and dissolved oxygen concentration profiles indicated that Ground Hemlock Lake stratified during the summer (Figure 2.4-6; Appendix 2.4H, Table H-6). A rapid temperature decrease with depth (metalimnion)



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DISSOLVED OXYGEN / TEMPERATURE PROFILES FOR GROUND HEMLOCK LAKE - STATION GH JUNE TO OCTOBER 1980

DAMES & MOORE

FIGURE 2.4-6

was recorded in June between 4 and 8 m (13.1 and 26.2 feet), and maximum dissolved oxygen (12.0 mg/l) was measured concurrently at 5 m (16.4 feet). The metalimnion and oxygen maximum became more pronounced in July and August, respectively. In July, the metalimnion exhibited its most extreme temperature change, a 16°C (29°F) drop between 3 and 7 m (9.8 and 23.0 feet). In August, the dissolved oxygen concentration at 5 m (16.4 feet) and within the metalimnion was so high (>20 mg/l) that it was not measurable with standard field meters.

Metalimnetic oxygen maxima as observed in Ground Hemlock Lake during June, July, and August are common phenomena that occur in clear, thermally stratified lakes and, typically, are generated by a bloom of blue-green algae (Eberly, 1959; Reynolds and Walsby, 1975). Observations made by a scuba equipped diver in August confirmed the presence of a sharply defined, dense growth of phytoplankton within the metalimnion.

Very low dissolved oxygen concentrations (typically <1 mg/l) were recorded from June through September at or below the metalimnion. This region of low dissolved oxygen rose from a depth of 8 m (26.2 feet) in June to 6 m (19.7 feet) by September. By October, the autumn overturn had occurred, as indicated by the uniform vertical temperature distribution and the diminished dissolved oxygen gradient.

In general, the concentrations of metals in Ground Hemlock Lake were either below detection limits or at very low levels. Lead was below detection limits at both sampling levels throughout this study except at GH-1 in December 1979 and April 1980 when concentrations of 0.02 and 0.03 mg/l were recorded, respectively.

2.4.4.3 Seepage Lakes

Oak Lake - Oak Lake is located approximately 1.4 km (0.9 mile) southwest of the ore body (Figure 2.4-5). It has a total surface area of 21 ha (51 acres) and a maximum depth of 14 m (47 feet). The shoreline vegetation is predominantly upland hardwoods with the remainder composed of bog, meadow, and shrub wetlands. The lake substrate was predominantly muck and sand (Table 2.4-18). The lake has no defined inlets and provides an intermittent headwater source of Hoffman Creek. The drainage of Oak Lake is poorly defined, and during the study period observations were made to better describe its drainage pattern. Oak Lake receives water directly from precipitation and from runoff within its drainage basin. During most of the year it appears to have no surface water connection to the remainder of the Hoffman Creek drainage basin; however, when a sufficient amount of water is delivered to the lake by thunderstorms or during snowmelt, it discharges surface water to Hoffman Creek. At those times, surface water enters Oak Lake around its edges and from the north through a culvert under Sand Lake Road. Surface water leaves Oak Lake and flows into a broad wetland area via a poorly defined, intermittent outlet on the lake's southwest margin. Water flow proceeds southwest and then north through a wetland area via a second culvert under Sand Lake Road as shown on Figure 2.4-5.

A stream gage on the outlet stream of Oak Lake (SG 10) was established and monitored during the study. Staff gage readings recorded are shown in Appendix 2.4A, Table A-9. The highest flow rate monitored at this location was 0.06 m^3/s (2 cubic feet/second) on April 18, 1979. Zero flow rate observations during the study period were common. Based on these observations, it is believed that the area immediately surrounding Oak Lake is a main ground water aquifer recharge area, which contributes to the discharge area at Hoffman Springs (also see Hoffman Creek).

A staff gage (LG 11) was established in Oak Lake to measure surface water levels (Figure 2.4-1). Appendix 2.4B, Table B-3 provides a record of gage readings at this location and Figures I-1 and I-2 of Appendix 2.4I show a continuous plot of these points. During the period of study, a 0.64-m (2.10-foot) fluctuation was recorded, reflecting the fairly constant water level. Lake levels during this study period varied from a high of 498.11 m (1,634.21 feet) MSL on April 21 and 22, 1979 to 497.47 m (1,632.11 feet) MSL on August 3, 1977.

Detailed field observations during January 1985 and subsequent data analyses were used to develop a water balance for Oak Lake. These studies suggest that during an average year, Oak Lake water surface elevation will rise 78.7 cm (31 inches) by precipitation on the lake surface and 63.5 cm (25 inches) from surface inflows, and will fall 66 cm (26 inches) from evaporation, 53.3 cm (21 inches) by surface outflow, and 22.9 cm (9 inches) because of subsurface seepage. Further details are contained in Dames & Moore (1985).

The water chemistry sampling location in the southwestern portion of Oak Lake was approximately at the 9-m (29.5-foot) depth contour (Figure 2.4-2). Samples collected at this location were obtained from two separate levels: 1 m (3.3 feet) (G-1) and 5 to 7 m (16.4 to 23.0 feet) (G-2). Collections for G-2 were always taken from the hypolimnion when present. The water chemistry collections for Oak Lake continued monthly from March and June 1977 for G-1 and G-2, respectively, through March 1978. Additional samples were collected at both G-1 and G-2 in May and August 1978. The data for the months sampled are presented in Appendix 2.4F, Table F-5. The maximum, minimum, and mean values are presented in Appendix 2.4G, Table G-5.

Results of water chemistry analyses indicated that Oak Lake was a soft, clear, slightly acidic to neutral pH lake. Average hardness, alkalinity, and specific conductance values at G-1 and G-2 were 11 and 11 mg/l as $CaCO_3$, <4 and <4 mg/l as $CaCO_3$, and 31 and 33 μmhos/cm, respectively. Mean pH values indicated that the deeper waters (G-2: mean pH of 5.9) were slightly more acidic than the near-surface waters (G-1: mean pH of 6.2). Throughout the study, Secchi disc transparency ranged from 3.2 to 5.3 m (10.5 to 17.4 feet). Mean true color measured at Oak Lake was <4 and <1 color units at G-1 and G-2, respectively.

Temperature and dissolved oxygen concentration profiles indicated that Oak Lake stratified during the summers of 1977 and 1978 (Figure 2.4-7; Appendix 2.4H, Table H-9). A rapid decrease in temperature with depth (metalimnion) was evident in July 1977 between 1 and 6 m (3.3 and 19.7 feet), and the maximum dissolved oxygen concentration (11.6 mg/l) was recorded concurrently at 5 m (16.4 feet). By August the metalimnion descended to 5-7 m (16.4-23.0 feet) and the maximum dissolved oxygen concentration (13.1 mg/l) was recorded at 6 m (19.7 feet). This metalimnetic oxygen maximum is a condition not uncommon in lakes (Reid, 1961). In September temperatures were similar (20.0 to 22.5°C [68.0 to 72.5°F]) throughout the water column, indicating no stratification. Dissolved oxygen concentration ranged from 9.4 mg/l at the surface to 9.2 mg/l at 6 m (19.7 feet), and then rapidly decreased to 3.8 mg/l at the bottom. Although a metalimnion was evident in August 1978 at 6 to 7 m (19.7 to 23.0 feet), no corresponding dissolved oxygen maximum was detected (Appendix 2.4H, Table H-9) and the shapes of the profiles were similar to those depicted in June 1977 (Figure 2.4-7).

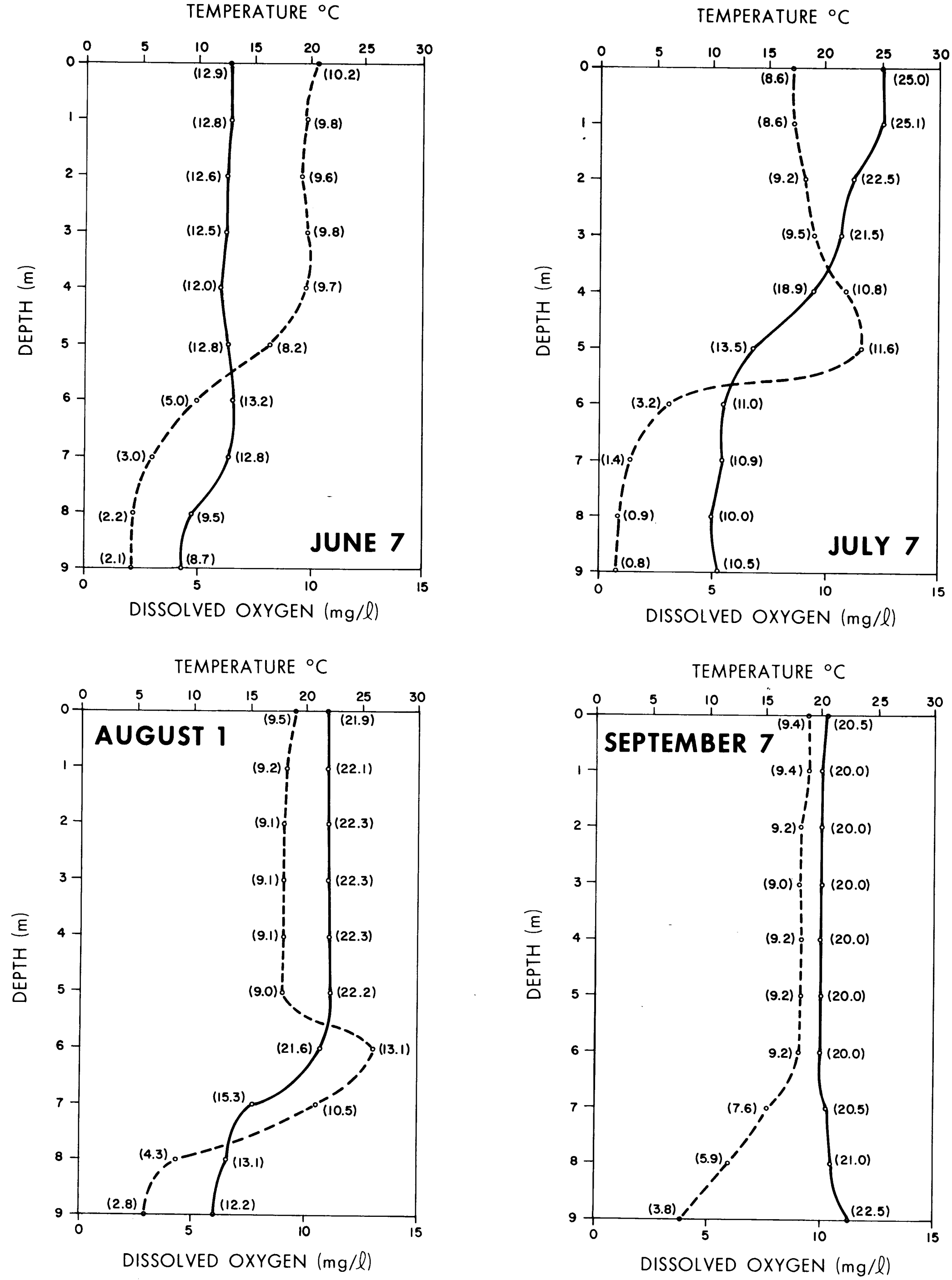
Although unsafe ice conditions prevented recording a depth profile from the designated sampling point in April 1977, the available data indicate that the spring overturn occurred between the March and May sampling periods in 1977 and 1978. The uniform temperature and oxygen content of the water column indicate that the autumn overturn occurred during October and November 1977 (Appendix 2.4H, Table H-9).

Metals measured in samples from Oak Lake were either in low concentrations or below detection limits. In March and December 1977, detectable levels of mercury were recorded at Station G-1 (0.2 and 0.1 μg/l, respectively). Mercury was below the detection limit of 0.1 μg/l, however, in all samples collected at G-2.

Metals were generally reported in lower concentrations from Oak Lake during the 1979-1980 seasonal sampling program than in 1977-1978 as were organic nitrogen, total sulfur, and total and dissolved solids (Appendix 2.4F, Table F-20 and Appendix 2.4G, Table G-20). Other parameters were found in concentrations similar to those reported from the earlier study.

A bottom sediment sample was collected for chemical analysis at Station G in March 1978. The results from this analysis are presented in Appendix 2.4E, Table E-1. Lead and zinc were measured in concentrations of 60 and 205 ppm, respectively.

Suspended sediment samples were collected at SG 10 in April 1979 and the results are presented in Appendix 2.4D, Table D-7. The average total suspended solids was 2.0 mg/l, which is considerably less than the average 11 mg/l for the Northern Highlands region (Hindall, 1976), indicating that the



KEY:

------- DISSOLVED OXYGEN

——— TEMPERATURE

EXXON MINERALS COMPANY
CRANDON PROJECT

DISSOLVED OXYGEN / TEMPERATURE PROFILES
FOR OAK LAKE - STATION G
JUNE TO SEPTEMBER 1977

DAMES & MOORE | FIGURE 2.4-7

Oak Lake outlet is essentially free of suspended sediments. The volatile portion of the suspended solids acts as an indicator of the organic content of sediment carried by the Oak Lake outlet; the remainder is clastic sediment. Volatile solids in the outlet from Oak Lake averaged 1.0 mg/l.

2.4.5 Pickerel Creek Drainage Basin

The portion of the environmental study area within the Pickerel Creek drainage basin is shown on Figures 2.4-4 and 2.4-5. The Pickerel Creek drainage basin has ground and surface water features that are characteristic of the environmental study area, as was described in subsection 2.4.3. It is located approximately in the center of the Wolf River drainage basin (Figure 2.4-4). Surface water drainage flows to the southwest via Pickerel Creek to its confluence with the Wolf River. Specific key basin characteristics are given in Tables 2.4-19 and 2.4-20. Selected surface water features included in the discussion of the Pickerel Creek drainage basin are Rolling Stone Lake, a drainage lake; Pickerel Creek and Creeks 12-9 and 11-4; and Little Sand, Duck, Deep Hole, Skunk, Mole, Walsh, and St. Johns lakes, which are seepage lakes. These features are described individually below.

2.4.5.1 Drainage Lakes and Associated Streams

Rolling Stone Lake - Rolling Stone Lake is a drainage lake located 5.6 km (3.5 miles) south of the ore body as shown on Figure 2.4-5. It has a surface area of 272 ha (672 acres) with a reported maximum depth of 3.7 m (12 feet). The lake substrates are primarily composed of sand and gravel (Table 2.4-20). The lake has two primary inlets, both on the north shore: Pickerel Creek and Creek 12-9. The lake has a simple man-made outlet structure at its southeast end that serves to partially control water levels.

TABLE 2.4-20

SUMMARY OF CHARACTERISTICS FOR THE PICKEREL CREEK AND WOLF RIVER DRAINAGE BASINS IN THE ENVIRONMENTAL STUDY AREA[a]

SURFACE WATER CATEGORY/ WATER BODY	DISTANCE AND DIRECTION FROM ORE BODY km (mi)	DRAINAGE BASIN AREA km^2 (mi^2)	LENGTH km (mi)	AVERAGE WIDTH m (ft)	AVERAGE DEPTH m (ft)	MAXIMUM DEPTH m (ft)	SURFACE AREA ha (acres)	GRADIENT[b] m/km (ft/mi)	ADJOINING WETLANDS ha (acre)	PREDOMINANT SHORELINE VEGETATION[c]	SUBSTRATE CLASSIFICATION
PICKEREL CREEK DRAINAGE BASIN											
Drainage Lake and Associated Streams											
Rolling Stone Lake	5.6 (3.5) South	—[d]	—	—	—	3.7 (12)	272 (672)	--	431.9 (1,067)	Dry-mesic or Mesic Northern Hardwoods	sand, gravel, muck, detritus, rubble
Pickerel Creek	4.7 (2.9) Southwest	115 (44.3)	15 (9.2)	14 (45)	0.533 (1.75)	--	20 (50)	0.8 (4.3)	471.1 (1,164)	Wet-mesic or Wet Northern Forest	muck
Creek 12-9	2.3 (1.4) South	16 (6.0)[e]	2.6 (1.6)	2.7 (9.0)	0.3 (1.0)	—	0.7 (1.7)	6.5 (35)	9.3 (23)	Wet-mesic or Wet Northern Forest	muck, sand, gravel
Creek 11-4	4.5 (2.8) Southwest	1.0 (0.4)	0.8 (0.5)	1.5 (5.0)	0.1 (0.3)	--	0.1 (0.3)	5.8 (31)	21 (53)	Wet-mesic or Wet Northern Forest	muck, sand, gravel
Seepage Lakes											
Little Sand Lake	0.6 (0.4) South	—	—	—	—	6.4 (21)	100 (248)	--	8.1 (20)	Dry-mesic or Mesic Northern Hardwoods	sand, gravel, muck
Duck Lake	1.8 (1.1) Southeast	—	--	—	—	3.0 (10)	11 (26)	—	8.9 (22)	Bog (Scrub/Shrub Wetland)	muck
Deep Hole Lake	2.4 (1.5) Southeast	—	—	—	—	3.0 (10)	39 (97)	—	14 (35)	Dry-mesic or Mesic Northern Hardwoods	muck, sand, gravel, rubble
Skunk Lake	0.6 (0.4) East	—	—	—	—	1.8 (6)	2.4 (6)	--	2 (5)	Dry-mesic or Mesic Northern Hardwoods	muck
Mole Lake	4.0 (2.5) East	—	—	—	—	5.2 (17)	30 (73)	--	7.3 (18)	Dry-mesic or Mesic Northern Hardwoods and Bog (Scrub/Shrub Wetland)	sand, muck, gravel, rubble
Walsh Lake	4.7 (2.9) Southeast	—	--	—	—	4.6 (15)	18 (45)	--	3.2 (8)	Dry-mesic or Mesic Northern Hardwoods	sand, gravel, muck, rubble
St. Johns Lake	5.6 (3.5) Southeast	—	—	—	—	6.1 (20)	39 (96)	--	7.3 (18)	Dry-mesic or Mesic Northern Hardwoods and Wet-mesic or Wet Northern Forest	sand, gravel, rubble, muck
WOLF RIVER DRAINAGE BASIN											
Wolf River above Langlade	12.2 (7.6) Southwest	1,191 (460)[f]	98.97 (61.50)[g]	45 (149)	0.6 (1.9)	—	479.93 (185.9)	1.2 (6.4)[h]	300.7 (8,156)	Wet-mesic and Wet Northern Forest and Aspen[i]	sand, gravel, silt, detritus, peat

[a]Steuck and Andrews, 1976; Steuck et al., 1977; Andrews and Threinen, 1966.

[b]Calculated from Exxon Minerals Company topographic maps.

[c]See Terrestrial Ecology, section 2.6.

[d]Not applicable.

[e]Calculated from data generated in current study.

[f]USGS, 1978.

[g]Northeastern Wisconsin Regional Planning Commission, 1970.

[h]Measured between Pine Lake and Langlade, Wisconsin.

[i]Wisconsin DNR, 1977.

The shoreline is 60 percent woodland and 40 percent wetland. As previously discussed, the influence of a wetland on water level fluctuations in associated lakes (i.e., Rolling Stone Lake) is dependent upon the individual hydrologic characteristics (e.g., source of water, relative position with respect to main aquifer) as well as the interrelationship between the wetland and the lake. Because the main source of water to the lake is stream discharge, fluctuations in the two water bodies would be related only if the wetland is also fed predominantly by stream discharge. If the wetland water source is ground water, little correlation in water level fluctuations would be expected. The wetland would be expected to increase the attenuation influence of the lake on stream discharge by increasing the storage capacity. The wetlands may also provide a source of water during drought periods.

Surface water levels in Rolling Stone Lake were measured at LG 9 (Figure 2.4-1). Appendix 2.4B, Table B-2 provides a record of gage readings at this location and Appendix 2.4I, Figures I-1 and I-2 show a continuous plot of these points. During the period of study, a 0.27-m (0.89-foot) water level fluctuation was observed. The high water level during the study period of 468.12 m (1,535.84 feet) MSL occurred on April 22, 1979. The lowest water level of 467.85 m (1,534.95 feet) MSL occurred on July 12, 1980.

Samples for water chemistry analyses were collected monthly at Rolling Stone Lake from October 1977 through September 1978 at Station M-2, located in the northern portion of the lake, and Station M-4, in the southern portion (Figure 2.4-2). Depths at Stations M-2 and M-4 were approximately 2.1 m (6.9 feet) and 2.0 m (6.6 feet), respectively. The data for the months sampled are presented in Appendix 2.4F, Table F-7. The maximum, minimum, and mean values for the parameters measured are presented in Appendix 2.4G, Table G-7.

Water chemistry data indicated that Rolling Stone Lake was a moderately hard, light brown, neutral pH lake. Mean hardness, alkalinity, and specific conductance values at Stations M-2 and M-4 were 91 and 93 mg/l $CaCO_3$, 83 and 87 mg/l $CaCO_3$, and 157 and 162 μmhos/cm, respectively. The mean pH was 7.7 for both stations. Dense aquatic macrophyte growth often prohibited Secchi disc transparency determinations. Mean transparency values calculated from measurements made during the study were 1.6 and 1.7 m (5.2 and 5.6 feet) for Stations M-2 and M-4, respectively. Mean true color values at M-2 and M-4 were 39 and 40 color units, respectively.

Mean dissolved oxygen concentrations were 8.0 and 7.8 mg/l at Stations M-2 and M-4, respectively (Appendix 2.4H, Table H-11). Concentrations below 5.0 mg/l were measured at both stations in February, March, and April 1978 when an extensive ice cover was present. This trend was noted first in January when depth profiles showed a depletion of oxygen near the lake bottom at both stations. In subsequent winter months, this condition became typical throughout the water column. Low dissolved oxygen levels (2.8 and 0.1 mg/l at Stations M-2 and M-4, respectively) were also found in near-bottom waters in July 1978 but during no other summer sampling.

Rolling Stone Lake is classified as eutrophic (Wisconsin DNR, 1978). Phosphorus and chlorophyll a concentrations were high, and aquatic macrophytes were abundant (section 2.5, Aquatic Ecology). The DNR report indicates that there has been little change in water quality over the past 15 years and that the present trophic status of Rolling Stone Lake is part of its maturation process upon which man has had little, if any, influence. In general, the results of the current study of Rolling Stone Lake were similar to those reported by the DNR. Alkalinity, pH, chloride and nitrogen, phosphorus and sulfur species during spring surveys were similar in both studies. Partial fish kills were documented during the winter of 1977-1978 (Wisconsin DNR, 1978) and low dissolved oxygen concentrations (<5 mg/l) were recorded during this investigation at Stations M-2 and M-4 in February, March, and April 1978 (Appendix 2.4F, Table F-7). Generally, the water chemistry data from Rolling Stone Lake at Stations M-2 and M-4 were similar, indicating that the lake is well mixed.

Metals measured in water samples from Rolling Stone Lake were generally either below detection limits or in low concentrations. Cadmium was detected in one-half of the samples collected at both stations. A concentration of 0.005 mg/l was detected in November 1977 at Station M-2.

Bottom sediments were collected for chemical analysis at Station M-2 and M-4 on Rolling Stone Lake in March 1978. The analytical results are presented in Appendix 2.4E, Table E-2. Reported concentrations between stations for a number of parameters were dissimilar. At Station M-4 chromium, copper, iron, lead, phenol, and sulfate occurred in much higher concentrations than at M-2. Conversely, only freon extractables were higher in concentration at Station M-2.

The difference in chemical concentrations at Stations M-2 and M-4 in Rolling Stone Lake sediments is less than the variance measured in the creeks and lake sediments of the Pickerel Creek drainage basin (Appendix 2.4E, Table E-2), or within the Swamp Creek drainage basin (Appendix 2.4E, Table E-1). Considering this range of values, there is essentially no difference between the values for the two stations.

Pickerel Creek - Pickerel Creek has a surface area of 20 ha (50 acres) and a total length of 15 km (9.2 miles). It is a perennial stream with a drainage area of 115 km^2 (44.3 $miles^2$) and originates in a large wetland area north-northwest of Rolling Stone Lake (Figure 2.4-5). The drainage basin is predominantly wooded and undeveloped with large tracts of adjoining wetlands in the headwaters. The stream originates in the wetlands south of Mole Lake, approximately 4.7 km (2.9 miles) west of the ore body, and intermittently flows south to Rolling Stone Lake, through a flat drainage basin (Table 2.4-20). Pickerel Creek emerges from Rolling Stone Lake and flows west to its confluence with the Wolf River.

Two stream gages, SG 19 and SG 22, were established on Pickerel Creek for measurement of surface water levels (Figure 2.4-1). Appendix 2.4A, Tables A-10 and A-11 provide the record of gage readings at these locations, and Appendix 2.4L provides a summary of monthly and annual flow values. The flat, well vegetated drainage basin results in relatively flat, broad-based surface water runoff hydrographs (Appendix 2.4J, Figures J-5 through J-8). A high flow rate of 0.66 m^3/s (23.4 cubic feet/second) was recorded on April 21, 1979 at SG 19. A staff gage reading indicates that at the same location, a low flow rate of 0.003 m^3/s (0.1 cubic foot/second) occurred on June 16 and 30, 1978, although this extreme low flow is well outside the defined range of the rating curve.

In any year, the minimum 7-day average flow rate at SG 19 is estimated to have a 50 percent chance of being less than 0.017 m^3/s (0.6 cubic foot/second) and a 10 percent chance of being less than 0.011 m^3/s (0.4 cubic foot/second).

Samples for water chemistry analyses were collected from one location on Pickerel Creek (Station M-5) monthly from October 1977 through September 1978. Station M-5 was located approximately 0.2 km (0.1 mile) upstream from Rolling Stone Lake (Figure 2.4-2). The data for the months sampled are presented in Appendix 2.4F, Table F-13. The maximum, minimum, and mean values for the parameters measured are presented in Appendix 2.4G, Table G-13.

The water chemistry data indicate that Pickerel Creek was a moderately hard, neutral pH stream. Mean hardness, alkalinity, and specific conductance values recorded were 83 mg/l as $CaCO_3$, 73 mg/l as $CaCO_3$, and 136 µmhos/cm, respectively. Mean pH recorded at Station M-5 was 6.9. Water color ranged from 5 to 175 color units. Dissolved oxygen concentrations ranged from 5.5 to 12.2 mg/l with an average concentration of 9.0 mg/l.

Metals measured in water samples from Pickerel Creek were either below detection limits or in low concentrations. In November 1977 mercury was found at Station M-5 in a concentration of 0.2 µg/l. This metal was not detected during any other months.

Results of the 1979-1980 seasonal water quality monitoring at Pickerel Creek are reported in Appendix 2.4F, Table F-28 and Appendix 2.4G, Table G-28. Lower concentrations of metals were found in the 1979-1980 program than in the 1977-1978 study. Lower values were also recorded in 1979-1980 for nitrate nitrogen, organic nitrogen, and total and dissolved solids. However, the fecal streptococcus bacteria count recorded in November 1979 was relatively high (400 organisms/100 ml) compared with bacteria populations from any other station studied.

Bottom sediments were collected for chemical analysis from Pickerel Creek at Station M-5 in March 1978. The results are presented in Appendix 2.4E, Table E-2.

Bottom sediment and suspended solids samples were collected for physical characterization. Bottom sediment sampling was accomplished in April 1978 at SG 22 on Pickerel Creek, and the results showing a graded sand are presented in Appendix 2.4D, Figure D-1. Suspended sediment samples were taken at SG 19 and SG 22 as indicated on Table 2.4-1 and the results are presented in Appendix 2.4D, Tables D-8 and D-9. The average total suspended solids was 4.1 mg/l, which is less than the average 11 mg/l for the Northern Highlands region (Hindall, 1976), indicating Pickerel Creek was essentially free of suspended sediments. The volatile portion of the suspended solids acts as an indicator of the organic content of sediment carried by Pickerel Creek; the remainder is clastic sediment. Volatile solids in Pickerel Creek averaged <2.9 mg/l.

Creek 12-9 - Creek 12-9 originates in a wetland area adjacent to the southern shore of Little Sand Lake; however, stream flow directly from the lake is intermittent (Figure 2.4-5). This stream has a drainage area of 16 km^2 (6.0 $miles^2$), a total surface area of 0.7 ha (1.7 acres), and flows southward 2.6 km (1.6 miles) prior to its entrance into Rolling Stone Lake, which serves as the confluence with Pickerel Creek. Creek 12-9 has an average width of 2.7 m (9.0 feet) and an average depth of 0.3 m (1.0 foot), and is adjoined by 9.3 ha (23 acres) of wetlands (Table 2.4-20). Its drainage basin primarily contains lakes and wetlands, and is wooded. Duck and Deep Hole lakes contribute surface water drainage intermittently to Little Sand Lake, which is the headwater of Creek 12-9.

The extensive adjoining wetlands provide a source of base flow to the creek. They tend to maintain flow in the stream under drought conditions longer than would be expected in their absence. The wetlands dampen changes in both high and low flows. This dampening is proportional to their surface area and hydraulic connection to the stream.

Two stream gages on Creek 12-9 (SG 8 and SG 23) were established to monitor surface water levels (Figure 2.4-1). Appendix 2.4A, Tables A-8 and A-12 provide the record of gage readings at these locations, and Appendix 2.4L provides monthly and annual flow summaries. Creek 12-9 has essentially no base flow as measured 0.2 km (0.1 mile) downstream of Little Sand Lake. Although the Creek 12-9 drainage basin is very steep, it consists of about 50 percent wetlands and lakes, which result in relatively flat, broad-based surface water runoff hydrographs (Appendix 2.4J, Figures J-5 through J-8). Discharges measured at SG A, which is located on the primary surface water stream flowing into Little Sand Lake, and those lower surface water discharges measured at SG 8, reflect the storage effect of Little Sand Lake and ground water recharge to the main ground water aquifer. The difference between flows measured and the time lag between SG 8 and SG 23 is primarily attributable to local runoff and ground water from the main ground water aquifer flowing into Creek 12-9 between Little Sand Lake and SG 23. The area between SG 8 and SG 23 is a main ground water aquifer discharge area with springs. This is discussed in more detail in section 2.3, Ground Water.

From August 15 through 17, 1978, intensive monitoring of stormwater runoff was conducted for Creek 12-9 drainage (Appendix 2.4A, Table A-12). The large increase in discharge rate at SG 23 indicated that storm runoff was reaching SG 23 by several routes. During periods of rapid storm runoff, the flow at SG 23 is a combination of ground water (section 2.3, Ground Water) and local surface water runoff that has passed directly through Little Sand Lake to Stream 12-9. During the study period, the highest flow rate of 1.20 m^3/s (42.2 cubic feet/second) was recorded at SG 23 on April 20, 1979. A low flow rate of 0.03 m^3/s (1.2 cubic feet/second) occurred on October 2, 1978 at SG 23.

Samples for water chemistry analyses were collected monthly from March 1977 through September 1978 at Station M-1, located approximately 100 m (328 feet) upstream from Rolling Stone Lake. The data from this location are presented in Appendix 2.4F, Table F-10, and the maximum, minimum, and mean values are presented in Appendix 2.4G, Table G-10.

Results of water chemistry analyses indicated that Creek 12-9 was a moderately hard, neutral pH stream. Mean values for hardness, alkalinity, and specific conductance were 108 mg/l as $CaCO_3$, 100 mg/l as $CaCO_3$, and 197 μmhos/cm, respectively. Mean pH was 7.4 and true color varied from <1 to 95 color units during the study. Dissolved oxygen concentrations were greater than 5.0 mg/l throughout the study. The lowest value recorded was 5.2 mg/l in March 1977.

Metals measured in water samples from Creek 12-9 were generally below detection limits. Mercury was detected at Station M-1 in December 1977 at a concentration of 0.1 μg/l.

Water chemistry data for the 1979-1980 seasonal monitoring program for Creek 12-9 are presented in Appendix 2.4F, Table F-26 and Appendix 2.4G, Table G-26. Except for aluminum, metals occurred in higher concentrations in 1977-1978 than in 1979-1980. Organic nitrogen and solids, both total and dissolved, also were recorded in higher concentrations in the 1977-1978 sampling period.

In November 1979, fecal streptococcus bacteria occurred at a density of 300 organisms/100 ml. This was the highest concentration recorded from Station M-1.

A bottom sediment sample was collected from Creek 12-9 at Station M-1 in March 1978. Appendix 2.4E, Table E-2 presents the results of these analyses. Chromium was found at a concentration of 92.1 ppm.

Suspended sediment samples were collected at SG 8 and SG 23 as indicated in Table 2.4-1 and the results are presented in Appendix 2.4D, Tables D-7 and D-10. The average total suspended solids was 8.1 mg/l, which is less than the average 11 mg/l for the Northern Highlands region (Hindall, 1976), indicating that Creek 12-9 is essentially free of suspended sediments. The volatile portion of the suspended solids acts as an indicator of the organic content of sediment carried by Creek 12-9; the remainder is clastic sediment. In Creek 12-9, volatile solids averaged <4.8 mg/l.

<u>Creek 11-4</u> - The headwaters for Creek 11-4 begin in a beaver pond located approximately 0.6 km (0.4 mile) north of Rolling Stone Lake (Figure 2.4-5). This creek has a watershed of 1 km^2 (0.4 $mile^2$), a total surface area of 0.1 ha (0.3 acre), and flows a distance of 0.8 km (0.5 mile) prior to its entrance into Rolling Stone Lake. Creek 11-4 has an average width of 1.5 m (5 feet), an average depth of 0.1 m (0.3 feet), and is adjoined by 21 ha (53 acres) of wetlands (Table 2.4-20).

Samples for water chemistry analyses were collected in Creek 11-4 at Station M-3, approximately 0.5 km (0.3 mile) upstream from Rolling Stone Lake. Samples were collected monthly from October 1977 through September 1978. The data are presented by month in Appendix 2.4F, Table F-9. The maximum, minimum, and mean values for the parameters measured are presented in Appendix 2.4G, Table G-9.

Water chemistry information indicated that Creek 11-4 was a moderately hard, neutral pH stream. Mean values recorded for hardness, alkalinity, and specific conductance were 93 mg/l as $CaCO_3$, 84 mg/l as $CaCO_3$, and 175 µmhos/cm, respectively. Mean pH at this station was 6.9 standard units. Water color varied during the study from clear to dark brown, 5 to 170 color units (mean: 87).

Dissolved oxygen concentrations ranged from 3.0 to 9.0 mg/l (mean: 5.9 mg/l). Concentrations below 5 mg/l were detected in October 1977 (4.5 mg/l) and from July through September in 1978 when values ranged from 3.0 to 4.3 mg/l.

Results of the analysis of water samples from the 1979-1980 seasonal monitoring at Creek 11-4 are presented in Appendix 2.4F, Table F-25 and Appendix 2.4G, Table G-25. Generally, the results from the two sampling periods are similar. The metals cadmium and copper were somewhat higher in 1977-1978, as were organic nitrogen and dissolved and total solids.

In November 1979, fecal streptococcus bacteria occurred at a density of 350 organisms/100 ml. This was the highest concentration recorded at Station M-3 during both the 1977-1978 and the 1979-1980 periods.

Bottom sediments were collected for chemical analysis in March 1978 from Creek 11-4 at Station M-3. The results are presented in Appendix 2.4E, Table E-2. The levels of metals and other parameters measured in these sediments were low.

2.4.5.2 Seepage Lakes

Little Sand Lake - Little Sand Lake is located 0.6 km (0.4 mile) south of the ore body (Figure 2.4-5). It has a surface area of 100 ha (248 acres) and a maximum depth of 6.4 m (21 feet); 86 percent of the lake has a depth of 3 m (10 feet) or less. The shoreline vegetation is predominantly upland hardwoods with some wetland. Most of the littoral substrate is sand (Table 2.4-20). The lake has a single intermittent inlet stream on its east side and a single intermittent outlet stream to the south. It receives water intermittently from the upstream lakes of Duck and Deep Hole.

A staff gage (LG 7) was established in Little Sand Lake to measure surface water levels (Figure 2.4-1). Appendix 2.4B, Table B-1 provides a record of gage readings at this location and Appendix 2.4I, Figures I-1 and I-2 show a continuous plot of these points. During the period of study a 0.65-m (2.14-foot) low to high water level was observed. The high water level during the study period of 485.53 m (1,592.96 feet) MSL occurred on April 21, 1979. The lowest water level of 484.88 m (1,590.82 feet) MSL was recorded on July 30, 1977 during the aforementioned driest period on record (Table 2.4-15).

Detailed field observations during January 1985 and subsequent data analyses were used to develop a water balance for Little Sand Lake. These studies suggest that during an average year, Little Sand Lake water surface elevation will rise 78.7 cm (31 inches) by precipitation on the lake surface and 94 cm (37 inches) from surface inflows, and will fall 66 cm (26 inches) from evaporation, 86.4 cm (34 inches) by surface outflow, and 20.3 cm (8 inches) because of subsurface seepage. Further details are contained in Dames & Moore (1985).

Samples for chemical analyses were collected from two locations in Little Sand Lake: one in the northern portion, Station H, and the other in the south-central portion, Station I (Figure 2.4-2). The depth measured at Station H was 3.2 m (10.5 feet) and the depth at Station I was 3.4 m (11.2 feet). Samples were collected monthly from March 1977 through March 1978, and in May and August 1978. The data for the months sampled are presented in Appendix 2.4F, Table F-3. The maximum, minimum, and mean values for the parameters measured are presented in Appendix 2.4G, Table G-3.

Water chemistry data indicated that Little Sand Lake was a soft, slightly acidic, clear water lake. Mean hardness, alkalinity and specific conductance values at Stations H and I were 12 and 10 mg/l as $CaCO_3$, <2 and <2 mg/l as $CaCO_3$, and 38 and 37 μmhos/cm, respectively. A mean pH value of 5.4 was calculated at both stations. High transparency permitted the Secchi disc to be read consistently to the bottom and low true color values were recorded at both stations. Mean values for color at Stations H and I were <5 and <4 units, respectively.

A mean dissolved oxygen concentration of 9.1 mg/l was recorded from a 1-m (3.3-foot) depth at both stations (Appendix 2.4H, Table H-7). Concentrations ranged from 2.8 to 11.8 mg/l at Station H and 2.5 to 15.5 mg/l at Station I. Oxygen levels below 5 mg/l occurred in March 1977 and February and March 1978 at both locations, and in February 1980 at Station H. The observation of low dissolved oxygen concentration levels during February and March was not unique to Little Sand Lake, but similar trends were observed in other lakes. Low dissolved oxygen concentrations are reasonable considering that lakes are likely to have been covered by ice since December.

Depth profiles of water chemistry parameters indicate that the waters of Little Sand Lake were well mixed throughout the ice-free periods (Appendix 2.4H, Table H-7). However, dissolved oxygen profiles recorded during February and March 1978 indicate inverse dissolved oxygen concentration gradients from the surface to bottom under the ice.

Metals measured in water samples from Little Sand Lake were either below detection limits or in low concentrations. Mercury was detected only once at Little Sand Lake at a concentration of 0.1 μg/l at Station I in December 1977.

Fecal coliform bacteria, seldom recorded in very high numbers from any water body examined in this study, occurred at a concentration of 184 organisms/100 ml in March 1977 at Station H. This was the highest concentration of fecal coliform bacteria recorded from any lake or stream examined in the 1977-1978 investigation.

Seasonal monitoring of Little Sand Lake from November 1979 through August 1980 did not include Station I. The results of the water sample analyses from Station H are presented in Appendix 2.4F, Table F-19 and Appendix 2.4G, Table G-19.

Although not detected in 1977-1978, aluminum occurred in all water samples collected at Station H during 1979-1980. Conversely, copper was detected in 1977-1978, but not in 1979-1980. Other constituents that differed between the two sampling periods were organic nitrogen, dissolved and total solids, fecal coliform bacteria, and fecal streptococcus bacteria, all of which were detected in higher concentrations in 1977-1978 than in 1979-1980.

Bottom sediments were collected in March 1978 for chemical analysis at Stations H and I in Little Sand Lake. The analytical results are presented in Appendix 2.4E, Table E-2. Lead and zinc at Station I were measured at concentrations of 156 ppm and 218 ppm, respectively. Further, these two values were the highest reported for any sediment samples from this study.

The analytical results indicate that concentrations of nearly all parameters measured were higher at Station I than at Station H. The difference in the mentioned chemical constituent concentrations at Stations H and I in Little Sand Lake is less than the natural variance measured in the creeks and lake sediments of the Pickerel Creek drainage basin (Appendix 2.4E, Table E-2) or within the Swamp Creek drainage basin (Appendix 2.4E, Table E-1). Considering this range of values, there is essentially no difference between the stations. The concentration of lead at Station I, 156 ppm, was approximately 10 standard deviations from the mean, 16.9 ppm (±13.3 ppm) of the nine samples (exclusive of Station I), and is the highest reported value for all sediments. Therefore, this value is not considered representative of the Pickerel Creek drainage basin.

Duck Lake - Duck Lake is located approximately 1.8 km (1.1 miles) southeast of the ore body (Figure 2.4-5). It has a surface area of 11 ha (26 acres) and a maximum depth of 3 m (10 feet). The shoreline is characterized mostly by swamp conifer or bog vegetation with mixed hardwoods in the upland areas. The lake sediments are primarily muck (Table 2.4-20). The lake has no clearly defined inlet stream and an intermittent outlet stream, which flows through a major wetland before discharging into Little Sand Lake.

Two stream gages on the outlet of Duck Lake (SG B, located approximately 0.3 km [0.2 mile] downstream from Duck Lake and SG A, located approximately 0.3 km [0.2 mile] upstream from Little Sand Lake) were established and monitored during the study period (Figure 2.4-1). Staff gage readings recorded are shown in Appendix 2.4A, Tables A-13 and A-14.

A staff gage, LG 12, was established in Duck Lake to measure surface water levels (Figure 2.4-1). Table B-4 of Appendix 2.4B provides a record of gage readings at this location and Appendix I, Figures I-1 and I-2 show a continuous plot of these points. During the period of study, a 0.62-m (2.02-foot) fluctuation from low to high readings was observed. The highest water level during the study period occurred on April 12, 1979, at which time the gage was submerged and no precise reading was possible. The lowest water level of 490.80 m (1,610.23 feet) MSL occurred on July 29, 1977.

Detailed field observations during January 1985 and subsequent data analyses were used to develop a water balance for Duck Lake. These studies suggest that during an average year, Duck Lake water surface elevation will rise 78.7 cm (31 inches) by precipitation on the lake surface and 48.3 cm (19 inches) from surface inflows, and will fall 66 cm (26 inches) from evaporation, 7.6 cm (3 inches) by surface outflow, and 53.3 cm (21 inches) because of subsurface seepage. Further details are contained in Dames & Moore (1985).

Samples for chemical analysis were collected monthly in Duck Lake from March 1977 through October 1978. The sampling location at Duck Lake (Station K) was at a depth contour of approximately 1.8 m (6 feet). The data are presented in Appendix 2.4F, Table F-2. The maximum, minimum, and mean values are presented in Appendix 2.4G, Table G-2.

Water chemistry data indicated that Duck Lake was a soft, slightly acidic, medium brown colored lake. Mean hardness, alkalinity, and specific conductance values were 15 mg/l as $CaCO_3$, <3 mg/l as $CaCO_3$, and 39 µmhos/cm, respectively. The calculated mean pH was 5.0, the lowest value calculated from all the water bodies sampled. Secchi disc transparency, which often reached to the bottom, ranged from 0.9 to 2.1 m (3.0 to 6.9 feet) and the color ranged from 12 to 100 color units (mean: 59 color units).

Dissolved oxygen concentrations measured at a depth of 1.0 m (3.3 feet) ranged from 0.5 to 13.9 mg/l (Appendix 2.4H, Table H-5). Concentrations were below 5 mg/l during periods when ice cover was present: March 1977 (1.1 mg/l) and February (3.3 mg/l), March (1.3 mg/l), and April (0.5 mg/l) 1978.

Depth profiles of water chemistry parameters indicated that Duck Lake was generally well mixed during the ice-free periods. In March 1978, the water column profile showed a typical winter temperature gradient of 1.0°C (34°F) at the surface to 4.5°C (40°F) at the bottom, but dissolved oxygen and conductivity did not show similar gradients (Appendix 2.4H, Table H-5).

Metals measured in water samples collected from Duck Lake were either below detection limits or low concentrations. Cadmium, the most frequent metal detected, was measured in five of the 20 water samples. The mean concentration was <0.002 mg/l and ranged from <0.001 to 0.006 mg/l. The concentration in both November 1977 and January 1978 was 0.006 mg/l, which is greater than the 0.004 mg/l recommended maximum concentration for the protection of aquatic life in soft water (U.S. EPA, 1976). Mercury was detected in two of 19 samples, November and December 1977. Concentrations of 0.1 µg/l were measured during both of these months.

Results of the 1979-1980 seasonal water quality monitoring program at Duck Lake are reported in Appendix 2.4F, Table F-17 and Appendix 2.4G, Table G-17. Generally, the water chemistry parameters measured during the 1979-1980 seasonal monitoring were similar to those recorded in 1977-1978. Except for aluminum, metals occurred in somewhat higher concentrations in 1977-1978, as did ammonia, nitrate, and organic nitrogen. Cadmium was not measured at the detection limit in 1979-1980. However, some water chemistry values were notably different, including alkalinity, conductivity, hardness, and pH, all of which exhibited increases in the summer of 1980. This was probably a result of the addition of approximately 0.090 to 0.091 m^3/s (1,420 to 1,440 gallons/minute) of ground water from a pumping test discharge to Duck Lake during a period of 24 days, from June 27 through July 21, 1980 (Golder Associates, 1981).

Chemical analysis data of water from Duck Lake are reported in Appendix 2.4F, Table F-17, for analyses conducted both before the pumping test and 3 weeks later. Although alkalinity, hardness, total dissolved solids, and pH had measured increases after the pumping test, there were no detectable increases in metal concentrations. Rainwater, which is low in total dissolved solids, alkalinity, hardness, and pH, should restore Duck Lake to its pre-pumping test water quality.

Bottom sediments were collected from Duck Lake at Station K for chemical analysis in March 1978. The results are presented in Appendix 2.4E, Table E-2. Except for freon extractables, all other parameters measured were found in low concentrations. However, the value reported for freon extractables (5,504 ppm) was the highest reported for any station in this study.

Suspended sediment samples were collected twice at SG A and nine times at SG B. The results are presented in Appendix 2.4D, Tables D-11 and D-12. The average total suspended solids was <3.3 mg/l, which is less than the average 11 mg/l for the Northern Highlands region (Hindall, 1976). The volatile portion of the suspended solids averaged <1.9 mg/l.

Deep Hole Lake - Deep Hole Lake is located approximately 2.4 km (1.5 miles) southeast of the ore body (Figure 2.4-5). It has a surface area of 39 ha (97 acres) and a maximum depth of 3 m (10 feet). The shoreline vegetation is characteristically upland hardwood and wooded, shrub-meadow wetland. The major components of the lake littoral sediments are sand and muck (Table 2.4-20).

Although the lake has no clearly defined inlet or outlet, an intermittent inlet is present through the wetlands to the east, and two intermittent outlets exist. During periods of high water levels, surface water discharge can occur from the main outlet of Deep Hole Lake through a shallow marsh located on the west-central part of the lake, which flows to Little Sand Lake. A beaver dam, located approximately 244 to 305 m (800 to 1000 feet) west of the lake proper, controls discharge from the lake. The U-shaped dam is approximately 38 m (125 feet) in length, and in August 1983 the water level was 0.3 to 0.5 m (1 to 1.5 feet) upstream of the dam. The only water flowing downstream of the dam was from seepage, which occurs at several locations at the toe of the dam. There is no well defined stream channel downstream from the dam. Water seeping from the dam flows through an area approximately 30 m (100 feet) in width before entering a coniferous swamp located approximately 46 m (150 feet) downstream.

A secondary outlet is located on the southwest side of the lake. A beaver dam, approximately 152 m (500 feet) south of the lake proper, controls flow from this outlet. A shallow marsh wetland is located between the open water part of the lake and the beaver dam. In August 1983, the water level was below the bottom of the 30-m (100-foot) long dam and there was no seepage through the dam. There is no well defined channel downstream of the dam. The area downstream of the dam is grass with scattered trees (streamside wetland). When the lake level is high and water flows over or through the dam, it enters this streamside wetland before entering a shrub swamp wetland approximately 250 m (820 feet) downstream.

Two stream gages on intermittent streams upstream of Deep Hole Lake (SG C and SG D) (Appendix 2.4A, Table A-13) were established and monitored several times during the study (Figure 2.4-1). Approximately halfway between Deep Hole and Little Sand lakes is the confluence with the Duck Lake outlet stream. Surface water flow from Duck Lake is measured by SG B (Appendix 2.4A, Table A-14), located on the Duck Lake outlet upstream of this confluence. Surface water flow from both Duck and Deep Hole lakes is measured at SG A (Appendix 2.4A, Table A-13) approximately halfway between Little Sand Lake and the aforementioned confluence. All of the surface water flows monitored were during spring snowmelt periods. Staff gage data indicate that, during spring, surface water flow rates measured at SG A, SG C, and SG D were in direct proportion to the drainage area. This result is expected because drainage area and surface water flow rates are highly correlated physiographic features (Bock et al., 1972). The topographic drainage areas for the subbasins monitored by SG C and SG D are 9 and 36 percent, respectively, of the total subbasin monitored by SG A. Similarly, surface water discharge at SG C and

SG D as measured on April 14, 1978 contributes 13 and 35 percent, respectively, of the total discharge measured at SG A. Appendix 2.4A, Table A-13 presents the flow rates recorded at these gages and Table 2.4-1 presents the topographic drainage area for each staff gage subbasin.

A staff gage (LG 13) was established to measure surface water levels in Deep Hole Lake (Figure 2.4-1). Appendix 2.4B, Table B-5 provides a record of gage readings at this location and Appendix 2.4I, Figures I-1 and I-2 show a continuous plot of these points. During the period of study, a fluctuation of more than 0.65 m (2.14 feet) was observed. The highest water level during the study period occurred on April 21, 1979, at which time the gage was submerged and no precise reading occurred. The lowest water level of 489.19 m (1,604.96 feet) MSL occurred on July 30, 1977.

Water samples for chemical analysis were collected monthly from March 1977 through October 1978 from Deep Hole Lake. Samples were collected at one location (Station L) in the northern portion of the lake at a depth contour of approximately 1.8 m (6 feet). The data for the months sampled are presented in Appendix 2.4F, Table F-1. The maximum, minimum, and mean values are presented in Appendix 2.4G, Table G-1.

The water chemistry data indicate that Deep Hole Lake is a soft, slightly acidic pH, light brown colored lake. Mean hardness, alkalinity and specific conductance values at Deep Hole Lake were 16 mg/l as $CaCO_3$, <5 mg/l as $CaCO_3$, and 39 μmhos/cm, respectively. The mean pH was 6.0 standard units. Secchi disc transparency generally extended to the lake bottom at Station L, and true color values ranged from <1 to 40 color units (mean: <23).

Dissolved oxygen concentrations measured at a depth of 1 m (3.3 feet) ranged from 1.3 to 14.8 mg/l (Appendix 2.4H, Table H-4). When Deep

Hole Lake was covered with ice and snow in March 1977 and 1978, oxygen concentrations below 5 mg/l were recorded (2.2 and 1.3 mg/l, respectively). In March 1978, the dissolved oxygen concentration measured immediately below the ice was 9.2 mg/l versus 1.3 mg/l at 1 m (3.3 feet). Depth profiles of general water quality parameters such as temperature, dissolved oxygen, pH, and conductivity indicated that Deep Hole Lake at Station L was generally well mixed (Appendix 2.4H, Table H-4).

Metals measured in water samples from Deep Hole Lake were either below detection limits or in low concentrations. Cadmium was detected in five of 20 monthly samples and ranged in concentration from 0.001 to 0.007 mg/l. Concentrations higher than 0.004 mg/l, the maximum concentration recommended by the U.S. EPA (1976) to ensure the protection of aquatic life in soft water, were measured in November 1977 (0.006 mg/l) and January 1978 (0.007 mg/l). Mercury was detected at Station L only in December 1977 at a concentration of 0.1 µg/l.

The water chemistry parameters measured during the 1979-1980 seasonal monitoring were very similar to those measured in 1977-1978. Some differences were noted in metal concentrations. Except for aluminum, metal concentrations recorded in 1979-1980 were lower than those recorded in 1977-1978. Aluminum, however, was found above detection limits (<0.01 mg/l) in three of the four seasonal samples in concentrations ranging from 0.07 to 0.08 mg/l. Also, organic nitrogen, dissolved solids, and total dissolved solids were found at higher levels in 1977-1978.

Bottom sediments were collected for chemical analysis from Deep Hole Lake at Station L in March 1978. The analytical results are reported in Appendix 2.4E, Table E-2. The concentrations determined for metals in these sediments and other parameters were low.

The location and frequency of suspended solids sampling are presented in Table 2.4-1. Single sediment samples were collected at SG D, a poorly defined, intermittent tributary southeast of the lake, and the results are presented in Appendix 2.4D, Table D-11. The value for total suspended solids was 4 mg/l, which is considerably less than the average of 11 mg/l for the Northern Highlands region, indicating that the inlet to Deep Hole Lake is essentially free of suspended sediments. The volatile portion of the suspended solids acts as an indicator of the organic content of sediment carried by Deep Hole Lake inlet; the remainder is clastic sediment. Deep Hole Lake inlet volatile solids measured 1 mg/l.

Skunk Lake - Skunk Lake is located 0.6 km (0.4 mile) east of the ore body in the uppermost portion of the Pickerel Creek drainage basin (Figure 2.4-5). It has a surface area of 2 ha (6 acres) and a maximum depth of 1.8 m (6 feet); however, depths in most of the lake are <1 m (<3.3 feet). The shoreline is predominantly upland hardwoods and the remainder marsh wetland. The bottom substrate consists primarily of muck (Table 2.4-20). Skunk Lake is located in a topographic depression and appears to have neither a surface water inlet nor outlet.

A staff gage was established in Skunk Lake (LG 15) to measure surface water levels (Figure 2.4-1). Appendix 2.4B, Table B-7 provides a record of gage readings at this location and Appendix 2.4I, Figures I-1 and I-2 show a continuous plot of these points. During the period of study a 0.54-m (1.78-foot) fluctuation was observed. The highest water level during the study period was 487.15 m (1,598.26 feet) MSL on May 16, 1980 and the lowest was 486.61 m (1,596.48 feet) MSL on October 30, 1977.

Detailed field observations during January 1985 and subsequent data analyses were used to develop a water balance for Skunk Lake. These studies suggest that during an average year, Skunk Lake water surface elevation will rise 78.7 cm (31 inches) by precipitation on the lake surface and 88.9 cm (35 inches) from surface inflows, and will fall 66 cm (26 inches) from evaporation and 101.6 cm (40 inches) because of subsurface seepage. Further details are contained in Dames & Moore (1985).

Water samples for chemical analyses were collected from Skunk Lake at Station J, in the central part of the lake, at a depth of approximately 1.0 m (3.3 feet). Monthly samples were collected and analyzed from March 1977 through March 1978. The data for each month sampled are presented in Appendix 2.4F, Table F-8. The maximum, minimum, and mean values for the parameters measured are presented in Appendix 2.4G, Table G-8.

Skunk Lake is a soft, slightly acidic, dark brown colored lake. Mean hardness, alkalinity, and specific conductance values were 15 mg/l as $CaCO_3$, 10 mg/l as $CaCO_3$, and 40 μmhos/cm, respectively. The pH during this study ranged from 5.2 to 6.6 with a calculated mean of 5.8. Secchi disc transparency consistently extended to the bottom of the lake. True color ranged from 84 to 190 color units (mean: 119 color units).

Low dissolved oxygen values were recorded at subsurface depths (<0.5 m) in summer and winter (Appendix 2.4H, Table H-13). Dissolved oxygen concentrations in July, August, and September 1977 were 4.4, 3.4, and 3.0 mg/l, respectively. In January, February, and March 1978, when extensive ice cover was present, concentrations of 0.7, 2.7, and 0.4 mg/l, respectively, were recorded. Dissolved oxygen concentrations in Skunk Lake were greater than 5.0 mg/l only in the spring and autumn. Depth profiles indicated that dissolved oxygen concentrations measured near the bottom of Skunk Lake were consistently lower than those at the surface.

Metals measured in water samples collected from Skunk Lake were usually below detection limits or in low concentrations. Cadmium was recorded in four of the 13 water samples collected. The mean concentration was <0.002 mg/l, with a range from <0.001 to 0.005 mg/l. The 0.005 mg/l concentration occurred in November 1977, and this level is greater than the 0.004 mg/l recommended maximum concentration for the protection of aquatic life in soft water (U.S. EPA, 1976).

Results of the 1979-1980 seasonal water quality monitoring program at Skunk Lake are reported in Appendix 2.4F, Table F-23 and Appendix 2.4G, Table G-23. Except for aluminum, which ranged from <0.01 to 0.10 mg/l, all metals detected in water samples from Skunk Lake occurred at the same level or in higher concentrations in 1977-1978 than in 1979-1980. Other parameters that were recorded in noticeably higher concentrations in 1977-1978 were orthophosphate, total phosphorus, nitrogen (ammonia, nitrate, and organic), solids (dissolved, total, and volatile), and true color. Conversely, sulfides and total sulfur were higher in concentration in 1979-1980 than in 1977-1978.

<u>Walsh Lake</u> - Walsh Lake is located 4.7 km (2.9 miles) southeast of the ore body (Figure 2.4-5). It has a surface area of 18 ha (45 acres) and a maximum depth of 4.6 m (15 feet). The shoreline is predominantly upland with the remainder wetland. The bottom substrate consists primarily of sand and gravel (Table 2.4-20). From topographic maps, it is not clear in which drainage basin -- Swamp Creek, Pickerel Creek, or Lily River -- Walsh Lake is

located; it is adjacent to the headwaters of each of these basins. Walsh Lake is closest to the Pickerel Creek watershed and has, therefore, been included with this basin. Walsh Lake has an intermittent surface water inlet and no clearly defined outlet although it is directly connected to Kimberly Lake by a channel through the wetlands between the two lakes.

A staff gage was established in Walsh Lake (LG 25) to measure surface water levels (Figure 2.4-1). Appendix 2.4B, Table B-9 provides a record of gage readings at this location and Appendix 2.4I, Figure I-2 shows a continuous plot of these points. During the period of study, a 0.24-m (0.79-foot) fluctuation was observed. The levels of this lake were monitored for only a 6-month period in mid-1980, and both the high level of 487.68 m (1,600.00 feet) MSL on April 12, 1980 and the low level of 487.44 m (1,599.21 feet) MSL occurred in 1980.

Water chemistry samples were collected monthly from November 1979 through October 1980 at one location on Walsh Lake (Station WL). Water depth at this station was approximately 4 m (13 feet). The data for the months sampled are presented in Appendix 2.4F, Table F-24. Maximum, minimum, and mean values for those parameters studied are presented in Appendix 2.4G, Table G-24.

A review of the water chemistry data indicates that Walsh Lake was a soft, neutral, clear water lake. Mean hardness, alkalinity, and specific conductance values at Station WL were 13 mg/l as $CaCO_3$, 5 mg/l as $CaCO_3$, and 30 μmhos/cm, respectively. Secchi disc transparency ranged from 2.0 to 3.4 m (6.6 to 11.2 feet) and true color ranged from 10 to 25 color units with a mean of 18 color units.

The mean dissolved oxygen concentration in Walsh Lake was 9.1 mg/l. Dissolved oxygen concentrations of <5 mg/l were recorded at depths below 2 m (6.6 feet) in February 1980 and below 1 m (3.3 feet) in March 1980 when ice covered the lake. In addition, a low dissolved oxygen concentration (4.7 mg/l) was recorded near the lake bottom in July 1980. Depth profiles of water chemistry parameters measured indicate that Walsh Lake was generally well mixed (Appendix 2.4H, Table H-14).

St. Johns Lake - St. Johns Lake is located 5.6 km (3.5 miles) southeast of the ore body (Figure 2.4-5). It has a surface area of 39 ha (96 acres) and a maximum depth of 6.1 m (20 feet). The shoreline is predominantly upland consisting of mixed hardwoods with the remainder of the shoreline in wetland. The bottom substrate consists primarily of sand and gravel (Table 2.4-20). St. Johns Lake is entirely within the Pickerel Creek drainage basin. It has no clearly defined surface water inlet and an intermittent outlet that flows south to Crane Lake.

No stream gages were established or exist near this lake from which information on stream flow can be obtained. The drainage basin of the lake consists largely of surface water, and the poorly defined runoff that occurs is expected to quickly be reflected as increased lake level.

A staff gage was established in St. Johns Lake (LG 26) to measure surface water levels (Figure 2.4-1). Appendix 2.5B, Table B-10 provides a record of gage readings at this location and Appendix 2.4I, Figure I-2 shows a continuous plot of these points. During the period of study, a 0.18-m (0.60-foot) fluctuation was observed. The levels of this lake were monitored only over a 6-month period in mid-1980; therefore, both the high level of 484.85 m (1,590.70 feet) MSL on April 12, 1980 and the low level of 484.66 m (1,590.10 feet) MSL occurred in 1980.

Monthly water samples were collected in St. Johns Lake at Station JL from November 1979 through October 1980. The water depth at Station JL was approximately 6 m (19.7 feet). The data for the months sampled are presented in Appendix 2.4F, Table F-22. Maximum, minimum, and mean values for those parameters studied are presented in Appendix 2.4G, Table G-22.

The water chemistry data indicate that St. Johns Lake is a soft, neutral, clear water lake. Mean hardness, alkalinity and specific conductance values at Station JL were 11 mg/l as $CaCO_3$, 4 mg/l as $CaCO_3$, and 19 μmhos/cm, respectively. Transparency, as measured with the Secchi disc, was relatively high ranging from 2.2 to 4.0 m (7.2 to 13.1 feet). Over the 12-month study period, true color ranged from 5 to 30 color units (mean: 14 color units).

The mean dissolved oxygen concentration for St. Johns Lake calculated from monthly measurements was 9.2 mg/l. Depth profiles showed a depletion of oxygen (<5 mg/l) near the lake bottom in January 1980. In subsequent months, with ice cover on the lake, dissolved oxygen concentrations below the depth of 1 m (3.3 feet) were consistently <5 mg/l. In addition, low dissolved oxygen concentrations were recorded near the lake bottom in June and July 1980 (0.8 and 0.7 mg/l, respectively). Although during most months depth profiles of water chemistry parameters measured indicated that St. Johns Lake was generally well mixed, the lake experienced very low dissolved oxygen concentrations during June (0.8 mg/l) and July (0.7 mg/l) 1980 (Appendix 2.4H, Table H-12).

2.4.5.3 Spring Lakes

Mole Lake - Mole Lake is located 4.0 km (2.5 miles) west of the ore body (Figure 2.4-5). The wetlands associated with the lake to the south form the headwaters of Pickerel Creek. The total surface area is 30 ha (73 acres) and the maximum depth is 5.2 m (17 feet). The shoreline is predominantly upland hardwoods with some wetlands. The bottom substrate consists primarily of sand and muck (Table 2.4-20).

Mole Lake is located immediately adjacent to the Swamp Creek-Pickerel Creek drainage basin divide. Surface water drainage enters Mole Lake from the east and south via culverts under Black Joe Road and South Mole Lake Road, respectively. Drainage from both of these sources is intermittent and is greatest in spring and early summer during periods of high runoff and precipitation.

Mole Lake has no known outlet. Local residents report that an outlet was present on the northwest side of the lake; however, drainage from the lake is no longer possible from this outlet because of road and home construction in this area. During periods of extremely high water, a portion of State Highway 55 has been flooded with water originating in Mole Lake and in the fields located west of Highway 55.

Mole Lake has a small drainage basin that consists primarily of lake surface and wetland. Hydrologically, it is a part of the Pickerel Creek drainage system and a further description of surface water runoff characteristics for the system is included in the discussion of Pickerel Creek. No record of lake levels is available.

Water chemistry samples were collected monthly from May 1977 through April 1978 at one location in Mole Lake (Station 0). Water depth at this station was approximately 2.6 m (8.5 feet). The data for the months sampled are presented in Appendix 2.4F, Table F-4. The maximum, minimum, and mean values are presented in Appendix 2.4G, Table G-4.

Water chemistry data indicated that Mole Lake was a soft, light-brown stained, neutral pH lake. Mean values for hardness, alkalinity, and specific conductance were 31 mg/l as $CaCO_3$, 26 mg/l as $CaCO_3$, and 70 µmhos/cm, respectively. The pH ranged from 5.6 to 8.4 standard units (mean: 7.2 standard units). Secchi disc transparency ranged from 1.5 to 2.0 m (4.9 to 6.6 feet), and true color ranged from 10 to 25 color units (mean: 20 color units).

The U.S. Geological Survey has collected water samples annually from Mole Lake since August 1977. Except for aluminum, which was reported in concentrations ranging from 0.030 to 0.200 mg/l by the USGS, concentrations of all other parameters measured were similar to those measured in 1977-1978 (USGS, 1978; 1979; 1980; 1981).

2.4.6 Wolf River Drainage Basin

The portion of the Wolf River studied included the area shown on Figure 2.4-2 and characteristics of the drainage basin upstream from Langlade are summarized in Table 2.4-20. In subsection 2.4.2, the Wolf River is described and the surface water runoff characteristics of the Wolf River basin are presented as measured at the USGS gaging station at Langlade. Two of its major drainage subbasins, the Swamp Creek basin and the Pickerel Creek basin, are described specifically in subsections 2.4.4 and 2.4.5, respectively, because the ore body lies on the watershed between these basins. Although the Wolf River is outside the environmental study area, a description of its surface characteristics places the entire basin into a more complete perspective. Swamp Creek and Pickerel Creek have drainage areas of 392 km^2 (151 $miles^2$) (Table 2.4-18) and 115 km^2 (44 $miles^2$) (Table 2.4-20), respectively, and the Wolf River at Langlade has a drainage area of 1,191 km^2 (460 $miles^2$).

The Wolf River originates in Hiles Mill Pond in Forest County and flows south approximately 359 km (223 miles) to Lake Poygan in Winnebago County (Wisconsin DNR, 1977). It flows on a course along the western margin of the environmental study area (Figure 2.4-2). The principal tributaries upstream from the town of Langlade are Swamp Creek, Pickerel Creek, Hunting River, Lily River, and Ninemile Creek (Figure 2.4-4). Ninety-five percent of the drainage basin is wooded and undeveloped, whereas the remaining 5 percent is farmland (Steuck et al., 1977). Table 2.4-15 presents stream discharge data for the Wolf River at Langlade. Above the community of Lily the river has a flat gradient, reflecting the large areas of lakes and wetlands through which it flows. Below Pearson the character of the river begins to change as it exhibits a steeper gradient. As calculated from USGS topographic maps, the gradient above Pearson averages 0.7 m/km (3.7 feet/mile), while below this area the gradient increases to 1.9 m/km (9.8 feet/mile).

Samples for water chemistry analyses were collected from the Wolf River monthly from October 1977 through October 1978 at Station Y located approximately 1.9 km (1.2 miles) upstream from the confluence with Swamp Creek, and at Station Z, located approximately 1.4 km (0.9 mile) downstream of the confluence with Pickerel Creek (Figure 2.4-2). The data are presented in

Appendix 2.4F, Table F-15. The maximum, minimum, and mean values for the parameters measured are presented in Appendix 2.4G, Table G-15.

Water chemistry information indicated that the Wolf River is a soft, neutral pH stream. Mean hardness, alkalinity, and conductivity values were 60 and 73 mg/l $CaCO_3$, 52 and 63 mg/l $CaCO_3$, and 84 and 99 μmhos/cm at Stations Y and Z, respectively. Mean pH values recorded at Stations Y and Z were 6.9 and 7.0, respectively. Water color at these stations varied from light to dark brown (combined range: 30 to 145 color units).

At Station Y, dissolved oxygen concentrations were consistently above 5 mg/l, whereas at Station Z in the summer of 1978 (July, August, and September) they ranged from 1.4 to 2.7 mg/l. The dissolved oxygen concentrations at both Stations Y and Z on the Wolf River reach their lowest value during the summer, when the water temperature is at its maximum. The lower range of dissolved oxygen concentration at Station Z does not correlate with differences in BOD, COD, or stream sediment chemistry. The Wolf River at Station Z has the additional input from Swamp, Spider, and Pickerel creeks, which may explain the differences in dissolved oxygen concentrations. Also, the presence of aquatic plant communities in this segment of the Wolf River may have affected dissolved oxygen concentrations in the water during this period.

Most metals measured in the Wolf River were either below detection limits or at very low levels. Cadmium was detected in approximately one-half the water samples collected at both stations. The highest concentration (0.005 mg/l) occurred in October 1978 at Station Y. Mercury was detected in only one sample from either station during the study. A concentration of 0.9 μg/l, the highest level recorded from any station during this study, was measured in October 1977 at Station Z.

Bottom sediments were collected at Stations Y and Z for chemical analyses in March 1978. The results of these analyses are presented in Appendix 2.4E, Table E-3. The values for metals and other parameters measured in the sediments were low.

2.4.7 Hydrological Relationships

Geography and climate have combined to provide a water surplus in northern Wisconsin. The excess of rainfall over evapotranspiration is reflected in the abundant ground water resources, and numerous lakes, wetlands, and perennial streams.

The streams of the environmental study area share very similar characteristics. They are small, often not well defined, have varying surface water runoff characteristics, act as ground water collectors with base water flow derived largely from ground water, and, as a result, have similar chemistry.

Comparison of direct surface water runoff peaks with precipitation indicates that a major portion of the water generated during these events infiltrates into the ground and becomes part of the ground water system (see also Golder Associates, 1982, and Freeze and Cherry, 1979). Some of this water may move laterally through the surface soils (subsurface flow) and become part of the base flow a short time after the direct runoff peak has occurred. The rest of the water percolates downward and supplies the local aquifers.

As discussed in section 2.3, Ground Water, there is a close relationship between the main ground water aquifer and the surface water. Similarities in surface water/ground water chemistry and correlation of surface water/ground water elevations serve to support this relationship. Therefore, it is evident that although the Swamp Creek and Pickerel Creek drainage basins are two geographically separate and independent basins, the drainage lakes and streams, and to an extent the seepage lakes, of each basin are related through the ground water system. This association becomes more evident when a water balance is analyzed.

Water Balances - A water balance for a drainage basin is an accounting of the water arriving and leaving the basin and the water stored on and under the surface of the basin. All water in the aquifers under the basin surface is included in the water budget. Surface water can arrive in the drainage basin either as precipitation or as ground water flow from the aquifers or can leave by evapotranspiration, stream flow, ground water flow, interflow (flow between basins via the soil above the main ground water table), or, in rare instances, by a man-made scheme. Water is stored above the ground surface as snow or in lakes and wetlands. Below the surface, water is stored in the form of soil moisture and ground water.

A mathematical expression, based on Chow et al. (1964), that includes all components of a water budget for a basin for any time period is:

$$P - E_T - Q - G - I = \Delta S_l + \Delta S_w + \Delta S_g + \Delta S_{so} + \Delta S_{sn}$$

in which:

P = precipitation

E_T = evapotranspiration

Q = stream flow

G = ground water flow

I = interflow from or into basin

ΔS_l = change in lake storage

ΔS_w = change in wetland storage

ΔS_g = change in ground water storage

ΔS_{so} = change in soil moisture

ΔS_{sn} = change in snow pack

This mathematical expression illustrates the components that should be considered when establishing a water budget but is only practical for controlled research conditions. The expression is greatly simplified for actual use since many of the components cannot be measured or reasonably estimated.

In general, the amount of interflow (I) leaving through the soil at the boundary of the basin is very small, especially when compared with other items in the balance. Therefore, it is assumed that I is zero. When the water balance is calculated for a period of time beginning and ending when there is no snow on the ground, then S_{sn} is zero.

It is possible in any one year that the changes in storage are not zero. For example, when a wet year follows a dry year, one can anticipate that all changes in storage for the wet year will be positive and may be important in the balance. However, the annual values of the change of storage in lakes, wetlands, ground water, and soil moisture when averaged over a long period of time are zero unless there is a pronounced climatic change or major man-made influence. Therefore, on an average annual basis, the above mathematical expression reduces to:

$$P - E_T - Q - G = 0$$

This simplified expression was the basis for estimating the water balances. For drainage basins having a major portion of their area outside the environmental study area, estimates of the water balances are marginal because of the lack of data. Conversely, drainage basins that lie completely within the environmental study area have water balances that are more rigidly estimated because the available data were more comprehensive.

When the above expression is used to estimate a water balance, it is assumed that the change of storage is equal to zero and the value for evapotranspiration (E_T) is estimated by establishing the values for precipitation (P), stream flow (Q), and ground water flow (G). Values for precipitation (P) and stream flow (Q), having relatively high precision and accuracy, can be obtained by continuous monitoring techniques. Periodic monitoring of precipitation (P) and stream flow (Q) provides data that are usable but not as accurate as data obtained during a continuous monitoring program.

Ground water flow (G) is usually subdivided into ground water outflow (G_o) and ground water inflow (G_i). A positive value is associated with ground water outflow (G_o) because precipitation over the basin is considered the source of water moving out of the drainage basin in question. Conversely, the value for ground water inflow (G_i) is negative. Since ground water inflow (G_i) originates outside the basin, it becomes an additional source of water for the basin. Therefore, the above expression can be written as follows:

$$P + G_i - E_T - Q - G_o = 0$$

Since the delineation of a drainage basin is a surface feature and independent of the ground water system, it is possible to have large variations in the net ground water flow. These variations may exist as variations in magnitude or as variations in direction.

Establishing a realistic value for ground water flow is difficult and, as a result, the estimate generated is not precise. The values for ground water flow used were calculated based on the length of drainage basin, thickness and permeability of the aquifer, ground water gradient beneath the drainage basin, and the porosity of the aquifer materials. Because of the difficulty in making reliable estimates of these parameters, the value for ground water flow is usually the weakest point in a water balance expression. Even with these apparent weaknesses, the water balance is useful in determining the relative differences between drainage basins.

Ground water inflow and outflow estimates were computed using Darcy's law for saturated flow,

$$g = ki\ A_N$$

where:

g = instantaneous rate of flow (cfs);

k = average aquifer permeability (ft/s);

i = slope of the piezometric gradeline (ft/ft); and

A_N = area of the aquifer normal to the direction of flow (ft^2).

The annual flow was computed by summing (integrating) the above equation over time.

Values of k were estimated from field tests, laboratory tests, and material grain size. The value of k was approximately 3 x 10^{-4} ft/s. Values of i were computed from the map shown on Figure 2.3-4. Finally, values of A were obtained by estimating the average depth of the aquifer from the drill logs and multiplying by the width of the subbasin boundary.

For the Wolf River drainage basin upstream from Langlade, the long-term average precipitation is 781.6 mm/year (30.77 inches/year) (Black, 1978), and the stream flow was 352 mm/year (13.87 inches/year) for the period 1966 to 1978 (Table 2.4-15) or 45 percent of the annual precipitation. Since ground water conditions are not known to the boundaries of this basin, no evaluation of the ground water flow was made. If it is assumed that the ground water flow out of the aquifers under this basin is very small (Olcott, 1968), then the long-term average annual evapotranspiration is approximately 432 mm (17 inches), which is 55 percent of the annual precipitation.

Based on the field data collected from October 1977 to September 1978, estimates of the annual water balances for the two subbasins upstream from SG 4 and SG 5B within the environmental study area (Figure 2.4-1) were calculated. The former subbasin contains Lake Metonga and the latter contains Lake Lucerne. However, little is known about the ground water flow except that the direction and gradient of flow can be ascertained from the regional potentiometric surface map.

Based on stream discharge and precipitation data, and soil permeabilities and ground water gradients, it was estimated that the annual evapotranspiration for the SG 4 drainage subbasin is 63 percent of the annual precipitation, the stream flow is 44 percent, and the ground water inflow is 7 percent. The ground water comes from the Lake Lucerne area. The balance is summarized in Table 2.4-21. For the SG 5B drainage subbasin, it was estimated that the annual evapotranspiration is also 63 percent of the annual precipitation, the stream flow is 13 percent, and the ground water flow from the subbasin is 24 percent. The ground water flows to the east, west, and south.

From the data collected in the field hydrology program, annual water balances were calculated for the subbasins upstream from SG 6, SG 8, and SG 23. These subbasins were chosen because the data base developed for them was more complete than that developed for other subbasins. In addition, a summertime water balance was determined for subbasin SG 23. The balances are summarized in Table 2.4-21. Available data were considered insufficient to perform a water balance above SG 19 on Pickerel Creek due to the inability to compute sufficiently accurate ground water flows under reasonable assumptions of aquifer permeability, the measured surface, and aquifer thickness.

As the site area potentiometric map (Figure 2.3-5) indicates, there is ground water flow from nearly all directions into the aquifers under the SG 6 subbasin. Annual ground water inflow was estimated to be 20 percent of the annual precipitation. This results in a large stream flow value of 60 percent of the annual precipitation with evapotranspiration accounting for the balance.

The ground water flow in the main ground water aquifer in the area of the SG 8 drainage subbasin is also very large (Figure 2.4-5), but it is an outflow. The main ground water aquifer in this area is a ground water mound with outflow in all directions (Figure 2.3-3). The annual ground water flow value was estimated to be 30 percent of the annual precipitation. The stream flow is correspondingly small, only 3 percent. The amount of evapo-

TABLE 2.4-21

WATER BALANCES

SUBBASIN	PRECIPITATION	PERCENT OF PRECIPITATION		
		EVAPOTRANSPIRATION	STREAM FLOW	GROUND WATER[a]
Annual				
SG 4	100	63	44	-7
SG 5B	100	63	13	+24
SG 6	100	60	60	-20
SG 8	100	67	3	+30
SG 23	100	67	17	+16
Summertime (171 days)				
SG 23[b]	100	62	18	+9

[a]The negative sign indicates the ground water is an inflow to the subbasin. Ground water outflow is designated with a plus sign.

[b]The water balance for subbasin SG 23 does not sum to zero because the water balance covers less than a full year, and changes in ground water, lake, and soil moisture levels occurred. Computed estimates of each were 17, 1, and -7 percent, respectively. When summed with other loss terms (i.e., 62, 18, and 9 above), they equal 100 percent. As previously stated, the annual values for the change in storage in lakes, methods, and ground water when averaged over a long time are zero. The compilation of a water balance from subbasin SG 23 for the summertime used the full equation previously cited from Chow et al. (1964).

transpiration was large, 67 percent, because lakes and wetlands constitute one-third of the subbasin area.

Stream flow data for SG 23 are limited to the 171 days between April 15 and October 2, 1978. For this summer period, the stream flow was approximately 18 percent, evapotranspiration 62 percent, and ground water outflow 9 percent of the estimated summertime precipitation for the subbasin.

The annual water balance for the SG 23 basin also was estimated. The annual values of stream flow and ground water flow are nearly equal at 17 and 16 percent, respectively, of the long-term annual precipitation. The evapotranspiration was 67 percent; again, a large value because lakes and wetlands constitute one-third of the total subbasin area.

The water balances indicate that evapotranspiration is the largest single component. Ground water flow is prominent, and in some cases, as in the subbasins upstream from SG 5B and SG 8, ground water flow from the aquifers under the basin was much greater than the stream flow.

A water balance was not computed for Swamp Creek above Highway 55 because the large size of the area would have required an extrapolation of the data base beyond the limits of its accuracy to define the hydrologic conditions in the subbasin.

Water Quality - Water chemistry of streams in the Swamp Creek and Pickerel Creek drainage basins was similar (Table 2.4-22) because of the influence of ground water discharge to both basins from the main ground water aquifer. Evidence is presented in section 2.3, Ground Water, which suggests that this same aquifer feeds Rice and Ground Hemlock lakes and the Hemlock-Swamp-Outlet Creek system in the Swamp Creek drainage basin, and

TABLE 2.4-22

SUMMARY OF WATER CHEMISTRY DATA TO IDENTIFY SIMILAR WATER BODIES IN THE ENVIRONMENTAL STUDY AREA

WATER BODY	SAMPLING STATION[a]	MEAN OF 1977-1978 VALUES (MEAN OF 1979-1980 VALUES) ALKALINITY mg/ as $CaCO_3$		HARDNESS mg/ as $CaCO_3$		pH		FIELD CONDUCTIVITY mhos/cm		TOTAL SOLIDS mg/		TRUE COLOR		HARDNESS CLASSIFICATION[b,c]	pH CLASSIFICATION[b,c]	COLOR CLASSIFICATION[b,c]
Little Sand Lake	H	<2	(5)	12	(10)	5.4	(6.0)	29	(19)	44	(22)	<5	(<15)	soft	slightly acidic	clear
Little Sand Lake	I	<2	—	10	—	5.4	—	27	—	40	—	<4	—	soft	slightly acidic	clear
Oak Lake	G-1	<4	(6)	11	(14)	6.2	(6.5)	23	(16)	56	(30)	<4	(<13)	soft	neutral	clear
Oak Lake	G-2	<4	—	11	—	5.9	—	24	—	38	—	<1	—	soft	slightly acidic	clear
Duck Lake	K	<3	(19)	15	(33)	5.0	(6.1)	30	(50)	53	(47)	59	(87)	soft	slightly acidic	medium brown
Skunk Lake	J	10	(8)	15	(13)	5.8	(5.7)	27	(20)	79	(26)	119	(64)	soft	slightly acidic	dark brown
Deep Hole Lake	L	<5	(5)	16	(15)	6.0	(6.2)	30	(21)	58	(24)	<23	(31)	soft	neutral	light brown
Mole Lake	O	26	—	31	—	7.2	—	52	—	69	—	20	—	soft	neutral	clear-light brown
Rice Lake	N	<81	(69)	102	(106)	7.3	(7.5)	145	(137)	192	(124)	<40	(41)	moderately hard	neutral	light brown
Rolling Stone Lake	M-2	83	—	91	—	7.7	—	117	—	130	—	39	—	moderately hard	neutral	light brown
Rolling Stone Lake	M-4	87	—	93	—	7.7	—	118	—	121	—	40	—	moderately hard	neutral	light brown
Hemlock Creek	A-1	101	(108)	107	(113)	7.4	(7.7)	136	(133)	161	(129)	<23	(26)	moderately hard	neutral	light brown
Hemlock Creek	A-2	105	—	115	—	7.2	—	140	—	143	—	22	—	moderately hard	neutral	light brown
Metonga Creek	C	88	—	93	—	7.6	—	132	—	168	—	<7	—	moderately hard	neutral	clear
Swamp Creek	B	103	—	110	—	7.4	—	140	—	182	—	<29	—	moderately hard	neutral	light brown
Swamp Creek	D	95	(96)	101	(97)	7.3	(7.4)	138	(124)	174	(106)	<28	(36)	moderately hard	neutral	light brown
Swamp Creek	E	94	(94)	99	(95)	7.3	(7.4)	132	(123)	171	(112)	<31	(36)	moderately hard	neutral	light brown
Swamp Creek	F[d]	98	—	108	—	7.1	—	138	—	194	—	<24	—	moderately hard	neutral	light brown
Swamp Creek	Q	88	—	110	—	7.4	—	115	—	144	—	75	—	moderately hard	neutral	medium brown
Swamp Creek	S	95	—	107	—	6.9	—	132	—	158	—	45	—	moderately hard	neutral	light brown
Swamp Creek	V	81	—	95	—	6.8	—	110	—	131	—	85	—	moderately hard	neutral	medium brown
Creek 12-9	M-1	100	(94)	108	(94)	7.4	(7.6)	132	(117)	174	(113)	<28	(27)	moderately hard	neutral	light brown
Creek 11-4	M-3	84	(96)	93	(102)	6.9	(7.3)	123	(142)	146	(105)	87	(47)	moderately hard	neutral	medium brown
Upper Pickerel Creek	M-5	73	(80)	83	(82)	6.9	(7.2)	92	(89)	126	(106)	106	(72)	moderately hard	neutral	dark brown
Wolf River	Y	52	—	60	—	6.9	—	84	—	115	—	91	—	soft	neutral	medium brown
Wolf River	Z	63	—	73	—	7.0	—	99	—	126	—	83	—	soft	neutral	medium brown
St. Johns Lake	JL	—	(4)	—	(11)	—	(6.1)	—	(14)	—	(21)	—	(14)	soft[e]	neutral[e]	clear[e]
Walsh Lake	WL	—	(5)	—	(13)	—	(6.2)	—	(22)	—	(24)	—	(18)	soft[e]	neutral[e]	clear[e]
Ground Hemlock Lake	GH-1	—	(110)	—	(112)	—	(8.2)	—	(155)	—	(133)	—	(<12)	moderately hard[e]	slightly basic[e]	clear[e]
Ground Hemlock Lake	GH-2	—	(129)	—	(128)	—	(7.7)	—	(180)	—	(171)	—	(<15)	moderately hard[e]	neutral[e]	clear[e]

[a]Sampling stations are illustrated on Figure 2.4-2.

[b]Based on 1977-1978 data.

[c]See Table 2.4-12.

[d]Sampling station located in Swamp Creek channel within Rice Lake.

[e]Based on [illegible]-1980 data.

Rolling Stone Lake, Pickerel Creek, and Creeks 12-9 and 11-4 in the Pickerel Creek drainage basin. This evidence includes the water chemistry summary data (Table 2.4-22), which indicate that all the above-mentioned water bodies have relatively high alkalinity and hardness and neutral pH. This water quality is characteristic of ground water from the main ground water aquifer (section 2.3, Ground Water).

Although the drainage lakes and streams are interrelated through ground water, the surface watersheds do not always reflect the pattern of ground water flow. Therefore, the ground water may flow from an area in one direction and discharge, for example, into the Pickerel Creek drainage basin, whereas the surface water flow from the same area may be part of the Swamp Creek drainage basin.

Rice and Rolling Stone lakes, although in separate drainage basins, share many similar characteristics. These lakes generally have lower transparency than seepage lakes and a greater abundance of aquatic macrophytes. In addition, particulate matter and stained water, rich in dissolved organic matter, are transported into these lakes.

The Hemlock-Swamp-Outlet Creek system discharges approximately 0.54 m^3/s (19 cubic feet/second) of base flow (average) to Rice Lake. Approximately 21 percent of this flow rate is contributed from Hemlock Creek, 37 percent from Outlet Creek, and an estimated 3 percent from Hoffman Creek. The balance comes from Lake Lucerne and Swamp Creek.

These streams are diluted by water from local aquifers or by water from the main ground water aquifer system wherein alkalinity has been attenuated (see section 2.3, Ground Water). The mean alkalinity values for these streams indicated that alkalinity decreased from 101 and 105 mg/l in

Hemlock Creek (Stations A-1 and A-2, respectively) to 81 mg/l on lower Swamp Creek (Station V) (Table 2.4-22).

Differences in water quality in Swamp Creek upstream and downstream of Rice Lake were slight. Upper Swamp Creek transports a greater load of total and dissolved solids than does its lower portion, and Rice Lake apparently acts as a trap for these materials. The presence of higher levels of dissolved organic material in lower Swamp Creek, as indicated by true color values, is also apparently from the influence of Rice Lake.

Ground water flows southwest in the main ground water aquifer from the site area (Figure 2.3-5) toward Rolling Stone Lake. Pickerel Creek, Creek 12-9, and Creek 11-4 receive discharge from this aquifer in the marshy areas that lie to the south of Mole, Oak, and Little Sand lakes. These creeks flow south into Rolling Stone Lake and contribute the major portion of the total flow measured at SG 22 in Pickerel Creek, downstream of the lake. The water quality parameters measured for Rolling Stone Lake typically are within the range of water quality values reported from Pickerel Creek (above Rolling Stone Lake), Creek 12-9, and Creek 11-4.

Of the eight seepage lakes described in this study, Little Sand, St. Johns, Walsh, and Oak are chemically similar. The substrate of each consists primarily of lacustrine sediments with littoral sand. These lakes contain the clearest water of the lakes in the study area (Table 2.4-22). Among these four lakes, only Oak Lake was deep enough to stratify during the summer, as noted by the temperature and dissolved oxygen curves (Figure 2.4-7). Depth profile data (Appendix 2.4H) indicate that the other three lakes generally were well mixed.

The bottom of Deep Hole Lake consists of lacustrine sediments (STS Consultants Ltd., 1984), whereas sand is the primary substrate in Mole Lake (Steuck and Andrews, 1976). As indicated by their light brown color and total dissolved solids content, both lakes have higher levels of dissolved organic and inorganic matter than either of the four previously discussed seepage lakes (Table 2.4-22). This color is probably imparted by wetlands adjoining the lakes. Although nutrient levels in both Deep Hole and Mole lakes were similar, mean values for alkalinity, hardness, and pH were all higher in Mole Lake (Table 2.4-22).

The remaining two seepage lakes, Duck and Skunk, also are influenced by adjoining wetlands. The mean pH in Duck Lake (5.0) was the lowest detected in the environmental study area (Table 2.4-22), and in addition to sphagnum moss that surrounds most of the lake, low pH is typical of bog systems (Boelter and Verry, 1977). The mean pH was higher at Skunk Lake (5.8), which is part of a marsh wetland. Both lakes were highly colored, indicating the presence of large amounts of organic matter that is probably imparted by the wetlands. High levels of organic matter also are indicated by the levels of ammonia nitrogen that are produced by the bacterial decomposition of organic matter (Hutchinson, 1957) in Duck Lake (1.28 mg/l; Appendix 2.4G, Table G-2) and Skunk Lake (1.57 mg/l; Appendix 2.4G, Table G-8).

Little Sand, St. Johns, and Mole lakes are most subject to potential change from human influence because of their low buffering capacity and the presence of the many dwellings that are established adjacent to the shorelines. The homes and cottages present potential sources for periodic nutrient loading from septic systems. Although nutrient loading was not apparent at any of these lakes, a relatively high level of fecal coliform bacteria (184 organisms/100 ml; Appendix 2.4F, Table F-3) was recorded in Little Sand Lake.

Bottom Sediment Chemistry - The summary of bottom sediment chemistry data suggests some notable differences between the Swamp Creek and Pickerel Creek drainage basins (Table 2.4-23). Higher concentrations of chromium, copper, iron, manganese, and sulfates occurred in the Swamp Creek basin sediments whereas higher concentrations of lead were present in the Pickerel Creek basin sediments. However, the high concentrations of the aforementioned parameters in these two basins reflect high values reported principally from a single sampling station in the Swamp Creek basin (Station D) and a single sampling station in the Pickerel Creek basin (Station I) and, except for these anomalous values, the sediments of the two basins were chemically similar.

The sediment chemistry of the Wolf River, as determined from samples collected at two locations, one upstream and one downstream from the reach where Swamp and Pickerel creeks join the Wolf River, is different from that in the two subbasins (Table 2.4-23). The Wolf River sediments generally exhibit much lower concentrations of the chemical parameters measured than either the Swamp Creek or the Pickerel Creek basin sediments.

Suspended Sediment and Bottom Sediment Physical Characteristics - The sediment yields in the environmental study area are typical of the Northern Highlands region of Wisconsin and appear to be a result of several factors: predominantly forested land cover, granular soils, mild slopes, low stream velocities, and an abundance of lakes and wetlands that serve as sediment traps. In the environmental study area there is little fine clastic stream bottom material -- material that is easily suspended and transported by the stream (Appendix 2.4D, Figure D-1). Maximum velocities occurring during discharge measurements at stream cross sections were typically less than 1 m/s

TABLE 2.4-23

BOTTOM SEDIMENT CHEMISTRY SUMMARY*

PARAMETER	SWAMP CREEK DRAINAGE BASIN (mean of 6 samples)	PICKEREL CREEK DRAINAGE BASIN (mean of 9 samples)	WOLF RIVER (mean of 2 samples)
Percent Solids	8.66	7.56	56.72
Arsenic	2.8	<2.3	0.4
Cadmium	1.9	1.6	0.1
Chromium	63.1	26.0	23.8
Copper	18.0	10.2	2.8
Iron	7,628	5,329	2,586
Lead	<18	31	2
Manganese	948	512	123
Mercury	<0.01	<0.01	<0.01
Zinc	90	107	11
Freon Extractables	2,581	2,867	152
Phenol	10.13	10.27	0.32
Sulfate	2,735	<912	<154
Sulfide	<2.2	<1.2	<0.3
Total Sulfur	3,592	3,187	178

*Concentrations (mg/ℓ) presented as dry weight.

(3 feet/second). Thus, the only abundant materials easily transported are the organic solids that have a low density.

Flood Potential - The streams in both the Swamp Creek and Pickerel Creek drainage basins can experience potential flooding as a result of thunderstorms and rain in combination with snowmelt. On these relatively small basins, peak stream water flows are most commonly caused by thunderstorms. However, the flood potential from either cause is low in comparison to basins of similar size in other regions because of the relatively high permeability of the surficial soils, which allows water to infiltrate into the ground water system (section 2.3, Ground Water). In addition, the extensive areas of lakes and wetlands associated with the drainage basins facilitate the storage of relatively large volumes of water, thereby keeping flood peaks low. No floods as such occurred during the study period. The generally high water levels in the spring of 1979, which were generated by snowmelt and rainfall, came closest to approximating flood conditions (USGS, 1980).

All the streams studied in both the Swamp Creek and Pickerel Creek drainage basins are subject to localized flooding caused by beaver dams. During the summer of 1979, the level of Ground Hemlock Lake was raised in this manner and flooded several docks. Other flooding caused by beaver activity was observed on Hemlock Creek near water chemistry sampling Station A-1, on Swamp Creek near water chemistry sampling Station E, on Hoffman Pond, on Hoffman Creek, on Creek 11-4 downstream from water chemistry sampling Station M-3, and on Creek 12-9 near SG 23. Flooding of this nature is unpredictable and somewhat independent of precipitation events.

Hemlock, Swamp, Outlet, and Hoffman creeks have all been mapped or partially mapped by the Federal Emergency Management Agency (FEMA) for flood hazards. Neither Pickerel Creek, Creek 12-9, nor Creek 11-4 has been mapped by the FEMA. No other published information is known to exist on flooding for these streams. However, there are no residences or other structures with a potential for flood damage along any of these creeks in either basin.

Flooding on the lakes in the environmental study area consists of a temporary rise in lake level from increased inflow. However, there is little potential for hazard to human life or structures on these lakes from flooding because the drainage areas are small and the lake level fluctuations are minor.

2.4.8 Summary and Conclusions

1. The regional study area lies within the area of northeast Wisconsin that is drained by the Wisconsin, Wolf, Fox, Peshtigo, Oconto, and Menominee rivers. The environmental study area is drained by Swamp and Pickerel creeks, which lie within the Wolf River drainage basin.

2. On the Wolf River, the highest average monthly stream discharge occurs in April when snowmelt runoff is highest and the lowest in January and February when precipitation is retained on the ground surface as snow and ice.

3. The environmental study area is characterized by forested lands, wetland areas, small perennial streams, and contains three basic lake types: drainage, seepage, and spring.

4. The streams in the environmental study area transport only small quantities of sediment, which appears to be a result of several factors: the land is forested, soils in the area are granular, slopes are moderate, stream velocities are low, and the many lakes and wetlands in the area serve as sediment traps.

5. There is a close relationship between ground water from the main ground water aquifer and surface water of the streams and drainage lakes as indicated by the similarities in surface

water/ground water chemistry and correlation of surface water/ ground water elevations. Therefore, the water chemistry of the drainage and spring lakes and streams in the Swamp Creek and Pickerel Creek drainage basins was similar.

6. Seepage lakes are, for the most part, isolated above the ground water from the main ground water table and, therefore, typically have lower hardness, alkalinity, conductivity, total solids, and pH values than the lakes and streams of the drainage systems.

7. No unusual chemical conditions were noted in either surface water or stream sediment samples. Although there is some variability in the concentrations of various metals in both the surface water and in the stream sediment samples among stations, there do not appear to be any concentrations that are greatly outside the ranges listed (Appendices 2.4E and 2.4F) for typical nonindustrial water and sediment samples.

8. Flood potential in the environmental study area is low in comparison to basins of similar size in other regions because of the relatively high permeability of the surficial soils, which allow water to infiltrate the ground water system. In addition, the extensive areas of lakes and wetlands associated with the drainage basins facilitate the storage of relatively large volumes of water, thereby keeping flood peaks low.

2.4.9 References

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2.5 AQUATIC ECOLOGY

The purpose of this investigation was to determine the composition, abundance, and distribution of aquatic biota in lakes and streams within the environmental study area. As described in the section 2.4, Surface Water, the environmental study area is entirely within the Wolf River drainage basin and is characterized by forested lands, lakes, wetland areas, and perennial streams that provide drainage routes. The ore body lies on a watershed (a line defining locations where water flows perpendicularly away from the line) that divides the Swamp Creek basin and the Pickerel Creek basin, both of which are part of the larger Wolf River drainage basin.

Lakes in the environmental study area that were investigated in the aquatic ecology program can be characterized as drainage or seepage as presented in Steuck and Andrews (1976) as follows:

> Drainage lakes have their main water source from stream drainage. These lakes have at least one inlet and an outlet.
>
> Seepage lakes have no inlets or outlets and are landlocked. An intermittent outlet may be present. Water level is maintained by the ground water table and basin seal.

Based on discussions presented in section 2.3, Ground Water, the seepage lakes studied are situated above the main ground water table, that is, the lake surface elevation is above the elevation of the main ground water table with water levels apparently maintained by a basin seal. Ground water is recharged by seepage from these lakes through the basin seal. Drainage lakes studied receive main ground water aquifer discharge (Figure 2.3-17).

As presented in the section 2.4, Surface Water, seepage lakes are characteristically low in pH (range of means: 5.0 to 6.2) and have soft water (range of means: hardness 10 to 16 mg/1 as $CaCO_3$) that is low in alkalinity (range of means: <2 to 10 mg/l as $CaCO_3$). Drainage lakes have water slightly basic in pH (7.3 to 7.7) and moderately hard water (range of means: 91 to 102 mg/l as $CaCO_3$) with mean alkalinity ranging from 80 to 87 mg/l as $CaCO_3$.

Streams in the environmental study area have similar characteristics. They are generally small, often not well defined, and have a base flow derived largely from the main ground water aquifer. Typically, pH of the water is neutral and hardness and alkalinity values are similar to those in drainage lakes.

Specific information on sampling times, methodologies, and rationale for the aquatic ecology sampling program in the environmental study area is presented in subsection 2.5.1. Results of analyses are presented and discussed in subsections 2.5.2 through 2.5.6. Information on specific taxa is included in Appendices 2.5A through 2.5F. Information on larval fish, and chemical analysis of aquatic macrophyte, benthic macroinvertebrate, and fish tissues is included in Appendix 2.5F.

2.5.1 Field and Laboratory Methods

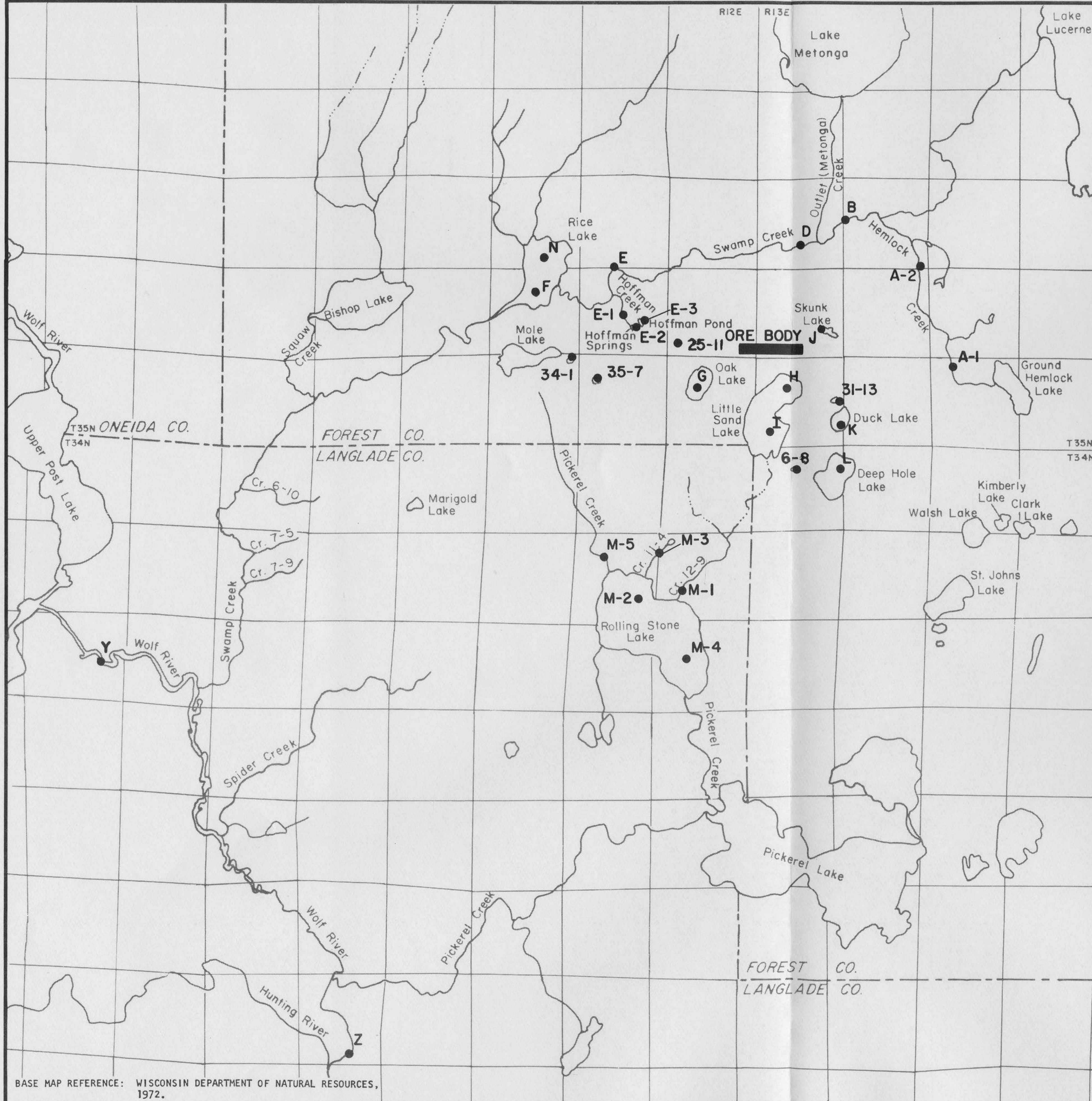
Aquatic ecology studies on water bodies within the environmental study area were undertaken from February 1977 through October 1978. Locations of the stations selected for sampling in the environmental study area are presented in Table 2.5-1 and on Figure 2.5-1, and the sampling schedule is presented in Tables 2.5-2 through 2.5-4. The basic rationale for the investigation was to provide biological data on a seasonal basis. For these studies, seasonal sampling was conducted in March (winter), May (spring), August (summer), and October (autumn). Sampling was conducted early in each

TABLE 2.5-1

SAMPLING STATIONS FOR
AQUATIC ECOLOGY STUDIES IN THE
ENVIRONMENTAL STUDY AREA 1977-1978

WATER BODY	STATIONS
Swamp Creek Drainage Basin	
Rice Lake	F, N
Hemlock Creek	A-1, A-2
Hoffman Creek	E-1
Swamp Creek	B, D, E
Oak Lake	G
Pond 25-11*	25-11
Hoffman Springs	E-2
Hoffman Pond	E-3
Pickerel Creek Drainage Basin	
Rolling Stone Lake	M-2, M-4
Pickerel Creek	M-5
Creek 12-9*	M-1
Creek 11-4*	M-3
Little Sand Lake	H, I
Duck Lake	K
Deep Hole Lake	L
Skunk Lake	J
Pond 31-13*	31-13
Pond 6-8*	6-8
Pond 35-7*	35-7
Pond 34-1*	34-1
Wolf River	Y, Z

*Wisconsin DNR Identification Code for unnamed streams and lakes.



N

KEY:

STREAM

25-11 WISCONSIN DNR IDENTIFICATION CODE FOR UNNAMED LAKES

Cr. 11-4 WISCONSIN DNR IDENTIFICATION CODE FOR UNNAMED STREAMS

AQUATIC ECOLOGY SAMPLING STATION

Note: Additional sampling was conducted in Swamp Creek downstream from Rice Lake. The results of this sampling program are presented in Ecological Analysts, Inc. (1983, 1984a,b).

1 .5 0 1 MILE

1 .5 0 1 KILOMETER

EXXON MINERALS COMPANY
CRANDON PROJECT

AQUATIC ECOLOGY SAMPLING STATIONS

DAMES & MOORE

FIGURE 2.5-1

TABLE [illegible]2

SCHEDULE OF SEASONAL BIOLOGICAL SAMPLING IN THE SWAMP CREEK DRAINAGE BASIN DURING 1977 AND 1978

		1977								1978				
WATER BODY	SAMPLE/STATION(S)	MAR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	MAR	APR	MAY	AUG	OCT
Rice Lake	Phytoplankton/Zooplankton													
	F	X	X	X	X	X	X	X	-	-	-	-	-	-
	N	X	X	X	X	X	X	X	-	X	-	X	X	-
	Chlorophyll <u>a</u>													
	F	-	X	X	X	X	X	X	-	X	-	-	-	-
	N	-	X	X	X	X	X	X	-	X	-	X	X	-
	Periphyton													
	F	-	X	X	X	X[a]	X	X	-	-	-	-	-	-
	N	-	X	-	X	X[a]	X	X	-	-	-	X	X	-
	Aquatic Macrophytes -													
	Lake Survey	-	-	-	-	X	-	-	-	-	-	-	-	-
	Benthos													
	F	X	X	-	-	X[a]	-	X	-	X[b]	-	-	-	-
	N	X	X	-	-	X[a]	-	X	-	X[b]	-	X	X	-
	Fish - Lake Survey													
	Electroshocking	-	X	-	-	X[a]	-	X	-	-	-	X	X[a]	-
	Gill Net	-	-	-	-	-	-	-	-	-	-	X	-	-
	Fyke Net	-	X	-	-	X[a]	-	X	-	-	-	X	X	-
	Minnow Trap	-	-	-	-	-	-	-	-	-	-	X	X	-
	Tissue Chemistry -													
	Lake Survey													
	Aquatic Macrophytes	-	-	-	-	X[a]	-	-	-	-	-	-	-	-
	Benthos	-	-	-	-	X[a]	-	-	-	-	-	-	-	-
	Fish	-	-	-	-	X[a]	-	-	-	-	-	-	X[a]	-
Hemlock Creek	Periphyton													
	A-1	-	-	-	-	-	-	X	-	-	-	X	X	
	Benthos													
	A-1	-	-	X	-	X[a]	-	X	-	X	-	X	X	-

Notes: (1) Additional sampling was conducted on Swamp Creek downstream from Rice Lake. For this information, see report by Ecological Analysts, Inc. (1983, 1984a,b).

(2) - indicates no sample collected.

[a]Sample collected in late July.

[b]Sample collected in late February.

TABLE 2.5-2 (continued)

		1977								1978				
WATER BODY	SAMPLE/STATION(S)	MAR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	MAR	APR	MAY	AUG	OCT
Hemlock Creek	Fish													
	Trout Redd Reconnaissance - Creek Survey	-	-	-	-	-	-	X	X	-	-	-	-	-
	Electroshocking													
	A-1	-	X	-	-	X[a]	-	X	-	-	-	X	X	-
	A-2	-	X	-	-	X[a]	-	X	-	-	-	-	-	-
	Tissue Chemistry													
	Fish													
	A-1	-	-	-	-	-	-	-	-	-	-	-	X	-
	A-2	-	-	-	-	X[a]	-	-	-	-	-	-	-	-
Hoffman Creek	Fish													
	Trout Redd Reconnaissance - Creek Survey	-	-	-	-	-	-	-	X	-	-	-	-	-
	Electroshocking													
	E-1	-	-	X	-	X[a]	-	X	-	-	-	-	-	-
Swamp Creek	Periphyton													
	D	X	X	X	X	X[a]	X	X	-	-	-	X	X[a]	-
	E	X	X	X	-	X[a]	X	X	-	-	-	X	X[a]	-
	Benthos													
	D	X	X	-	-	X[a]	-	X	-	X	-	X	X[a]	-
	E	X	X	-	-	X[a]	-	X	-	X[b]	-	X	X[a]	-
	Fish													
	Trout Redd Reconnaissance - Creek Survey	-	-	-	-	-	-	X	X	-	-	-	-	-
	Electroshocking													
	B	-	X	-	-	X[a]	-	X	-	-	-	-	-	-
	D	-	X	-	-	X[a]	-	X	-	-	-	X	X[a]	-
	Tissue Chemistry													
	Aquatic Macrophytes													
	E	-	-	-	-	X[a]	-	-	-	-	-	-	-	-
	Benthos													
	D	-	-	-	-	X[a]	-	-	-	-	-	-	-	-
	E	-	-	-	-	X[a]	-	-	-	-	-	-	-	-
	Fish													
	B	-	-	-	-	X[a]	-	-	-	-	-	-	-	-
	D	-	-	-	-	X[a]	-	-	-	-	-	-	X[a]	-

TABLE 2.5-2 (continued)

WATER BODY	SAMPLE/STATION(S)	1977 MAR	1977 MAY	1977 JUN	1977 JUL	1977 AUG	1977 SEP	1977 OCT	1977 NOV	1978 MAR	1978 APR	1978 MAY	1978 AUG	1978 OCT
Outlet Creek and Tributaries of Hemlock Creek	Fish													
	Trout Redd Reconnaissance - Creek Survey	-	-	-	-	-	-	-	X	-	-	-	-	-
Oak Lake	Phytoplankton/Zooplankton													
	G	X	X	X	X	X	X	X	-	X	-	X	X	-
	Chlorophyll a													
	G	-	X	X	X	X	X	X	-	X	-	X	X	-
	Periphyton													
	G (near shore)	-	X	X	X	X[a]	X	X	-	-	-	X	-	-
	Aquatic Macrophytes -													
	Lake Survey	-	-	-	-	X	-	-	-	-	-	-	-	-
	Benthos													
	G	X[b]	X	-	-	X[a]	-	X	-	X	-	X	X[a]	-
	Fish - Lake Survey													
	Metered Larval Net	-	X	X	X	-	-	-	-	-	-	-	-	-
	Electroshocking	-	-	-	-	X	-	-	-	-	-	X	X[a]	-
	Gill Net	-	X	-	-	X[a]	-	X	-	-	-	X	X[a]	-
	Seining	-	X	-	-	X[a]	-	-	-	-	-	X	X	-
	Tissue Chemistry-													
	Lake Survey													
	Aquatic Macrophytes	-	-	-	-	X[a]	-	-	-	-	-	-	-	-
	Benthos	-	-	-	-	X[a]	-	-	-	-	-	-	-	-
	Fish	-	-	-	-	X[a]	-	-	-	-	-	-	X[a]	-
Pond 25-11	Aquatic Macrophytes -													
	Pond Survey	-	-	-	-	X	-	-	-	-	-	-	-	-
	Fish													
	Minnow Trap													
	25-11	-	-	-	-	-	-	X	-	-	-	-	-	-
Hoffman Springs	Aquatic Macrophytes -													
	Spring Survey	-	-	-	-	X	-	-	-	-	-	-	-	-
	Fish													
	Minnow Trap													
	E-2	-	-	-	-	-	-	-	-	-	-	-	-	X
Hoffman Pond	Fish													
	Minnow Trap													
	E-3	-	-	-	-	-	-	-	-	-	-	-	-	X

TABLE 2.5-3

SCHEDULE OF SEASONAL BIOLOGICAL SAMPLING IN THE PICKEREL CREEK DRAINAGE BASIN DURING 1977 AND 1978

WATER BODY	SAMPLE/STATION(S)	1977 MAR	1977 MAY	1977 JUN	1977 JUL	1977 AUG	1977 SEP	1977 OCT	1978 MAR	1978 MAY	1978 JUN	1978 JUL	1978 AUG	1978 SEP	1978 OCT
Pickerel Creek	Periphyton														
	M-5	-	-	-	-	-	-	X	-	X	-	-	X[a]	-	-
	Benthos														
	M-5	-	-	-	-	-	-	X	X[b]	X	-	-	X[a]	-	-
	Fish														
	Trout Redd Reconnaissance - Creek Survey	-	-	-	-	-	-	-	-	-	-	-	-	-	X
	Electroshocking														
	M-5	-	-	-	-	-	-	X	-	X	-	-	X[a]	-	-
	Tissue Chemistry														
	Fish														
	M-5	-	-	-	-	-	-	-	-	-	-	-	X[a]	-	-
Creek 12-9	Periphyton														
	M-1	-	-	-	-	-	-	X	-	X	-	-	X[a]	-	-
	Benthos														
	M-1	-	-	-	-	-	-	X	X[b]	X	-	-	X[a]	-	-
	Fish														
	Trout Redd Reconnaissance - Creek Survey	-	-	-	-	-	-	-	-	-	-	-	-	-	X
	Electroshocking														
	M-1	-	-	-	-	-	-	X	-	X	-	-	X	-	-
	Minnow Trap														
	M-1	-	-	-	-	-	-	-	-	X	-	-	-	-	-
	Tissue Chemistry														
	Fish														
	M-1	-	-	-	-	-	-	-	-	-	-	-	X	-	-
Creek 11-4	Periphyton														
	M-3	-	-	-	-	-	-	X	-	X	-	-	X[a]	-	-
	Benthos														
	M-3	-	-	-	-	-	-	X	X[b]	X	-	-	X[a]	-	-
	Fish														
	Electroshocking														
	M-3	-	-	-	-	-	-	X	-	X	-	-	X[a]	-	-
	Minnow Trap														
	M-3	-	-	-	-	-	-	-	-	X	-	-	-	-	-
	Tissue Chemistry														
	Fish														
	M-3	-	-	-	-	-	-	-	-	-	-	-	X[a]	-	-

Note: - Indicates no sample collected.

[a]Sample collected in late July.

[b]Sample collected in late February.

TABLE 2.5-3 (continued)

WATER BODY	SAMPLE/STATION(S)	1977 MAR	1977 MAY	1977 JUN	1977 JUL	1977 AUG	1977 SEP	1977 OCT	1978 MAR	1978 MAY	1978 JUN	1978 JUL	1978 AUG	1978 SEP	1978 OCT
Rolling Stone Lake	Phytoplankton/Zooplankton														
	M-2	-	-	-	-	-	-	X	X	X	-	-	X	-	-
	M-4	-	-	-	-	-	-	X	X	X	-	-	X	-	-
	Chlorophyll a														
	M-2	-	-	-	-	-	-	X	X	X	-	-	X	-	-
	M-4	-	-	-	-	-	-	X	X	X	-	-	X	-	-
	Periphyton														
	M-2	-	-	-	-	-	-	X	-	X	-	-	X[a]	-	-
	M-4	-	-	-	-	-	-	X	-	X	-	-	X[a]	-	-
	Aquatic Macrophytes - Lake Survey	-	-	-	-	-	-	-	-	-	-	-	X[a]	-	-
	Benthos														
	M-2	-	-	-	-	-	-	X	X	X	-	-	X[a]	-	-
	M-4	-	-	-	-	-	-	X	X	X	-	-	X[a]	-	-
	Fish - Lake Survey														
	Electroshocking	-	-	-	-	-	-	-	-	X	-	-	X[a]	-	-
	Gill Net	-	-	-	-	-	-	X	-	X	-	-	-	-	-
	Fyke Net	-	-	-	-	-	-	-	-	X	-	-	X[a]	-	-
	Minnow Trap	-	-	-	-	-	-	-	-	X	-	-	-	-	-
	Tissue Chemistry - Lake Survey														
	Fish	-	-	-	-	-	-	-	-	X	-	-	X	-	-
Deep Hole Lake	Phytoplankton/Zooplankton														
	L	-	-	-	-	-	-	X	X	X	X	X	X	X	X
	Chlorophyll a														
	L	-	-	-	-	-	-	X	X	X	X	X	X	X	X
	Periphyton														
	L (near shore)	-	-	-	-	-	-	X	-	X	X	X	X[a]	X	X
	Aquatic Macrophytes - Lake Survey	-	-	-	-	X	-	-	-	-	-	-	-	-	-
	Benthos														
	L	-	X	-	-	X[a]	-	X	X	X	-	-	X[a]	-	-
	Fish - Lake Survey														
	Electroshocking	-	-	-	-	-	-	-	-	X	-	-	X[a]		
	Gill Net	-	X	-	-	X[a]	-	X	-	X	-	-	X[a]	-	-
	Minnow Trap	-	-	-	-	-	-	-	-	X	-	-	-	-	-
	Tissue Chemistry - Lake Survey														
	Fish	-	-	-	-	X[a]	-	-	-	-	-	-	X[a]	-	-

TABLE 2.5-3 (continued)

WATER BODY	SAMPLE/STATION(S)	1977 MAR	1977 MAY	1977 JUN	1977 JUL	1977 AUG	1977 SEP	1977 OCT	1978 MAR	1978 MAY	1978 JUN	1978 JUL	1978 AUG	1978 SEP	1978 OCT
Duck Lake	Phytoplankton/Zooplankton														
	K	-	-	-	-	-	-	X	X	X	X	X	X	X	X
	Chlorophyll a														
	K	-	-	-	-	-	-	X	X	X	X	X	X	X	X
	Periphyton														
	K (near shore)	-	-	-	-	-	-	X	-	X	X	X	X	X	X
	Aquatic Macrophytes -														
	Lake Survey	-	-	-	-	X	-	-	-	-	-	-	-	-	-
	Benthos														
	K	-	X	-	-	X[a]	-	X	X[b]	X	-	-	X	-	-
	Fish - Lake Survey														
	Electroshocking	-	-	-	-	-	-	-	-	-	-	-	X[a]	-	-
	Gill Net	-	X	-	-	X[a]	-	X	-	X	-	-	X	-	-
	Minnow Trap	-	-	-	-	-	-	-	-	X	-	-	-	-	-
	Tissue Chemistry -														
	Lake Survey														
	Fish	-	-	-	-	-	-	-	-	X	-	-	X[a]	-	-
Little Sand Lake	Phytoplankton/Zooplankton														
	H	X	X	X	X	X	X	X	X	X	-	-	X	-	-
	I	X	X	X	X	X	X	X	X	X	-	-	X	-	-
	Chlorophyll a														
	H	-	X	X	X	X	X	X	X	X	-	-	X	-	-
	I	-	X	X	X	X	X	X	X	X	-	-	X	-	-
	Periphyton														
	H (near shore)	-	X	X	X	X[a]	X	X	-	X	-	-	X	-	-
	I (near shore)	-	X	X	X	X[a]	X	X	-	X	-	-	X	-	-
	Benthos														
	H	X[b]	X	-	-	X[a]	-	X	X[b]	X	-	-	X	-	-
	I	X[b]	X	-	-	X[a]	-	X	X[b]	X	-	-	X	-	-
	Aquatic Macrophytes -														
	Lake Survey	-	-	-	-	X	-	-	-	-	-	-	-	-	-
	Fish - Lake Survey														
	Metered Larval Net	-	X	X	X	-	-	-	-	-	-	-	-	-	-
	Electroshocking	-	-	-	-	X[a]	-	-	-	X	-	-	X	-	-

TABLE 2.5-3 (continued)

WATER BODY	SAMPLE/STATION(S)	1977 MAR	1977 MAY	1977 JUN	1977 JUL	1977 AUG	1977 SEP	1977 OCT	1978 MAR	1978 MAY	1978 JUN	1978 JUL	1978 AUG	1978 SEP	1978 OCT
Skunk Lake	Phytoplankton/Zooplankton J	-	-	X	X	X	X	X	-	-	-	-	-	-	-
	Chlorophyll a J	-	-	X	X	X	X	X	X	-	-	-	-	-	-
	Periphyton J	-	-	X	X	X[a]	X	X	-	-	-	-	-	-	-
	Aquatic Macrophytes - Lake Survey	-	-	-	-	X	-	-	-	-	-	-	-	-	-
	Benthos J	-	X	-	-	X[a]	-	-	-	-	-	-	-	-	-
	Fish - Lake Survey														
	Electroshocking	-	-	-	-	-	-	-	-	X	-	-	-	-	-
	Minnow Trap	-	-	-	-	-	-	-	-	X	-	-	-	-	-
Pond 6-8	Aquatic Macrophytes - Pond Survey	-	-	-	-	X	-	-	-	-	-	-	-	-	-
	Fish Minnow Trap 6-8	-	-	-	-	-	-	X	-	-	-	-	-	-	-
Pond 31-13	Aquatic Macrophytes - Pond Survey	-	-	-	-	X	-	-	-	-	-	-	-	-	-
	Fish Minnow Trap 31-13	-	-	-	-	-	-	X	-	-	-	-	-	-	-
Pond 34-1	Aquatic Macrophytes - Pond Survey	-	-	-	-	X	-	-	-	-	-	-	-	-	-
	Fish Minnow Trap 34-1	-	-	-	-	-	-	X	-	-	-	-	-	-	-
Pond 35-7	Aquatic Macrophytes - Pond Survey	-	-	-	-	X	-	-	-	-	-	-	-	-	-
	Fish Minnow Trap 35-7	-	-	-	-	-	-	X	-	-	-	-	-	-	-

TABLE 2.5-4

SCHEDULE OF SEASONAL BIOLOGICAL SAMPLING IN THE WOLF RIVER DURING 1977 AND 1978

WATER BODY	SAMPLE/STATION(S)	1977 OCT	1978 MAR	1978 MAY	1978 AUG	1978 OCT
Wolf River	Periphyton					
	Y	X	-	X	X[a]	X
	Z	X	-	X	X[a]	X
	Benthos					
	Y	-	X[b]	X	X[a]	X
	Z	-	X[b]	X	X[a]	X
	Fish					
	Electroshocking					
	Y	-	-	X	X[a]	X
	Z	-	-	X	X[a]	X

Note: - Indicates no sample collected.

[a]Sample collected in late July.

[b]Sample collected in late Feburary.

of the months except for late February and late July, when sampling extended to the following month, but for the sake of simplicity are considered March or August samples. At the request of the DNR, plankton was collected monthly from May through October 1977 (Huntoon, 1977; Bulger, 1978).

These studies included an investigation of the Swamp Creek and Pickerel Creek drainage basins and the Wolf River immediately upstream and downstream from the confluence of these two tributaries. The existing water bodies and drainage systems within the area of the ore body were initially reviewed using available topographic maps. On the basis of this topographic review and a general knowledge of the location of the proposed mine, locations of the aquatic sampling stations were preliminarily selected. Actual sampling stations were established after field reconnaissance to delineate reasonably accessible locations containing habitat that appeared representative of the overall stream or lake system.

Stream sampling stations were selected on the basis of the following rationale. For the Swamp Creek basin, three stations (B, D, and E) were established on Swamp Creek. The locations of Stations B, D, and E were selected to include pool and riffle sampling areas in the general vicinity of the ore body and potential mining activities. Station B was located approximately 2.4 km (1.5 miles) northeast of the ore body, and 0.8 km (0.5 mile) downstream from the confluence with Hemlock Creek. Station D was located 1.0 km (0.6 mile) downstream from Station B and 0.3 km (0.2 mile) downstream from the confluence with Outlet Creek. Station E was located 3.4 km (2.1 miles) downstream from Station D, approximately 0.5 km (0.3 mile) upstream from the confluence with Hoffman Creek, and 1.4 km (0.9 mile) upstream from Rice Lake.

Sampling stations for the Swamp Creek basin also were established on Hemlock Creek (Stations A-1 and A-2), a major tributary to Swamp Creek, upstream from the potential mine area. Station A-1 was located approximately 1.1 km (0.7 mile) downstream from Ground Hemlock Lake at Berry Lane, and Station A-2 was located approximately 1.8 km (1.1 mile) downstream from Station A-1. A sampling station (E-1) also was established on Hoffman Creek, a tributary to Swamp Creek, downstream from the potential mine area. Sampling was conducted in Hoffman Creek approximately 396 m (1,300 feet) downstream from Hoffman Springs.

For the Pickerel Creek basin, stations on Pickerel Creek (M-5), Creek 11-4 (M-3) and Creek 12-9 (M-1) were established to sample aquatic systems that might receive water from potential mine waste disposal areas. At Pickerel Creek, samples were collected from Station M-5, located approximately 0.2 km (0.1 mile) upstream from Rolling Stone Lake. Samples from Creek 12-9 were obtained from Station M-1, approximately 100 m (328 feet) upstream from Rolling Stone Lake. At Creek 11-4, samples were obtained from Station M-3, approximately 0.5 km (0.3 mile) upstream from Rolling Stone Lake.

The two stations on the Wolf River (Y and Z) were selected to permit sampling of this major aquatic system above and below the drainage from the environmental study area via Swamp and Pickerel creeks. Samples were collected at Station Y, located approximately 1.9 km (1.2 miles) upstream from the confluence with Swamp Creek, and Station Z, located approximately 1.4 km (0.9 miles) downstream from the confluence with Pickerel Creek. Although outside the designated 8-km (5-mile) radius, these stations are considered part of the environmental study area.

Sampling stations were established on lakes that were either adjacent to or in a location that could potentially receive runoff from the proposed site area or candidate mine waste disposal areas. Actual stations within each lake were selected in habitat types that were most representative of the lake. Typically one station was established in each lake; however, two stations were established in Rice, Little Sand, and Rolling Stone lakes. In Rice Lake samples were collected at Station N which was centrally situated in the lake and Station F, located in the southern portion within the channel of Swamp Creek that meanders through the lake. In Little Sand Lake, samples were collected from Station H in the northern, more developed portion of the lake, and Station I in the southern, less developed portion near the outlet creek. In Rolling Stone Lake samples were collected at Station M-2 in the northern portion of the lake near the mouths of Pickerel Creek and Creeks 11-4 and 12-9 and Station M-4 in the southern portion near the lake outlet, Pickerel Creek.

The number of locations sampled in the environmental study area and the intensity of sampling were adjusted during the investigation, to address the environmental concerns associated with candidate areas for mine waste disposal facilities. As a result, sampling of water bodies in the study area did not begin simultaneously, and replication of some sampling varied in 1977 and 1978.

Methods are presented below for the collection and analysis of samples for phytoplankton, zooplankton, periphyton, aquatic macrophytes, benthic macroinvertebrates (benthos), fish, and tissue chemistry. A description of the quality control program, which consisted of field and laboratory procedures and data analyses for the aquatic ecology investigations, is also presented.

2.5.1.1 Phytoplankton

At each phytoplankton sampling station, duplicate samples were collected with water pumps (Schwoerbel, 1972). Two calibrated centrifugal pumps were deployed in tandem and equipped with a pair of intake hoses of 19-mm (0.75-inch) inside diameter. Water was pumped from 1-m (3.3-foot) intervals in the water column. Two pumps in tandem were utilized in the collection to increase volume in order to minimize sampling time. In Rice and Skunk lakes, which are shallow (depth <2.0 m [6.6 feet]), the entire volume was withdrawn from mid-depth. For each replicate, an integrated sample of 50 liters (13.2 gallons) of water was collected in a large container. After thorough mixing of the sample, a minimum subsample of 1 liter (0.26 gallon) was obtained. Each phytoplankton sample was preserved in the field with 3 percent buffered formalin, shipped to the laboratory, and stored. Although Weber (1973) recommends preservation of phytoplankton with 5 percent buffered formalin, experience has demonstrated that a 3 percent solution is more desirable in that it reduces cellular distortion and provides adequate preservation.

Each sample was analyzed in the laboratory using a Sedgewick-Rafter counting cell for the identification and enumeration of species present (Weber, 1973; American Public Health Association [APHA] et al., 1976) All planktonic algae were identified to the lowest positive taxon, generally species. Individuals enumerated were expressed as units/ml where a "unit" is equivalent to a filament, colony, partial colony, mass, or one complete diatom cell (2 valves). A minimum of 400 individuals was counted to facilitate an accurate estimate of the density (number/liter) and relative abundance of algal taxa. Less than 400 individuals were enumerated if, on the basis of four strips traversed, the densities were very sparse or were at a level that would excessively exceed the 400 minimum if a fifth strip was enumerated. The majority of the samples were analyzed within 3 months of the date of collection. Algae were identified using taxonomic keys presented in Collins (1909), Smith (1920, 1924, 1950), Lackey (1938), Patrick (1959), Thompson (1959), Prescott (1962, 1970), Patrick and Reimer (1966), Weber (1966), Whitford and Schumacher (1969), and Taft and Taft (1971). Identifications and enumerations were verified by reanalysis of approximately 10 percent of the samples by either Dr. Theodore S. Roeder, Associate Professor, University of Wisconsin at Stevens Point or Mr. Mason G. Fenwick, Assistant Professor, Northern Illinois University, DeKalb. Consultation for identification was also provided by Dr. Gary B. Collins and Mr. Benjamin H. MacFarland, Aquatic Biologists, U.S. EPA, Cincinnati, Ohio. A reference collection consisting of preserved subsamples was prepared and retained.

Diversity was calculated using the formula presented in Shannon and Weaver (1949) and numbers of organisms identified to the lowest positive taxa (based on $\log_{10}$).

Samples for chlorophyll a analysis were obtained from lake stations where phytoplankton was collected (Table 2.5-2), except in March 1977. Samples were filtered on site, and the filters were placed in vials containing aqueous acetone solution (Weber, 1973). Approximately 500 ml of sample was filtered utilizing 0.45 μ membrane filters. The sample vials were wrapped in aluminum foil, packed in ice, and shipped in insulated containers via air freight on the day of collection to Aqualab, Inc. for analysis. The analysis was conducted in accordance with Section 602c, "Determination of Chlorophyll a in the Presence of Pheophytin a" in Standard Methods for the Examination of Water and Waste Water (APHA et al., 1971). The chlorophyll a data reported represent pheophytin a corrected data.

2.5.1.2 Zooplankton

At each zooplankton sampling station, duplicate samples were collected with water pumps (Schwoerbel, 1972). Two calibrated centrifugal pumps were deployed in tandem and equipped with a pair of intake hoses of 19-mm (0.75-inch) inside diameter. For each sample, the intake hoses were lowered to a position immediately above the substrate and then raised at approximately 152-mm (6-inch) intervals to obtain an integrated sample of the water column. Each sample consisted of a minimum of 250 liters (66 gallons) of water pumped through a No. 20 mesh net, 76 μm (0.003 inch). To reduce the potential of forcing zooplankton through the mesh, the net was suspended in water. The samples were concentrated into prelabeled containers and preserved with 5 percent buffered formalin (Weber, 1973).

Enumeration by subsampling was conducted by the open grid method (Weber, 1973). To facilitate counting organisms in the subsample, a brass grid was used to subdivide an 80 x 100 x 5-mm (3.15 x 4 x 0.2-inch) chamber. All organisms for the entire subsample, usually 2 to 5 ml, or a minimum of 300 organisms were enumerated and identified to the lowest positive taxon, generally species.

Taxonomic keys used for zooplankton identifications were Ahlstrom (1940, 1943), Edmondson (1959), and Ruttner-Kolisko (1974) for Rotifera; Brooks (1957, 1959) and Deevey and Deevey (1971) for cladocera; Yeatman (1959) and Torke (1976) for cyclopoid copepods; and Wilson (1959) for calanoid copepods.

Cyclopoid and calanoid copepodites and nauplii were reported as such. Identifications were verified by Dr. Byron G. Torke, Assistant Professor, Ball State University, Muncie, Indiana, through review of reference slide mounts of the voucher specimens.

A reference collection consisting of permanent slide mounts of each taxon identified was prepared and retained. Individuals enumerated were expressed in number per liter. Diversity was calculated on all mature individuals identified to be lowest positive taxon using the formula presented in Shannon and Weaver (1949) (based on $\log_{10}$). The relative abundance was calculated and expressed as the percent of all organisms collected.

2.5.1.3 Periphyton

Qualitative samples of periphytic algae were collected from commonly occurring natural substrates found at near-shore areas in the vicinity of the sampling stations. Entire substrates such as plants or rocks, along with material scraped from larger substrates, such as logs or boulders, were preserved in 5 percent buffered formalin (Weber, 1973) and transported to the laboratory for analysis.

In the laboratory, algae were scraped from the collected substrates and two aliquots were withdrawn from the well mixed sample. One aliquot was transferred to a Sedgewick-Rafter counting cell for enumeration and non-diatom identification (APHA et al., 1976). Strips of the counting cell were examined until a minimum of 250 diatom cells were enumerated. Diatoms were identified from the other aliquot using standard diatom mounts (APHA et al., 1976) after centrifugation and mounting with Cover Bond. Raw counts of diatoms were extrapolated to whole samples through Diatom Species Proportional Counts

(Weber, 1973). Periphyton were identified to lowest positive taxon, generally species, and counts were expressed as relative abundance.

Verification of identifications and enumerations was completed by reanalysis of 10 percent of the samples by Mr. Keith E. Kamburn, Phycologist, Kentucky Nature Preserves Commission, Frankfort. For reference, the permanent slides used in the analyses were retained in addition to preserved subsamples.

2.5.1.4 Aquatic Macrophytes

The survey consisted of the observation of macrophyte beds during a systematic reconnaissance of each water body. The extent of growth was visually estimated and described as "dense" when coverage was continuous, "moderate" when growths were common, or "sparse" when the growth was rarely encountered (Weber, 1973). Representative specimens were collected, dried in a plant press, and mounted for identification. Species were identified using taxonomic keys presented in Gleason and Cronquist (1963). An estimation of the relative composition was made, and a general map outlining the macrophyte beds was subsequently prepared. A reference collection of pressed and dried specimens of each species was prepared and retained. Identifications were verified through review of mounted specimens by Dr. Hugh H. Iltis, Professor of Botany and Director of the Herbarium, University of Wisconsin at Madison.

In addition to the survey of aquatic macrophytes in site area lakes and ponds (Tables 2.5-2 and 2.5-3), an inventory to determine the relative abundance of aquatic macrophytes in Swamp Creek and the Wolf River was completed in June 1983. The inventory was initiated 0.4 km (0.25 mile) upstream of the proposed discharge site on Swamp Creek and terminated on the Wolf River approximately 1.2 km (0.75 mile) downstream from the confluence with Swamp Creek at the bend in Lost Lake Road. The relative abundance of aquatic macrophyte species was determined by visual estimates.

2.5.1.5 Benthic Macroinvertebrates

Quantitative sampling consisted of two, three, or five replicate samples in 1977, and three replicate samples in 1978. Samples were collected utilizing an Ekman sampler, except at Station D on Swamp Creek, where a Surber sampler was used, from the predominant substrate type, which was visually determined, at each station. The substrates encountered were visually characterized according to the classification system presented in Weber (1973) and in Table 2.5-5. Samples were screened in the field through a No. 30 U.S. Standard sieve and preserved in 10 percent buffered formalin with rose bengal stain added to facilitate subsequent sorting (APHA et al., 1976).

Qualitative sampling, consisting of hand-picked or dip-net samples of miscellaneous substrates near each sampling station, was conducted in 1977 and 1978 (Table 2.5-6). Typically, shoreline areas were investigated for suitable substrates such as rocks or sticks that might provide benthic habitat. Also, a dip-net was swept through aquatic macrophytes and/or overhanging terrestrial vegetation, if present, and surficial sediments. Organisms were preserved in 10 percent buffered formalin.

In the laboratory, benthic organisms were sorted manually from the substrate materials and placed in vials containing 70 percent ethanol (APHA et al., 1976). Chironomidae and Oligochaeta were subsequently mounted in CMC-10 medium on glass slides. All organisms were identified to the lowest positive taxon and enumerated. Enumeration and identification were verified by review of samples and reference specimens by an investigator

TABLE 2.5-5

CATEGORIES FOR THE FIELD CLASSIFICATION
OF THE GENERAL SUBSTRATE CHARACTERISTICS*
OF THE WATER BODIES IN THE ENVIRONMENTAL STUDY AREA

TYPE	SIZE OR CHARACTERISTIC
Inorganic Components	
Bedrock or solid rock	
Boulders	>256 mm (10 inches) in diameter
Rubble	64 to 256 mm (2-1/2 to 10 inches) in diameter
Gravel	2 to 64 mm (1/12 to 2-1/2 inches) in diameter
Sand	0.06 to 2.0 mm in diameter; gritty texture when rubbed between fingers
Silt	0.004 to 0.06 mm in diameter
Clay	<0.004 mm in diameter; smooth slick feeling when rubbed between fingers
Marl	Calcium carbonate; usually gray; often contains fragments of mollusc shells or *Chara*; effervesces freely with hydrochloric acid
Organic Components	
Detritus	Accumulated wood, sticks, and other undecayed coarse plant materials
Fibrous peat	Partially decomposed plant remains; parts of plants readily distinguishable
Pulpy peat	Very finely divided plant remains; parts of plants not distinguishable; varies in color from green to brown; varies greatly in consistency, often being semi-fluid
Muck	Black, finely divided organic matter; completely decomposed

*Weber, 1973

TABLE 2.5-6

SUBSTRATE TYPES SAMPLED FOR THE COLLECTION OF QUALITATIVE BENTHIC MACROINVERTEBRATES

LOCATION	SAMPLING STATION	SUBSTRATE
Swamp Creek Drainage Basin		
Rice Lake	F	Aquatic vegetation, peat, muck, detritus
Rice Lake	N	Aquatic vegetation, peat, muck, detritus
Hemlock Creek	A-1	Silt, sand, detritus, sticks
Swamp Creek	D	Rocks, gravel, sticks, shoreline vegetation
Swamp Creek	E	Shoreline vegetation, aquatic vegetation, sticks, detritus
Oak Lake	G	Aquatic macrophytes, sticks, sand
Pickerel Creek Drainage Basin		
Rolling Stone Lake	M-2	Aquatic macrophytes, detritus, sticks
Rolling Stone Lake	M-4	Aquatic macrophytes, rocks, gravel, muck
Pickerel Creek	M-5	Shoreline vegetation, detritus, sticks
Creek 12-9	M-1	Shoreline vegetation, detritus, sticks
Creek 11-4	M-3	Shoreline vegetation, detritus, sand, sticks
Little Sand Lake	H	Shoreline vegetation, detritus, sticks
Little Sand Lake	I	Aquatic macrophytes, rocks, sand, sticks
Duck Lake	K	Aquatic macrophytes, muck, peat, detritus, sticks
Deep Hole Lake	L	Aquatic macrophytes, rubble, sand, gravel, muck, detritus
Skunk Lake	J	Aquatic macrophytes, muck
Wolf River	Y	Sand, detritus, sticks
Wolf River	Z	Aquatic macrophytes, rocks, gravel, sand, detritus

other than the original analyst. Taxonomic keys used for identification of invertebrates were Ross (1944), Roback (1957), Saether (1971), Brown (1972), Bryce and Hobart (1972), Mason (1973), Stewart and Loch (1973), Hilsenhoff (1975), Wiggins (1977), Oliver (1978), and Pennak (1978) for insects; Bousefield (1958), Hobbs (1972), Holsinger (1972), Williams (1972), and Pennak (1978) for crustacea; Brinkhurst (1964), Hiltunen (1967, 1973), and Brinkhurst and Jamieson (1971) for Oligochaeta; Klem (1972) and Pennak (1978) for Hirudinea; and Baker (1928), Eddy and Hodson (1961), and Pennak (1978) for Mollusca.

A reference collection consisting of permanent slide mounts and specimens preserved in vials of each taxon identified was prepared and retained. Numbers of individuals collected in quantitative samples were expressed as number per square meter of substrate. Diversity was calculated using Brillouin's formula (based on $\log_{10}$) (Pielou, 1966) and the number of organisms identified in the sample:

$$H = \frac{1}{N} \ln \frac{N!}{N_1!N_2!\ldots N_s!}$$

where: H = Diversity;

N = The total number of individuals in the sample;

$N_1, N_2, \ldots$ = The number of individuals in taxa 1, 2, ...; and

s = The total number of taxa in the collection.

The taxa level used to calculate diversity was the lowest positive taxon to which each organism was identified. In general, this was as follows:

Coelenterata: genus
Platyhelminthes: order
Nematoda: phylum
Oligochaeta

Naididae: species
Tubificidae: species (except immatures)
Enchytraeidae: family
Lumbriculicae: family
Branchiobdellida: family

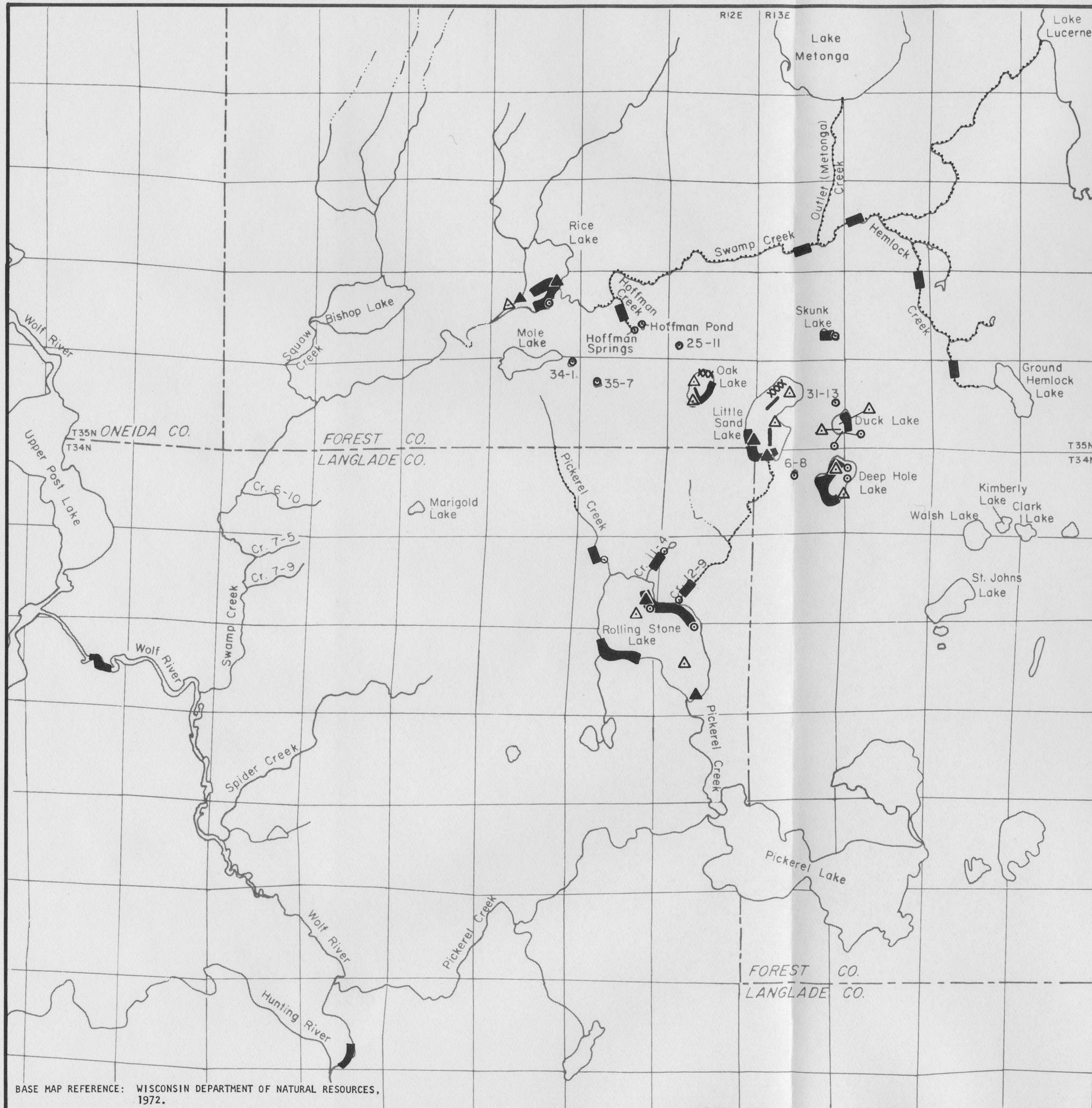
Hirudinea: family, genus, species
Crustacea: genus, species
Hydracarina: order
Insecta: genus, species
Mollusca: genus

The relative abundance of taxa collected in quantitative samples was calculated and expressed as the percent of all organisms collected.

2.5.1.6 Fish

Fish surveys were conducted in the environmental study area during ice-free sampling periods (Table 2.5-2). A variety of fish sampling techniques was utilized to overcome the selectivity inherent in each type of fish sampling gear. Sampling techniques included gill and fyke netting, beach haul or minnow seining, electroshocking, and minnow trapping. Sampling stations where these techniques were used are shown on Figure 2.5-2. In addition, larval fish were sampled at stations located in Oak and Little Sand lakes (Figure 2.5-1) and a trout redd reconnaissance was conducted in several creeks (Figure 2.5-2).

Experimental monofilament gill nets, each 24.4 m (80 feet) in length, were fished along the bottom for two consecutive 12-hour periods at selected lake areas. The nets were 1.8 m (6 feet) deep and consisted of eight 3.0-m (10-foot) panels. Each panel had an individual mesh size, with the panels arranged so mesh size increased in approximately 12.7-mm (0.5-inch) increments from 12.7 mm (0.5 inch) to 101.6 mm (4 inches) bar measure. Care was taken to avoid areas of potentially low dissolved oxygen.



KEY:

- STREAM
- 25-11 — WISCONSIN DNR IDENTIFICATION CODE FOR UNNAMED LAKES
- Cr. 11-4 — WISCONSIN DNR IDENTIFICATION CODE FOR UNNAMED STREAMS
- ELECTROSHOCKING
- FYKE NET
- GILL NET
- MINNOW TRAP
- SEINING - BEACH HAUL OR MINNOW SEINE
- TROUT REDD RECONNAISSANCE
- LARVAL FISH

1 .5 0 1 MILE

1 .5 0 1 KILOMETER

EXXON MINERALS COMPANY
CRANDON PROJECT

FISH SAMPLING
TECHNIQUES AND LOCATIONS

DAMES & MOORE

FIGURE 2.5-2

Modified fyke nets with a rectangular entrance 0.9 m (3 feet) high and 1.8 m (6 feet) wide were utilized. The remainder of the net assembly included four hoops, 0.8 m (2.5 feet) in diameter with a single Crowfoot-style throat and a 18.3-m (60-foot) lead. The entire net was composed of 1.3-cm (0.5-inch) mesh netting. The nets were set for a 24-hour period in shallow areas at depths less than 1.2 m (4 feet) with the lead attached to a shoreline stake and the remaining lead and trap extended perpendicularly offshore. A double lead net was utilized in Rice Lake.

Seining was conducted during daylight with a beach haul seine or a minnow seine to obtain qualitative samples along suitable shoreline areas at depths of 1.2 m (4 feet) or less. The beach haul seine had dimensions of 36.6 x 1.8 m (120 x 6 feet), a mesh size of 12.7 mm (0.5 inch) bar measure, and contained a 1.8 x 1.8-m (6 x 6-foot) bag of 6.4-mm (0.25-inch) mesh. The minnow seine had dimensions of 7.6 x 1.2 m (25 x 4 feet) and a mesh size of 6.4 mm (0.25 inch). Two to four hauls were collected depending on the quantity of fish collected.

Electrofishing was conducted in selected areas (Figure 2.5-2) with either a Coffelt VVP-2C stream electroshocker unit, a Smith-Root Type VII backpack unit, or a boat-mounted boom electroshocker unit. The Coffelt and Smith-Root units were utilized primarily for stream sampling, and the boom electroshocker for lakes and the Wolf River. Because of inaccessibility or motorboat usage constraints, the Coffelt unit was mounted in a row boat for use in Rice, Duck, and Skunk lakes. Both AC and DC current were utilized in the water bodies studied depending on the conductivity of the water and the specific electrofishing equipment employed for sampling.

Stream electrofishing at Swamp Creek (Stations B and D) and Hemlock Creek (Station A-2) was conducted over a distance of approximately 305 m (1,000 feet). In areas where the streams were greatly obstructed, Creek 11-4 (M-3), Pickerel Creek (M-5), Creek 12-9 (M-1), and Hemlock Creek (A-1), electrofishing was conducted over a distance of approximately 100 m (328 feet). In Hoffman Creek (Station E), which was also greatly obstructed, the distance was 85 m (279 feet). All stream electrofishing was conducted during daylight in an upstream direction. Daytime electrofishing on the Wolf River was conducted for 30-minute intervals along shoreline areas with the boom electroshocker unit. For all stream electrofishing with the Coffelt unit and the Smith-Root unit, a pulsed current of 250 to 300 volts DC (at 2 to 3 amps for the Coffelt unit and 1 amp for the Smith-Root unit) was utilized. A pulsed current of 250 to 300 volts AC (2 to 3 amps) was used in the Wolf River.

Except for Rice Lake, lake electrofishing was conducted at night (1900 to 2330 hours) along selected shoreline areas for 30-minute intervals. In Rice Lake, sampling was conducted during the daylight within the Swamp Creek channel area of the lake for a 30-minute interval. A pulsed current of 250 to 300 volts DC (2 to 3 amps) was utilized for Rice Lake and Rolling Stone Lake, and a pulsed current of 250 to 300 volts AC (2 to 3 amps) was utilized for all other lake sampling.

Minnow traps baited with bread were set for two consecutive 12-hour periods in several small ponds in the environmental study area and in Deep Hole, Duck, Skunk, Rice, and Rolling Stone lakes, and Creeks 11-4 and 12-9 (Figure 2.5-2).

Fish collected were identified, enumerated, measured (mm, total length), and weighed (g) on a spring scale. Identifications were made using taxonomic keys presented in Hubbs and Lagler (1958) and Becker and Johnson (1970). If catches were large, approximately 100 or more fish, the total number for each species was recorded, lengths were obtained from as many fish as practical, and a representative sample, approximating the size frequency of captured fish, was weighed. All fish were examined externally for incidence of parasitism, fungal growths, or apparent disease. Obvious external characteristics of gonadal conditions were also recorded. Except for fish preserved for later identification, enumeration, to serve as voucher specimens or utilized for tissue chemistry, all fish were returned to the water.

Relative abundance of species caught by the various collection techniques and condition factors for the processed fish were calculated. Relative abundance was expressed as the percent that a species contributed to the catch for a particular collection technique. The condition factor is an expression of the relative well-being of fish (Carlander, 1969). The heavier a fish is at a given length, the larger the factor, and, by implication, the better the "condition" of the fish. The factor is expressed in the form $K = W \times 10^5/L^3$ where W is the weight of the fish in grams, L is the total length of the fish in millimeters, and 10^5 is a factor to bring the value of K near unity.

Because Oak or Little Sand lakes were considered as potential water sources, larval fish were sampled at 1-month intervals during May, June, and July 1977. Duplicate samples were collected in two areas in Little Sand Lake and one in Oak Lake (Figure 2.5-2) with a 0.6-m (2-foot) diameter metered (TSK type) flow net, constructed of 00 mesh, 752 μm (0.03 inch), with a terminal oceanographic bucket. The net was towed at a low constant speed 0.5 m (1.6 feet) below the surface for 5 minutes for each replicate.

Potential brook trout spawning areas were located by traversing Swamp Creek upstream of Rice Lake, Hemlock Creek, Outlet Creek, and Hoffman Creek during October and November 1977 and segments of Creek 12-9 and Pickerel Creek during October 1978 (Figure 2.5-2). A fisheries biologist either walked or canoed each creek. Mr. Ronald A. Theis, Fisheries Biologist Wisconsin Department of Natural Resources, participated in the survey along Swamp Creek upstream of Keith Siding Road, portions of Hemlock Creek, and Creek 26-14. Potential spawning areas were characterized as riffles or the downstream edges of pools that contained sand and gravel substrate with indications of ground water discharge, such as seeps and springs (Latta, 1965). Potential redds were considered to be in areas where brook trout were observed to be congregated in suitable riffle areas.

Fish identifications were verified by Mr. Donald M. Fago, Fishery Biologist, Wisconsin Department of Natural Resources, Madison; Dr. George E. Becker, Professor, University of Wisconsin at Stevens Point; or Dr. Lawrence M. Page, Associate Taxonomist, Illinois Natural History Survey, Urbana.

2.5.1.7 Tissue Chemistry

Trace metal analyses were performed on the tissues of selected aquatic species. Aquatic macrophytes, benthos, and fish were collected during 1977 from water bodies in the Swamp Creek drainage basin (Swamp and Hemlock creeks and Oak and Rice lakes) and the Pickerel Creek drainage basin (Deep Hole and Little Sand lakes). During 1978, fish samples were again collected from these same water bodies and from additional locations in the Pickerel

Creek drainage basin (Duck and Rolling Stone lakes, Pickerel Creek, and Creeks 11-4 and 12-9).

Common aquatic macrophytes were collected from the shoreline. The lower portions of the main stalks of larger species (that is, bur reed, cattail, water lily) and the entire plant above the substrate of smaller species (that is, pipewort, spike rush, wild rice) were collected and used in the analyses. At least 30 g (wet weight) of tissue were obtained. Samples were rinsed in distilled water in the field to remove sediment particles attached to the plants (Mathis and Kevern, 1973). Except for wild rice from Rice Lake, macrophytes were placed in a separate plastic bag and analyzed as a composite sample of the aquatic macrophyte community at each sampling station. Wild rice plants from Rice Lake were analyzed separately.

Benthic macroinvertebrate organisms were collected for tissue analysis in conjunction with qualitative benthos collections, which consisted of hand-picked or dip-net sampling of miscellaneous substrates near each sampling station. Two or more grams of tissue were collected. In the field, organisms were rinsed in distilled water to remove sediment particles (Copeland and Ayers, 1972). Except for crayfish from Rice Lake, benthic organisms were placed whole in a separate plastic bag for each station and analyzed as a composite sample of the benthic community at each sampling station. Muscle tissue from crayfish tails was analyzed separately.

Fish for tissue analysis were collected by electroshocking, gill nets, and fyke nets. All fish were measured and weighed prior to dissection in the field. Dissections were performed with a stainless steel knife (Copeland et al., 1973), which was cleaned after each dissection with distilled water. Tissues were gently rinsed in distilled water (Mathis and

Kevern, 1973) and placed in a plastic bag. Two fish tissue types were utilized in 1977: muscle (skinless fillet), because it is the most commonly consumed portion, and liver, because the presence of some trace metals in low concentrations is better detected in this tissue (Hannerz, 1967).

In 1978, tissue from a commonly occurring fish species was selected for analysis. Generally, samples consisted of muscle tissues composited from 25 yellow perch that were similar in size from each body of water. However, black bullhead, white sucker, redbelly dace, and mottled sculpin comprised the samples from Hemlock Creek, Swamp Creek, Rice Lake, and Creek 11-4 because yellow perch were not found. For small fish such as redbelly dace, mottled sculpin, and young white sucker, whole fish were used for analysis (Table 2.5-7). For composite samples, care was taken to select fish of similar size and to excise tissue samples of similar size. In addition to the composite sample from each water body, an additional 23 yellow perch of a wide range of lengths from Little Sand Lake were analyzed individually to document intraspecies variation of metal concentrations. Immediately after collection, all tissue samples were placed on ice in an insulated container and frozen within 8 hours of collection.

In the laboratory, the tissues were homogenized in an electric blender, food processor, or manual grinding depending on amount and consistency of tissue.

In preparation for analysis, the homogenized tissue samples were separated into subsamples for analysis for the specific parameters as follows:

TABLE 2.5-7

DETERMINATION OF TRACE METALS IN FISH TISSUES COLLECTED FROM WATER BODIES IN THE ENVIRONMENTAL STUDY AREA IN 1978

LOCATION STATION	MONTH OF COLLECTION	NUMBER OF OF INDIVIDUALS THAT COMPRISED THE SAMPLE	SPECIES	TISSUE ANALYZED
Swamp Creek Drainage Basin				
Rice Lake	August	25	Black bullhead	muscle
Hemlock Creek Station A-1	August	24	White sucker	muscle
Swamp Creek Station D	May	21	White sucker	whole fish
Station D	August	7	Mottled sculpin	whole fish
Oak Lake	August	25	Yellow perch	muscle
Pickerel Creek Drainage Basin				
Rolling Stone Lake	May	20	Yellow perch	muscle
	August	26	Yellow perch	muscle
Pickerel Creek M-5	August	25	Yellow perch	muscle
Creek 12-9 M-1	August	5	Yellow perch	muscle
Creek 11-4 M-3	August	25	Redbelly dace	whole fish
Little Sand Lake	August	20	Yellow perch	muscle
Little Sand Lake	August	1*	Yellow perch	muscle
Duck Lake	May	20	Yellow perch	muscle
	August	25	Yellow perch	muscle
Deep Hole Lake	August	25	Yellow perch	muscle

*23 yellow perch were analyzed individually.

SUBSAMPLE	PARAMETERS
1	cadmium, chromium, cobalt, copper, lead, manganese, zinc, and percent moisture
2	arsenic
3	mercury

Subsample 1 was weighed to determine wet weight, dried to constant weight at 135-150°C (275-302°F) and the final dry weight determined. The relationship between wet and dry tissue weights was expressed as percent moisture and was used to convert metal concentrations based on dry weight to concentrations based on wet weight. The sample was ashed at 450°C (842°F) and subsequently dissolved in hydrochloric acid and analyzed by atomic absorption (AA) spectroscopy using direct aspiration (Horowitz, 1975).

Subsample 2 was weighed wet, dissolved in 1+1 sulfuric and concentrated nitric acids and analyzed for arsenic using AA and the hydride generation technique (U.S. EPA, 1974). The percent moisture was used to convert arsenic concentrations based on dry weight to concentrations based on wet weight.

Subsample 3 was weighed wet, dissolved in concentrated sulfuric and nitric acids, potassium permanganate, and potassium persulfate. Sodium chloride hydroxylamine hydrochloride solution was then added and the sample analyzed for mercury using AA and the conventional cold vapor technique (U.S. EPA, 1974). The percent moisture was used to convert mercury concentrations based on dry weight to concentrations based on wet weight.

All analyses were performed using a Perkin-Elmer model 306 atomic absorption spectrophotometer.

2.5.1.8 Quality Control

Field and laboratory quality control procedures were utilized during the aquatic ecology studies as a means of assuring that they were completed according to currently accepted standards of practice for ecological investigations.

Field Procedures - A daily log of field activities was maintained by the field team leader who signed and dated the entries. These entries were supplemented by information from the daily logs of individual field personnel.

Two types of field data sheets were used for aquatic ecology field work. One data sheet was used for recording data pertaining to plankton, periphyton, benthos, and larval fish. The second data sheet was used to record data on juvenile and adult fish captured. Data regarding sample station number (or location), date, time, weather conditions, and sampling equipment used were entered on both types of sheets.

Plankton pumps were calibrated daily by recording the time that elapsed for a known volume of water to pass through the pump. This was done at least four separate times prior to each sampling to calculate an average time per unit volume. This calibration was utilized to determine the pumping intervals for zooplankton and phytoplankton sampling so that equal volumes of water were withdrawn at each depth interval.

The meter on the larval fish net was calibrated prior to each use in the field. Calibration was performed by making subsurface (depth 0.5-m [1.6-foot]) tows over a measured distance. Meter values, for tows made with the complete device and tows made with the terminal bucket removed, were compared with the manufacturers' standards and recorded in the daily field log. If more than 5 percent difference was discovered, the meter was returned to the manufacturer for maintenance.

Laboratory Procedures - Chemical analyses for chlorophyll a and tissue trace metals were conducted by Aqualab, Inc. All laboratory analyses completed by Aqualab, Inc. were subject to the review and verification procedures described in subsection 2.3.1.7.

For the analysis of biological samples, a continuous daily log was maintained at the Environmental Laboratory in the Dames & Moore Park Ridge, Illinois office, and all log entries were signed and dated. Each set of biological samples brought into the laboratory was accompanied by a copy of the field sampling notes and data sheets. The field notes were placed in the project files following their review and the transfer of pertinent data to laboratory data sheets. Upon receipt in the laboratory, all samples were arranged in order of station and depth at which each was collected to verify that all samples were present. Permanent tags with assigned laboratory numbers were attached to each sample container. Field identification tags or labels were retained until sample processing was completed. A continuous master list of all laboratory sample numbers with brief sample descriptions was maintained. The assigned laboratory numbers were used in all data records and on labels for preserved and mounted specimens.

Pertinent sample history and analytical data for each biological sample were recorded on pre-prepared laboratory data sheets. Completion of laboratory analysis for biological samples was verified by checking against the master list. All original data were filed by month and segment of the biological sampling program. Release of any samples for quality control analysis was accompanied by a transmittal sheet. Information on transmittal of samples was documented in the laboratory log.

All preserved and identified biological specimens were labeled, where applicable, with names of organisms, job number, and laboratory number. Upon completion of laboratory analysis, each voucher sample was carefully examined for correct label information, sufficient volume of preservative, and proper sealing for storage. The samples were then organized and stored in a container labeled with description of contents, date of samples, job number, and location.

A master file was maintained with a list of all the laboratory equipment subject to calibration and the information on:

1. Calibration requirements;
2. Sources of calibration standards (for example, National Bureau of Standards, equipment vendor specifications, recognized natural physical constants); and
3. Location of individual equipment maintenance and calibration logs.

Individual equipment logs contained the dates of calibration and the next date of calibration (or a statement that calibration was not required). Where appropriate, tags or stickers for recording dates of calibration were affixed to the piece of equipment. Mandatory recall requirements and acceptance criteria, where applicable, were recorded in the equipment log.

For verification of specimen identifications, every tenth sample was reanalyzed by another professional employee with comparable technical expertise or by an outside expert.

For the Crandon Project, independent verification was undertaken by the following outside experts:

Fish	Mr. D. Fago, Wisconsin DNR, Madison Dr. L. Page, Illinois Natural History Survey, Urbana Dr. G. Becker, University of Wisconsin at Stevens Point
Phytoplankton	Dr. T. Roeder, University of Wisconsin at Stevens Point Mr. M. Fenwick, Northern Illinois University, DeKalb
Periphyton	Mr. K. Kamburn, Kentucky Nature Preserves Commission, Frankfort
Zooplankton	Dr. B. Torke, Ball State University, Muncie, Indiana
Aquatic Macrophytes	Dr. H. Iltis, University of Wisconsin at Madison

Outside consultation for phytoplankton identifications was also provided by Dr. Gary B. Collins and Mr. Benjamin H. MacFarland, U.S. EPA, Cincinnati. Benthos identifications and enumerations were reviewed by a Dames & Moore analyst other than the original investigator.

Data Analyses - All data were rechecked by a Dames & Moore employee other than the original investigator. This review included proofing all scientific names and checking calculations where applicable and signing and dating the document reviewed. Any discrepancies were reviewed by the originator of the document before changes were made.

All data and scientific names were transcribed onto computer code forms and checked for accuracy by a second individual who made corrections where needed and signed and dated the coding forms.

The transmittal of these materials to the keypunch and computer service was documented and entered into the laboratory log. The completed computer printouts underwent a final documented review upon return from the computer services to check for misspellings and incorrect data calculations. Calculations were performed with a formally verified computer program.

2.5.2 Swamp Creek Drainage Basin

The major streams of the Swamp Creek drainage basin upstream of Rice Lake and their headwaters are as follows:

Streams	Headwaters
Swamp Creek	Lake Lucerne
Hemlock Creek	Ground Hemlock Lake
Outlet (Metonga) Creek	Lake Metonga
Hoffman Creek	Hoffman Springs

Swamp Creek flows west along the northern edge of the site area through an extensive wetland, the center of which is Rice Lake, and then southwest through a broad wetland to its confluence with the Wolf River. Its major tributaries in the environmental study area are Hemlock, Hoffman, and Outlet (Metonga) creeks (Figure 2.5-1).

The lakes in the basin upstream of Rice Lake are Lucerne, Metonga, Ground Hemlock, and Oak. Rice Lake receives surface drainage primarily from Swamp Creek to the east and Gliske Creek to the north. Oak Lake (a seepage lake), Pond 25-11, and Hoffman Pond intermittently drain toward Hoffman Creek. A detailed discussion of the surface water drainage is presented in the section 2.4, Surface Water.

Surface waters selected for investigation of periphyton, benthic macroinvertebrates, fish, and fish tissue chemistry were Rice and Oak lakes, and stations on Swamp and Hemlock creeks. In addition to these components, phytoplankton, zooplankton, and aquatic macrophytes were investigated at Rice and Oak lakes. Hoffman Spring, Hoffman Pond, and Pond 25-11 were surveyed for aquatic macrophyte and fish species at the request of the DNR (Brasch, 1977). Hoffman Creek was sampled to investigate the occurrence of brook trout. A summary of the characteristics of these water bodies is presented in Table 2.5-8.

2.5.2.1 Drainage Lakes and Associated Streams

Within the Swamp Creek drainage basin, Rice Lake and Hemlock, Hoffman, and Swamp creeks were included in the aquatic ecology survey. These water bodies are within 4.3 km (2.7 miles) of the ore body (Table 2.5-8). Stream gradient was 1.5 m/km (0.28 feet/mile) or less and bottom composition was generally muck, but small sand and gravel areas also occurred. The surface area of Rice Lake is 84.2 ha (208 acres) and the bottom is predominantly soft muck. Wet-mesic or Wet Northern Forest is the predominant shoreline vegetation for most of the water bodies. The shorelines of all water bodies are undeveloped. As described in section 2.9, Land Use, Swamp Creek above Rice Lake and the tributaries Hemlock, Hoffman and Outlet (Metonga) creeks are classified Class II trout streams. Streams in this classification may have some natural reproduction, but not enough to utilize available food and space (Kmiotek, 1980).

Biological sampling stations were established near reasonably accessible locations containing habitat that was typical of the overall stream or lake system. Station locations are depicted on Figure 2.5-1. At Rice Lake samples were collected at Station N, which was centrally situated in the lake and Station F, located in the southern portion of the lake within the channel of Swamp Creek that meanders through the lake. At Hemlock Creek, samples were obtained from Station A-1, located downstream from Ground Hemlock Lake at Berry Lane and Station A-2, located downstream from Station A-1. At Hoffman Creek, Station E-1 was located downstream from Hoffman Springs. At Swamp Creek, samples were collected from Station B downstream from the confluence with Hemlock Creek, Station D downstream from the confluence with Outlet

TABLE 2.5-8

SUMMARY OF CHARACTERISTICS OF THE WATER BODIES IN THE SWAMP CREEK DRAINAGE BASIN FROM WHICH BIOLOGICAL SAMPLES WERE OBTAINED[a]

SURFACE WATER CATEGORY/ WATER BODY	DISTANCE AND DIRECTION FROM ORE BODY (km)		DEPTH (m)		MEAN WIDTH (m)	LENGTH (km)	GRADIENT (m/km)	TOTAL SURFACE AREA (ha)	PREDOMINANT SHORELINE VEGETATION[b]	SUBSTRATE CLASSIFICATION
			MEAN	MAX						
Drainage Lakes and Associated Streams										
Rice Lake	4.3	Northwest	--[c]	1.8	--	--	--	84.2	Sedge Meadow, Emergent Wetland	Muck, peat, detritus
Hemlock Creek	2.6	East	0.3	--	4.3	3.9	0.5	1.7	Wet-mesic or Wet Northern Forest	Silt, detritus, some sand
Hoffman Creek	2.9	West	0.2	--	2.4	0.8	1.5	0.2	Wet-mesic or Wet Northern Forest	Sand, gravel and muck
Swamp Creek	1.6	North	0.3	--	7.0	24.9	1.5	17.8	Wet-mesic or Wet Northern Forest	Rubble, gravel, sand;[d] and silt, detritus with some sand[e]
Seepage Lakes										
Oak Lake	1.4	South	--	14.3	--	--	--	20.6	Dry-mesic or Mesic Northern Hardwoods	Silt, detritus, peat, in deep portions, sand in littoral areas
Ponds										
Pond 25-11	1.9	West	--	0.6	--	--	--	0.6	Wet-mesic or Wet Northern Forest	-
Hoffman Springs	2.8	East	--	2.1	--	--	--	0.2	Wet-mesic or Wet Northern Forest	-
Hoffman Pond	2.8	East	--	--	--	--	--	--	Wet-mesic or Wet Northern Forest	-

[a]See Surface Water, Table 2.4-18.

[b]See Terrestrial Ecology, Figure 2.6-7.

[c]Information not available or not applicable.

[d]Information pertains to area near Station D.

[e]Information pertains to area near Station E.

Creek, and Station E upstream of the confluence with Hoffman Creek. Station D was located on a riffle section of Swamp Creek with rock outcroppings and gravel and coarse sand substrate. The other stations were located on reaches of the creek with predominantly less coarse substrates.

Information on organisms collected from the water bodies sampled within the Swamp Creek drainage basin is presented according to the following scheme:

BIOTIC COMPONENT	WATER BODY
Phytoplankton	Rice Lake
Zooplankton	Rice Lake
Periphytic Algae	Rice Lake, Hemlock Creek, Swamp Creek
Aquatic Macrophytes	Rice Lake
Benthic Macroinvertebrates	Rice Lake, Hemlock Creek, Swamp Creek
Fish	Rice Lake, Hemlock Creek, Hoffman Creek, Swamp Creek

Additional data on fish and benthos collected from Swamp Creek below Rice Lake in 1982 are presented in Appendix 2.5G.

Phytoplankton

Rice Lake - Phytoplankton samples were collected from Rice Lake at Stations F and N. Sampling was conducted at both stations during March 1977, monthly from May through October 1977, and at Station N during March, May, and August 1978. Density and relative abundance of the eight major taxa identified and enumerated during the study are presented in Table 2.5-9. The density and relative abundance of taxa from individual collections are

TABLE 2.5-9

MEAN DENSITY[a] (units/ml), RELATIVE ABUNDANCE (%), AND DIVERSITY[b]
OF PHYTOPLANKTON COLLECTED AT RICE LAKE - STATIONS F and N
MARCH 1977, MAY THROUGH OCTOBER 1977, AND MARCH, MAY AND AUGUST 1978

	1977														1978					
	MARCH		MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER		MARCH		MAY		AUGUST	
	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%
Bacillariophyceae																				
F	177	67	76	5	762	35	225	17	122	3	143	2	55	3	--[c]	--	--	--	--	--
N	2,010	99	65	4	82	4	176	5	493	6	57	2	66	3	26	7	330	29	74	1
Chlorophyceae																				
F	2	1	104	7	139	6	0	0	8	<1	78	1	4	<1	--	--	--	--	--	--
N	11	1	7	<1	18	1	32	1	92	1	19	1	5	<1	1	<1	40	4	763	8
Chrysophyceae																				
F	2	1	1,208	84	1,200	55	1,067	82	3,636	96	7,978	97	1,988	97	--	--	--	--	--	--
N	0	0	1,590	90	1,853	94	3,444	91	7,878	90	2,823	96	2,295	97	76	20	754	66	7,364	77
Cryptophyceae																				
F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	--	--	--	--	--	--
N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,298	14
Cyanophyceae																				
F	82	31	45	3	8	<1	0	0	3	<1	0	0	3	<1	--	--	--	--	--	--
N	18	1	93	5	10	<1	0	0	0	0	3	<1	3	<1	272	72	15	1	11	<1
Dinophyceae																				
F	0	0	0	0	14	1	0	0	0	0	0	0	0	0	--	--	--	--	--	--
N	0	0	2	<1	0	0	0	0	12	<1	0	0	0	0	0	0	1	<1	0	0
Euglenophyceae																				
F	0	0	8	1	17	1	10	1	5	<1	34	<1	0	0	--	--	--	--	--	--
N	0	0	8	<1	3	<1	144	4	233	3	25	1	3	<1	0	0	7	1	36	<1
Xanthophyceae																				
F	0	0	0	0	28	1	0	0	0	0	0	0	0	0	--	--	--	--	--	--
N	0	0	0	0	6	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total																				
F	262		1,441		2,166		1,302		3,774		8,234		2,049		--	--	--	--	--	--
N	2,040		1,765		1,971		3,795		8,708		2,927		2,372		375		1,147		9,548	
Diversity																				
F	1.0		0.3		0.8		0.3		0.1		0.1		0.1		--		--		--	
N	0.6		0.2		0.2		0.3		0.2		0.1		0.1		0.5		0.7		0.4	

[a]Density is the mean of two replicates rounded to the nearest whole number.

[b]Calculated by Shannon-Weaver formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5A, Tables A-37 through A-46.

[c]No sample collected.

presented in Appendix 2.5A, Tables A-37 through A-46. The 78 individual taxa identified from samples collected at Station F and the 97 taxa from Station N are presented in Appendix 2.5A, Table A-60.

Phytoplankton was generally similar at both stations in Rice Lake. During 1977 density in March was considerably higher at Station N (2,040 units/ml), than at Station F, (262 units/ml). However, during May, June, and October densities were similar at both stations, ranging from 1,441 to 2,166 units/ml at Station F and from 1,765 to 2,372 units/ml at Station N. Peak density was recorded in August at Station N (8,708 units/ml) and in September at Station F (8,234 units/ml).

During 1978, the number of phytoplankton at Station N was considerably lower in March (375 units/ml) than in March 1977, but was similar to the number collected at Station F during March 1977. Numbers collected in May and August of 1977 and 1978 were similar.

Golden-brown algae (Chrysophyceae), diatoms (Bacillariophyceae), and blue-green algae (Cyanophyceae) were the major algal families collected in Rice Lake. Golden-brown algae comprised from 55 to 97 percent of the collections from May through October at both stations. During March 1977 diatoms predominated at both stations, and during March 1978 blue-green algae predominated at Station N.

Golden-brown algae primarily consisted of an unidentified Chrysococcus-like alga* and common diatom species included Fragilaria

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*Mr. Benjamin MacFarland of the Environmental Monitoring and Support Laboratory, U.S. EPA, Cincinnati, suggested that organisms tentatively identified as Chrysococcus rufescens, C. hemisphaerica, C. cylindrica, and C. ovalis be referred to as unidentified Chrysococcus-like algae, based on their size and quality of preservation.

construens, F. crotonensis, and F. intermedia. The blue-green algal species, Oscillatoria agardhi, was the most common alga collected in March 1978.

Diversity values varied from 0.1 to 1.0. A low diversity value indicates that most of the individuals observed in the phytoplankton community were from only a few taxa. A high diversity value indicates that the number of individuals were broadly distributed over several taxa. Diversity values could theoretically go to infinity depending on the total number of taxa present (Fager, 1972).

The highest diversity value of 1.0 at Station F in October 1977 (Table 2.5-9) was associated with a relatively balanced phytoplankton community. Low values (0.1 to 0.2) corresponded to the high (≥90 percent) relative abundance of Chrysophyceae, which was almost exclusively represented by the unidentified Chrysococcus-like alga.

The mean chlorophyll a concentration recorded from stations in Rice Lake was ≤11 μg/l and ranged from ≤1 to 49 μg/l (Appendix 2.5F, Table F-1). The highest value at each of the two stations was reported in July 1977. Pheophytin a values for 1978 are reported in Appendix 2.5F, Table F-12.

Zooplankton

Rice Lake - The studies conducted on Rice Lake included collection of zooplankton samples at Stations F and N during March and monthly from May to October 1977. Collections also were made at Station N in March, May, and August 1978. Zooplankton were classified into the orders Copepoda and Cladocera or the phylum Rotatoria; the density and relative abundance of these three major taxa are presented in Table 2.5-10. Density and relative abundance of taxa from individual collections are presented in Appendix 2.5B,

TABLE 2.5-10

MEAN DENSITY[a] (no./1), RELATIVE ABUNDANCE (%), AND DIVERSITY[b]
OF ZOOPLANKTON COLLECTED AT RICE LAKE - STATIONS F AND N
MARCH 1977, MAY THROUGH OCTOBER 1977, AND MARCH, MAY AND AUGUST 1978

	1977														1978					
	MARCH		MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER		MARCH		MAY		AUGUST	
	no./1	%	no./1	%	no./1	%	no./1	%	no./1	%	no./1	%	no./1	%	no./1	%	no./1	%	no./1	%
Cladocera																				
F	<1	1	2	4	150	44	19	25	1	5	<1	4	<1	5	--[c]	--	--	--	--	--
N	<1	2	3	14	219	74	1	6	19	14	3	2	<1	2	<1	3	3	28	1	13
Copepoda																				
F	4	39	4	8	102	30	52	68	12	55	7	48	<1	14	--	--	--	--	--	--
N	42	88	3	15	56	19	9	51	73	53	104	61	<1	5	5	78	3	36	4	43
Rotatoria																				
F	5	60	36	87	89	26	6	8	9	40	7	47	5	82	--	--	--	--	--	--
N	5	10	15	70	22	8	7	42	45	33	63	37	17	93	1	19	3	36	4	44
Total																				
F	9		42		342		77		22		15		6		--		--		--	
N	47		21		297		17		137		169		18		6		10		9	
Diversity																				
F	0.9		0.9		1.0		1.2		0.9		1.0		0.5		--		--		--	
N	0.9		1.0		0.9		1.2		1.0		0.7		0.4		0.7		0.9		0.9	

[a]Density is the mean of two replicate samples rounded to the nearest whole number.

[b]Calculated using the Shannon-Weaver formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5B, Tables B-37 through B-46. Immature life stages were not included in the calculations.

[c]No sample collected.

Tables B-37 through B-46. The 50 taxa identified from samples collected at Station F and the 53 taxa from Station N are presented in Appendix 2.5B, Table B-60.

The zooplankton community was generally similar at the stations in Rice Lake. In 1977, densities were lower than 50/1 at both stations in March, May, and October. Peak densities of 342/1 were observed in June at Station F and of 297/1 at Station N. During July, August, and September densities at Station F decreased from 77 to 15/1, but at Station N densities increased from 17 to 169/1. During 1978, densities were considerably lower ($\leq$10/1) than in corresponding sampling periods in 1977 collections and were not greater than 10/1.

Community composition at Rice Lake fluctuated throughout the year. In 1977 rotifers were most abundant in March, May, and October at both stations, except at Station N in March when copepods were most common. In June, when highest total numbers were observed, cladocerans were most common, comprising 44 percent of the collection at Station F and 24 percent at Station N. Copepods were most abundant at both stations during July, August, and September comprising 48 percent or more of the zooplankton collections.

In 1978 at Station N copepods were abundant in March and were codominant with rotifers during May and August.

Nauplii were the most abundant copepod forms and cyclopoid copepodites occurred commonly. Common rotifer forms included *Trichocera longiseta*, *Ploesoma* sp., and *Synchaeta* sp. The most abundant cladoceran species were *Acroperus harpae*, *Chydorus sphaericus*, *Diaphanosoma brachyurum*, and *Eubosmina tubicen* (Appendix 2.5B, Tables B-37 through B-46).

Diversity values during the period of investigation ranged from 0.4 at Station N in October 1977 to 1.2 at both stations in July 1977. The low value of 0.4 corresponded to an abundance of Rotatoria, which were represented primarily by Synchaeta sp. (67 percent of the zooplankton community).

Periphyton

Rice Lake - Periphytic algae samples were collected from Rice Lake in the vicinity of Station F monthly from May through October 1977 and from Station N in May and monthly from July through October 1977, and May and August 1978. The relative abundances of the five major taxa identified during the study are presented in Table 2.5-11. The relative abundances of taxa identified from individual collections are presented in Appendix 2.5C, Table C-5. The 77 and 86 individual taxa identified in samples from Stations F and N, respectively, are presented in Appendix 2.5C, Table C-18.

Diatoms comprised over 85 percent of the collections except during August or September. During August 1977 at Station F diatoms comprised 72 percent of the collections and during September 1977 and August 1978 at Station N diatoms made up 69 and 47 percent of the respective collections. The most abundant diatom enumerated from Rice Lake was Cocconeis placentula.

The largest relative abundance (35 percent) of algae other than diatoms was recorded for the blue-green algae at Station N in August 1978 when Chroococcus minor was the most abundant blue-green algae species.

Hemlock Creek - Periphytic algae samples were collected from Station A-1 in October 1977 and May and August of 1978. The relative abundances of the four major taxa identified during the study are presented in Table

TABLE 2.5-11

RELATIVE ABUNDANCE (PERCENT COMPOSITION) OF MAJOR TAXA OF PERIPHYTON COLLECTED FROM WATER BODIES IN THE SWAMP CREEK DRAINAGE BASIN MARCH, MAY THROUGH OCTOBER 1977, AND MAY AND AUGUST 1978

LOCATION/TAXA	1977 MARCH	1977 MAY	1977 JUNE	1977 JULY	1977 AUGUST	1977 SEPTEMBER	1977 OCTOBER	1978 MAY	1978 AUGUST
Rice Lake (F and N)									
Bacillariophyceae									
F	--	97	100	97	72	95	86	--	--
N	--	93	--	87	97	69	98	100	47
Chlorophyceae									
F	--	<1	<1	2	2	4	2	--	--
N	--	6	--	1	1	17	2	<1	2
Chrysophyceae									
F	--	0	0	0	19	0	0	--	--
N	--	0	--	0	0	0	0	0	16
Cyanophyceae									
F	--	2	0	1	6	1	12	--	--
N	--	1	--	12	2	8	0	0	35
Xanthophyceae									
F	--	0	0	0	0	0	0	--	--
N	--	0	--	0	0	6	0	0	0
Hemlock Creek (A-1)									
Bacillariophyceae	--	--	--	--	--	--	99	99	98
Chlorophyceae	--	--	--	--	--	--	0	<1	2
Chrysophyceae	--	--	--	--	--	--	0	<1	0
Cyanophyceae	--	--	--	--	--	--	1	<1	<1
Swamp Creek (D and E)									
Bacillariophyceae									
D	72	62	86	100	48	99	100	100	97
E	98	94	99	--	67	100	100	100	96
Chlorophyceae									
D	0	<1	0	0	<1	0	0	<1	3
E	0	2	1	--	<1	0	<1	0	3
Chrysophyceae									
D	1	34	0	0	52	0	0	0	0
E	1	0	0	--	33	0	0	0	0
Cyanophyceae									
D	27	3	14	0	<1	1	0	0	<1
E	1	4	0	--	0	0	0	0	<1
Xanthophyceae									
D	0	0	0	0	0	0	0	0	0
E	0	0	0	--	<1	0	0	0	0
Euglenophyceae									
D	0	0	0	0	0	0	0	0	0
E	0	<1	0	--	0	0	0	0	0

Note: -- Indicates no sample collected.

2.5-11. The relative abundance of taxa identified from individual collections are presented in Appendix 2.5C, Table C-10. The 71 individual taxa identified are presented in Appendix 2.5C, Table C-23.

The periphyton community at Station A-1 consisted primarily of diatoms (≥98 percent) and Achnanthes minutissima was most abundant. Other diatoms never comprised more than 10 percent of the periphyton community, except for Fragilaria pinnata, 16 percent in August 1978, and A. microcephala, 15 percent in May 1978 (Appendix 2.5C, Table C-10).

Swamp Creek - Periphytic algae samples were collected at two locations in Swamp Creek upstream of Rice Lake, Stations D and E. Station D was sampled in March and monthly from May through October 1977 and May and July 1978, and Station E was sampled in March and monthly from May through July, September, and October 1977 and May and August 1978. The relative abundance of the six major taxa identified during the study are presented in Table 2.5-11. The relative abundances of taxa identified from individual collections are presented in Appendix 2.5C, Table C-12. The 104 and 93 individual taxa identified in samples from Stations D and E, respectively, are presented in Appendix 2.5C, Table C-25.

Diatoms were the most abundant algae collected at both stations. This group comprised from 48 to 100 percent of the periphyton community at Station D and from 67 to 100 percent at Station E. The two most abundant diatom species encountered at both stations were Cocconeis placentula and Achnanthes minutissima.

Except for golden-brown algae, other major taxa did not comprise more than 27 percent of any one collection. Golden-brown algae, represented entirely by an unidentified Chrysococcus-like alga, accounted for 34 and 52 percent of the total periphyton at Station D in May and August 1977, respectively. The group accounted for 33 percent of the periphyton at Station E in August and were not found in May 1977 (Appendix 2.5C, Table C-12). This motile algal form probably originated in an upstream, still water area. During the sampling period, there was a large beaver pond upstream of Station D that may have been the source of this algae.

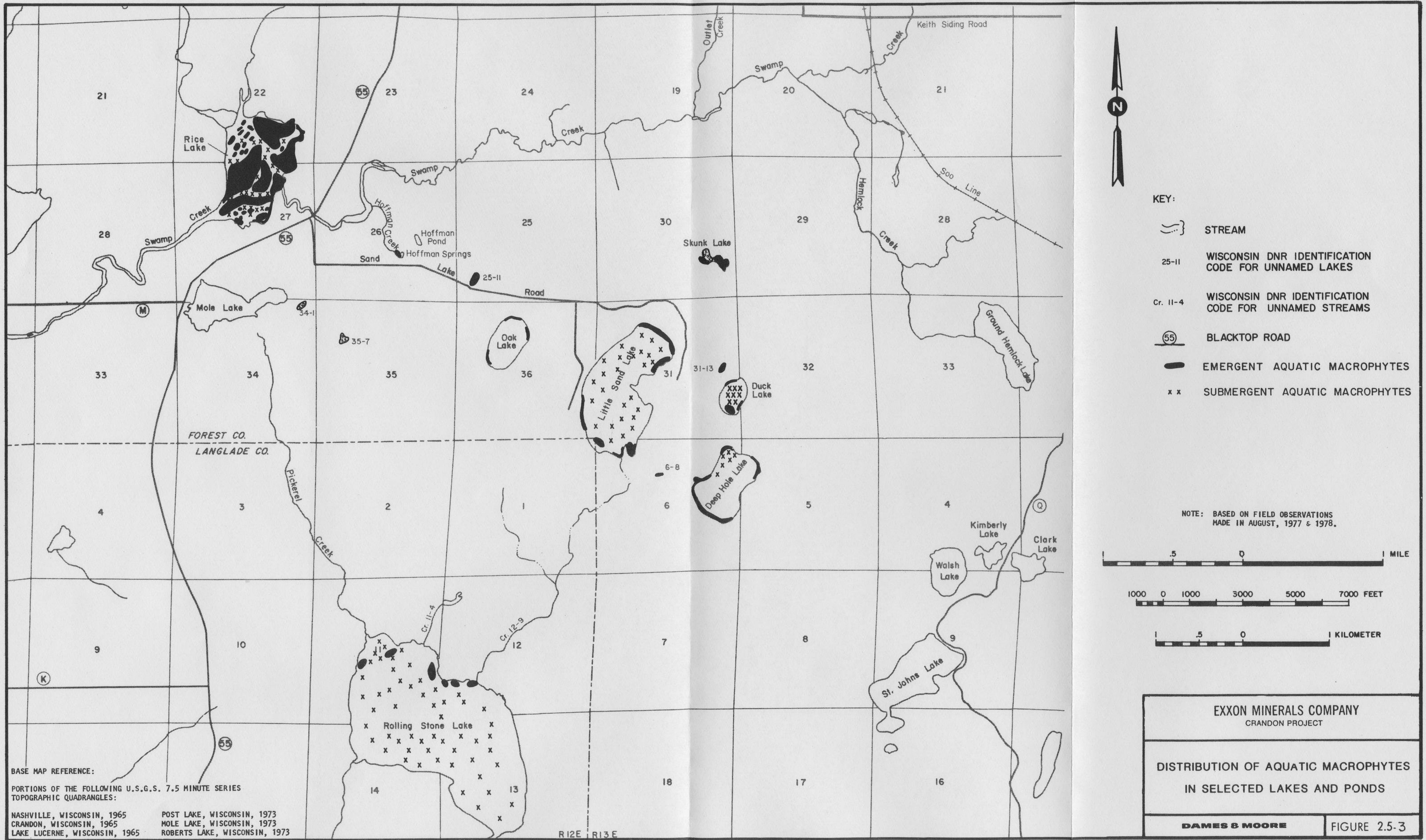
Aquatic Macrophytes

Rice Lake - The aquatic macrophyte community of Rice Lake was dense and consisted mainly of emergent species with some submersed and floating species (Figure 2.5-3).

Most of the emergent vegetation in the central portion of the lake was wild rice (*Zizania aquatica*) interspersed with sparse beds of yellow water lily (*Nuphar variegatum*) and arrowhead (*Sagittaria latifolia*). Moderate to dense beds of water marigold (*Megalodonta beckii*), flatstem pondweed (*Potamogeton zosteriformis*), and pondweed (*P. friesii*) were also observed.

The channel area where Swamp Creek meanders through Rice Lake was characterized by dense submerged vegetation, primarily coontail (*Ceratophyllum demersum*) and water weed (*Elodea canadensis*), with moderate occurrences of the previously listed emergent species.

The Swamp Creek inlet area of Rice Lake was characterized by a dense emergent growth of bulrush (*Scirpus fluviatilis*) and bur reed (*Sparganium eurycarpum*). The vegetation in the shallow area adjacent to the south shore of the lake was composed of sparse to moderate beds of arrowhead, yellow water lily, water weed, and water lily (*Nymphaea tuberosa*).



EXXON MINERALS COMPANY
CRANDON PROJECT

DISTRIBUTION OF AQUATIC MACROPHYTES IN SELECTED LAKES AND PONDS

DAMES & MOORE

FIGURE 2.5-3

Floating vegetation, observed throughout the lake, consisted primarily of big duckweed (Spirodela polyrhiza) and star duckweed (Lemna trisulca). The common emergent shoreline vegetation included moderate stands of cattail (Typha latifolia), sedge (Scirpus validus), and water hemlock (Cicuta bulbifera).

Benthic Macroinvertebrates

Rice Lake - Benthic macroinvertebrate samples were collected from Rice Lake at Stations F and N in March, May, August, and October 1977 and March 1978, and from Station N in May and August 1978. The eight major taxa collected in quantitative sampling and their relative abundance are presented in Table 2.5-12. The density and relative abundance of individual taxa collected in each quantitative sampling are presented in Appendix 2.5D, Tables D-33 through D-58. A total of 103 and 114 taxa were identified during quantitative sampling conducted at Stations F and N, respectively, and an additional 8 taxa were collected in qualitative samples from Rice Lake. These data are presented in Appendix 2.5D, Table D-73.

In 1977 considerably greater fluctuations in density of benthic macroinvertebrates occurred at Station N than at Station F. At Station F density ranged from 16,691/m^2 in August to 32,911/m^2 in October, and at Station N from 6,146/m^2 in March to 57,987/m^2 in August. In 1978 at Station N densities in March, May, and August differed up to seven fold (March) from corresponding months in 1977 but were within the range observed throughout 1977.

TABLE 2.5-12

MEAN DENSITY[a] (no./m^2), RELATIVE ABUNDANCE (%), AND DIVERSITY[b]
OF BENTHIC MACROINVERTEBRATES COLLECTED FROM RICE LAKE, STATIONS F AND N
MARCH, MAY, AUGUST, AND OCTOBER 1977 AND MARCH, MAY, AND AUGUST 1978

	1977								1978					
	MARCH		MAY		AUGUST		OCTOBER		MARCH		MAY		AUGUST	
	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%
Oligochaeta														
F	1,905	9	3,267	16	5,034	30	10,146	31	3,477	15	--[c]	--	--	--
N	60	1	1,052	4	11,947	21	1,060	6	603	1	144	1	1,250	12
Isopoda														
F	0	0	0	0	0	0	0	0	29	<1	--	--	--	--
N	9	<1	0	0	0	0	0	0	0	0	0	0	29	<1
Amphipoda														
F	9,051	44	3,534	17	4,681	28	2,724	8	3,276	14	--	--	--	--
N	2,095	34	3,026	11	11,534	20	4,431	27	8,347	18	3,189	18	3,592	33
Ephemeroptera														
F	43	<1	34	<1	172	1	17	<1	29	<1	--	--	--	--
N	60	1	17	<1	78	<1	60	<1	0	0	0	0	0	0
Trichoptera														
F	69	<1	69	<1	9	<1	34	<1	72	<1	--	--	--	--
N	60	1	328	1	60	<1	43	<1	58	<1	101	1	115	1
Chironomidae														
F	5,413	26	6,603	32	1,965	12	7,439	23	6,882	30	--	--	--	--
N	2,465	40	17,024	62	23,162	40	3,569	22	9,108	20	3,132	17	2,399	22
Gastropoda														
F	3,017	15	2,957	14	2,345	14	8,008	24	7,614	33	--	--	--	--
N	595	10	3,526	13	3,198	6	4,888	30	25,041	54	9,051	50	1,911	18
Pelecypoda														
F	379	2	3,120	15	948	6	1,940	6	216	1	--	--	--	--
N	491	8	129	<1	52	<1	466	3	474	1	330	2	431	4
All Others[d]														
F	552	3	1,328	6	1,465	9	2,604	8	1,250	5	--	--	--	--
N	310	5	2,146	7	7,956	14	2,008	12	3,002	6	2,212	12	1,006	9
Total														
F	20,429	100	20,912	100	16,691	100	32,911	100	22,843	100	--	--	--	--
N	6,146	100	27,248	100	57,987	100	16,524	100	46,635	100	18,160	100	10,732	100
Number of Replicates	5		5		5		5		3		3		3	
Diversity														
F	0.9		1.3		1.1		1.1		1.0		--		--	
N	0.8		1.3		1.1		1.0		1.1		0.9		1.0	

[a]Density is the mean of three or five replicate samples, as indicated above, rounded to the nearest whole number.

[b]Calculated using Brillouin's formula ($\log_{10}$) using the numbers of organisms presented in Appendix 2.5D, Tables D-27 through D-33.

[c]No sample collected.

[d]Includes Hydracarina, Coelenterata, Tricladida, Lepidoptera, Coleoptera, Alloeocoela, Hirudinea, Ostracoda, Odonata, Hemiptera, Nematoda, and Diptera other than Chironomidae.

The four most commonly collected groups at Rice Lake were Chironomidae (midges), Amphipoda (amphipods), Oligochaeta (worms), and Gastropoda (snails) (Table 2.5-12).

The common midges at both sampling locations were Dicrotendipes sp., Chironomus sp., Procladius sp., and Tanytarsus sp.

The amphipod most commonly found in the benthic samples from the two Rice Lake sampling locations was Hyalella azteca; other amphipods identified were Cragonyx sp. and Gammarus pseudolimnaeus.

Enumerations of worms from the two Rice Lake sampling locations indicated that naidid species, Nais sp. and Dero digitata, were most abundant, although immature tubificid forms were occasionally collected in moderate to high densities. Amnicola sp. was the most numerous snail collected.

Mean benthic diversity values were similar for these two sampling locations and ranged from 0.8 at Station N in March 1977 to 1.3 at both Stations N and F in May 1977 (Table 2.5-12).

Hemlock Creek - Macroinvertebrate samples were collected from Hemlock Creek at Station A-1 in June, August, and October 1977 and March, May, and August 1978. The nine major taxa collected in quantitative sampling and their density and relative abundance are presented in Table 2.5-13. The density and relative abundance of taxa from individual collections are presented in Appendix 2.5D, Tables D-48 through D-53. The 87 benthic macroinvertebrate taxa identified from quantitative samples and an additional 25 taxa identified from qualitative samples from Hemlock Creek (Station A-1) are presented in Appendix 2.5D, Table D-78.

TABLE 2.5-13

MEAN DENSITY[a] (no./m^2), RELATIVE ABUNDANCE (%), AND DIVERSITY[b] OF BENTHIC MACROINVERTEBRATES COLLECTED FROM HEMLOCK CREEK - STATION A-1 JUNE, AUGUST, AND OCTOBER 1977 AND MARCH, MAY, AND AUGUST 1978

	1977						1978					
	JUNE		AUGUST		OCTOBER		MARCH		MAY		AUGUST	
	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%
Oligochaeta	216	10	724	3	974	4	101	1	445	2	761	4
Isopoda	0	0	0	0	0	0	0	0	14	<1	0	0
Amphipoda	17	1	0	0	34	<1	29	<1	43	<1	115	1
Ephemeroptera	0	0	95	<1	3,414	14	216	2	302	1	3,060	16
Trichoptera	9	<1	0	0	60	<1	58	<1	101	<1	618	3
Chironomidae	1,172	57	18,300	85	13,326	56	11,809	83	26,205	92	12,140	65
Gastropoda	60	3	0	0	2,612	11	747	5	201	1	58	<1
Pelecypoda	284	14	86	<1	1,155	5	690	5	359	1	230	1
All Others[c]	310	15	2,440	11	2,302	10	517	4	718	3	1,710	9
Total	2,069	100	21,645	100	23,877	100	14,166	100	28,388	100	18,691	100
Number of Replicates	5		5		5		3		3		3	
Diversity	0.6		0.7		1.0		0.9		0.6		1.0	

[a]Density is the mean of three or five replicate samples rounded to the nearest whole number.

[b]Calculated using Brillouin's formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5D, Table D-48 through D-53.

[c]Includes Nematoda, Hirudinea, Ostracoda, Hydracarina, Anisoptera, Hemiptera, Megaloptera, Lepidoptera, Coleoptera, and Diptera other than Chironomidae.

In 1977 total density of benthic forms ranged from 2,069/m^2 in June to 23,877/m^2 in October. In 1978 density ranged from 14,166/m^2 in March to 28,388/m^2 in May. The community was dominated by midges, which comprised from 57 to 92 percent of the numbers collected. Tanytarsus sp. and Procladius sp. were the most abundant genera.

Benthic organisms from other major taxonomic groups, mayflies and worms, were commonly collected but comprised not more than 16 percent of any sample. Members of the genus Caenis were the most abundant mayfly, and the immature tubificid form with hair setae was the most abundant worm enumerated during the study.

Pelecypods (clams) enumerated from Hemlock Creek were typically from the family Sphaeriidae, although one specimen from the family Unionidae was recorded. The mature sphaeriids enumerated were Pisidium sp. and Sphaerium sp.

The benthic diversity values at Hemlock Creek were relatively consistent. They ranged from 0.6 in June 1977 and May 1978 to 1.0 in October 1977 and August 1978 and averaged 0.8 (Table 2.5-13).

Taxa collected by the DNR during verification studies are presented in Appendix 2.5D, Table D-87. The sample was obtained with a kick net during October 1979 near Station A-1 (Ramharter, 1982a).

Swamp Creek - Benthic macroinvertebrate samples were collected from Swamp Creek at Stations D and E in March, May, August, and October 1977 and March, May, and August 1978. The eight major taxa collected in quantitative sampling and their density and relative abundance are presented in Table 2.5-14. The density and relative abundance of taxa collected in individual

TABLE 2.5-14

MEAN DENSITY[a] (no./m^2), RELATIVE ABUNDANCE (%), AND DIVERSITY[b]
OF BENTHIC MACROINVERTEBRATES COLLECTED FROM SWAMP CREEK - STATIONS D AND E
MARCH, MAY, AUGUST, AND OCTOBER 1977 AND MARCH, MAY, AND AUGUST 1978

	1977								1978					
	MARCH		MAY		AUGUST		OCTOBER		MARCH		MAY		AUGUST	
	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%
Oligochaeta														
D	0	0	3	<1	9	2	11	<1	4	<1	0	0	18	1
E	1,207	13	2,474	20	716	10	1,146	12	273	6	216	3	819	7
Amphipoda														
D	0	0	0	0	0	0	0	0	0	0	4	1	0	0
E	1,319	15	698	6	34	<1	138	1	115	2	86	1	345	3
Ephemeroptera														
D	93	8	100	8	179	5	231	6	166	14	68	11	32	2
E	172	2	233	2	716	10	2,000	21	704	14	1,853	22	488	4
Trichoptera														
D	404	34	575	44	460	12	1,363	35	148	12	65	11	274	14
E	78	1	43	<1	17	<1	9	<1	0	0	0	0	158	1
Chironomidae														
D	378	32	189	14	1,955	52	1,151	30	551	46	180	29	540	28
E	3,776	42	5,586	44	2,655	37	2,569	26	1,379	28	2,715	32	3,663	30
Gastropoda														
D	76	6	86	7	166	4	408	11	79	7	32	5	194	10
E	750	8	1,836	15	612	9	560	6	359	7	1,537	18	230	2
Pelecypoda														
D	11	1	35	3	302	8	175	5	25	2	112	18	392	20
E	1,310	14	974	8	1,336	19	1,776	18	1,825	38	1,552	18	2,572	21
All Others[c]														
D	222	18	319	24	687	18	525	14	234	20	151	25	475	25
E	439	5	793	6	1,103	15	1,526	16	201	4	489	6	4,023	33
Total														
D	1,173		1,307		3,758		3,864		1,206		612		1,926	
E	9,051		12,637		7,189		9,723		4,856		8,448		12,298	
Number of Replicates	5		5		5		5		3		3		3	
Diversity														
D	1.0		1.1		1.1		1.1		0.9		1.0		1.0	
E	1.2		1.2		1.0		0.9		0.8		1.0		1.0	

[a]Density is the mean of three or five replicate samples, as indicated above, rounded to the nearest whole number.

[b]Calculated using Brillouin's formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5D, Tables D-58 through D-64.

[c]Includes Plecoptera, Megaloptera, Coelenterata, Alloeocoela, Hirudinea, Anisoptera, Tricladida, Nematoda, Ostracoda, Zygoptera, Coleoptera, Hydracarina, Hemiptera, and Diptera other than Chironomidae.

quantitative sampling are presented in Appendix 2.5D, Tables D-58 through D-64. A total of 126 and 106 taxa were identified in quantitative samples and an additional 9 and 16 taxa were identified in qualitative samples from Stations D and E, respectively. These data are presented in Appendix 2.5D, Table D-80.

Density was consistently higher at Station E than at Station D. In 1977 density at Station D ranged from 1,173/m^2 in March to 3,864/m^2 in October and at Station E from 7,189/m^2 in August to 9,723/m^2 in October. In 1978 density at Station D ranged from 612/m^2 in May to 1,926/m^2 in August and at Station E from 4,856/m^2 in March to 12,298/m^2 in August.

Although midges were the most abundant organisms in the benthic communities at both stations, more were consistently collected at Station E than Station D. Micropsectra sp. and Rheotanytarsus sp. were the most abundant genera at Station D, whereas Procladius sp., Tanytarsus sp., and Cladotanytarsus sp. were most abundant at Station E.

Caddisflies comprised from 11 to 44 percent of the total benthos enumerated at Station D during the study, but were $\leq$1 percent at Station E. Twenty-three caddisfly genera were identified in quantitative samples from Station D, whereas only 7 genera were identified from Station E. Caddisflies from only two of these genera were identified from both locations. For Station D, the most common and abundant caddisflies were generally Leucotrichia pictipes, Glossosoma sp., and various Hydropsyche species. At Station E, the most common caddisflies were Platycentropus sp. and Phylocentropus sp.

Mayflies also comprised similar percentages of the total benthos at the two sampling locations, from 2 to 14 percent at Station D and from 2 to 22 percent at Station E. However, the numbers of organisms and the individual genera of mayflies occurring at the two locations were generally quite different. Density of mayflies ranged from 32 to $231/m^2$ at Station D and from 172 to $2,000/m^2$ at Station E. Only 4 of the 13 total genera identified in quantitative samples occurred at both sampling locations. At Station D mayflies from the genera *Ephemerella* sp., *Baetis* sp., *Paraleptophlebia* sp., and *Stenonema* sp. were common. The most abundant mayflies at Station E were from the genera *Hexagenia* sp. and *Caenis* sp., although *Baetis* sp. and *Ephemerella* sp. also occurred at this station.

At Station D, worms typically occurred in densities of less than $20/m^2$ and typically comprised less than 1 percent of the benthos enumerated during each sample period. However, at Station E, worms ranged from 216 to $2,474/m^2$ in mean densities and comprised from 3 to 20 percent of the benthic macroinvertebrate community (Table 2.5-14).

Snails comprised from 4 to 11 percent of the benthos at Station D and from 2 to 18 percent at Station E. The major snail at Station D was the freshwater limpet, *Ferrissia* sp., which comprised most of the gastropods identified. At Station E, the snail *Amnicola* sp. comprised most of the snails identified.

Clams comprised from 1 to 20 percent of the benthos identified at Station D and from 8 to 38 percent at Station E. The clams identified from both sampling locations were exclusively from the family Sphaeriidae; mature specimens were identified to the genera *Sphaerium* and *Pisidium*.

Plecopterans (stoneflies) were collected in low numbers ($<80/m^2$) in all months at Station D and were found at Station E in March 1977 only.

Although differences were observed in the species composition of the benthic communities at Stations D and E, diversity values were similar. Values at Station D ranged from 0.9 in March 1978 to 1.1 in May, August, and October 1977. At Station E, values ranged from 0.8 in March 1978 to 1.2 in March and May 1977. Mean diversity at both stations was 1.0.

Information on the composition and density of benthic macroinvertebrates in Swamp Creek downstream from County Trunk Highway M is presented in Ecological Analysts, Inc. (1983, 1984a). These results are from qualitative and quantitative sampling of macroinvertebrate communities during 1982 and 1983 in the vicinity of the proposed water discharge site.

Taxa collected by the DNR during verification sampling are presented in Appendix 2.5D, Table D-88. The sample was obtained with a kick net during October 1979 downstream of Route 55, approximately 1.1 km (0.7 miles) downstream of Station E (Ramharter, 1982a).

Fish

Rice Lake - Fish were collected from Rice Lake during May, August, and October 1977 and May and August 1978. Numbers and relative abundance of the species collected are presented in Table 2.5-15. The length-weight data for the 15 species collected are summarized in Appendix 2.5E, Tables E-9 and E-10.

Fish samples in Rice Lake were numerically dominated by black bullhead. This species was collected in all sampling periods, and it comprised from 7 to 96 percent of the fyke net catches and from 12 to 86 percent of the electrofishing samples. Other common species in the collections included pumpkinseed and white sucker. Pumpkinseed comprised up

TABLE 2.5-15

NUMBERS AND RELATIVE ABUNDANCE (PERCENT OF TOTAL CATCH) OF FISH COLLECTED
BY FYKE NET (FN), GILL NET (GN), AND ELECTROSHOCKING (ES)
RICE LAKE
MAY, AUGUST, OCTOBER 1977 AND MAY, AUGUST 1978

	1977												1978									
	MAY				AUGUST				OCTOBER				MAY						AUGUST			
	FN		ES		FN		ES		FN		ES		FN		GN		ES		FN		ES	
FISH	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Catostomidae																						
White sucker	1	1	6	25	0	0	1	3	0	0	4	9	2	2	6	40	1	1	5	3	0	0
Shorthead redhorse	0	0	2	8	0	0	0	0	0	0	0	0	1	1	1	7	0	0	0	0	0	0
Centrarchidae																						
Bluegill	0	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	1	1	0	0	0	0
Rock bass	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Pumpkinseed	0	0	6	25	52	88	3	10	0	0	3	7	1	1	0	0	3	4	0	0	1	14
Cyprinidae																						
Golden shiner	0	0	0	0	0	0	0	0	0	0	5	11	0	0	0	0	0	0	0	0	0	0
Common shiner	0	0	0	0	1	2	0	0	2	7	0	0	0	0	0	0	6	9	0	0	0	0
Blackchin shiner	0	0	0	0	0	0	1	3	0	0	2	4	0	0	0	0	0	0	0	0	0	0
Blacknose shiner	0	0	0	0	0	0	7	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Esocidae																						
Northern pike	2	2	0	0	0	0	0	0	2	7	0	0	1	1	4	27	0	0	1	<1	0	0
Ictaluridae																						
Black bullhead	92	96	3	12	4	7	15	52	16	57	28	62	104	95	4	27	58	84	177	95	6	86
Yellow bullhead	1	1	0	0	2	3	0	0	7	25	0	0	0	0	0	0	0	0	4	2	0	0
Percidae																						
Yellow perch	0	0	7	29	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0
Salmonidae																						
Brook trout	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0
Umbridae																						
Mudminnow	0	0	0	0	0	0	2	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	96		24		59		29		28		45		110		15		69		187		7	

to 88 percent of fyke net and from 4 to 25 percent of the electrofishing samples. No fish were caught in minnow traps set in May and August 1978.

Hemlock Creek - Fish were collected from Stations A-1 and A-2 in Hemlock Creek in May, August, and October 1977 and from Station A-1 during May and August 1978. Numbers and relative abundance of the species collected are presented in Table 2.5-16. The length-weight data for the 24 species collected are summarized in Appendix 2.5E, Tables E-17 and E-18.

Most fish collected at both stations were representatives of the family Cyprinidae (minnows). Common shiner and northern redbelly dace, collected in all sampling periods, were the most common species. In 1977 common shiner comprised from 12 to 36 percent of the samples at Station A-1 and from 3 to 29 percent of the samples at Station A-2. In 1978 common shiner and northern redbelly dace comprised 14 to 56 percent and 10 to 25 percent of the respective samples at A-1. Other common minnow species included creek chub and fathead minnow.

Except for small sunfish (Centrarchidae) and yellow perch, species generally sought by anglers that occurred in the collections included brook trout and white sucker. In addition, longnose dace and northern pike were collected by the DNR in verification studies (Ramharter, 1982a).

Hoffman Creek - Fish were collected from Hoffman Creek during June, August, and October 1977. Numbers and relative abundance of the species collected are presented in Table 2.5-17. The length-weight data of the nine species collected are summarized in Appendix 2.5E, Table E-19.

Brook trout and mottled sculpin were the numerically dominant fish species collected. Both species were captured in all sampling periods. Brook

TABLE 2.5-16

NUMBERS AND RELATIVE ABUNDANCE (PERCENT OF TOTAL CATCH) OF FISH COLLECTED BY ELECTROSHOCKING
HEMLOCK CREEK - STATIONS A-1 AND A-2
MAY, AUGUST, OCTOBER 1977 AND MAY, AUGUST 1978

	1977												1978			
	MAY				AUGUST				OCTOBER				MAY		AUGUST	
	A-1		A-2		A-1		A-2		A-1		A-2		A-1		A-1	
FISH	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Catostomidae																
White sucker	3	3	3	2	9	3	12	2	8	3	0	0	2	1	28	13
Centrarchidae																
Rock bass	0	0	0	0	1	<1	0	0	0	0	0	0	0	0	0	0
Pumpkinseed	0	0	0	0	3	1	0	0	1	<1	0	0	0	0	1	<1
Bluegill	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0
Cottidae																
Mottled sculpin	7	7	1	<1	0	0	1	<1	6	2	0	0	3	2	1	<1
Cyprinidae																
Brassy minnow	0	0	0	0	0	0	0	0	15	6	0	0	4	3	36	17
Hornyhead chub	1	1	0	0	0	0	0	0	0	0	0	0	1	<1	1	<1
Golden shiner	0	0	0	0	0	0	0	0	8	3	1	1	0	0	0	0
Common shiner	12	12	4	3	79	28	76	14	97	36	26	29	78	56	30	14
Blackchin shiner	0	0	0	0	0	0	0	0	1	<1	0	0	0	0	0	0
Blacknose shiner	0	0	2	1	18	6	1	<1	1	<1	1	1	2	1	0	0
Northern redbelly dace	11	11	53	34	54	19	299	54	6	2	30	33	14	10	54	25
Fathead minnow	4	4	17	11	11	4	6	1	69	26	0	0	1	<1	5	2
Bluntnose minnow	0	0	2	1	0	0	2	<1	2	1	1	1	1	<1	1	<1
Blacknose dace	7	7	0	0	24	9	0	0	6	2	0	0	3	2	9	4
Creek chub	16	16	5	3	18	6	12	2	27	10	5	6	15	11	26	12
Pearl dace	1	1	0	0	34	12	5	<1	4	2	0	0	0	0	10	5
Cyprinidae (unid. sp.)	4	4	2	1	14	5	87	16	0	0	0	0	0	0	0	0
Gasterosteidae																
Brook stickleback	22	23	51	32	0	0	12	2	1	<1	11	12	8	6	8	4
Ictaluridae																
Black bullhead	0	0	3	2	0	0	15	3	1	<1	2	2	0	0	2	<1
Percidae																
Johnny darter	3	3	11	7	1	<1	6	1	4	2	5	6	5	4	0	0
Yellow perch	5	5	0	0	9	3	1	<1	2	<1	4	4	0	0	1	<1
Salmonidae																
Brook trout	0	0	0	0	0	0	0	0	7	3	0	0	3	2	0	0
Umbridae																
Mudminnow	1	1	4	3	0	0	21	4	0	0	4	4	0	0	0	0
Total	97		158		279		558		266		90		140		213	

TABLE 2.5-17

NUMBERS AND RELATIVE ABUNDANCE (PERCENT OF TOTAL CATCH)
OF FISH COLLECTED BY ELECTROSHOCKING
HOFFMAN CREEK - STATION E-1
JUNE, AUGUST, OCTOBER 1977

FISH	1977 JUNE no.	%	AUGUST no.	%	OCTOBER no.	%
Catostomidae						
White sucker	0	0	1	3	5	18
Centrarchidae						
Bluegill	0	0	0	0	1	4
Cottidae						
Mottled sculpin	23	34	6	19	3	11
Cyprinidae						
Common shiner	0	0	0	0	1	4
Blacknose dace	4	6	11	34	0	0
Creek chub	-	0	1	3	2	7
Esocidae						
Northern pike	2	3	0	0	0	0
Salmonidae						
Brook trout	39	57	12	38	16	57
Umbridae						
Mudminnow	0	0	1	3	0	0
Total	68		32		28	

trout constituted from 38 to 57 percent of numbers of fish collected, and mottled sculpin comprised from 11 to 34 percent of the catches.

Swamp Creek - Fish were collected from Stations B and D during May, August, and October 1977 and at Station D during May and August 1978. Numbers and relative abundance of the species collected are presented in Table 2.5-18. The length-weight data for the 22 species collected at Stations B and D are summarized in Appendix 2.5E, Tables E-22 and E-23.

Minnow species generally numerically dominated the catches at both Stations B and D. Common shiner and creek chub were the most common species and were collected during each sampling period. In 1977 the common shiner comprised from 27 to 66 percent of the samples at Station B and from 4 to 21 percent of the samples at Station D. Creek chub comprised from 6 to 11 percent of the samples at Station B and from 1 to 9 percent at Station D. In 1978 common shiner comprised 23 and 5 percent of the samples and creek chub 5 and 14 percent of the samples at Station D. Blacknose dace and longnose dace were also abundant minnows at Station D but few were caught at Station B.

White sucker was another commonly collected species. It occurred in all collections, in 1977 and comprised from 14 to 17 percent of the collections at Station B and from 1 to 37 percent at Station D.

Black bullhead was the most abundant species at Station B in August 1977 but were uncommon during other sampling periods. Additional species collected by the DNR in verification sampling were shorthead redhorse, Iowa darter, bluegill, and rockbass (Ramharter, 1982a).

Information on species composition and relative abundance of fish in Swamp Creek downstream of County Trunk Highway M is presented in Ecological

TABLE 2.5-18

NUMBERS AND RELATIVE ABUNDANCE (PERCENT OF TOTAL CATCH) OF FISH COLLECTED BY ELECTROSHOCKING
SWAMP CREEK - STATIONS B AND D
MAY, AUGUST, OCTOBER 1977 AND MAY, AUGUST 1978

	1977												1978			
	MAY				AUGUST				OCTOBER				MAY		AUGUST	
	B		D		B		D		B		D		D		D	
FISH	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Catostomidae																
White sucker	29	17	117	37	35	17	9	5	21	14	12	5	31	10	2	1
Centrarchidae																
Pumpkinseed	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0
Largemouth bass	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Cottidae																
Mottled sculpin	41	24	4	1	1	<1	13	7	5	3	9	4	0	0	7	4
Cyprinidae																
Brassy minnow	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0	0
Hornyhead chub	3	2	1	<1	7	3	2	1	9	6	24	11	9	3	0	0
Golden shiner	1	<1	0	0	0	0	0	0	0	0	0	0	0	0	2	1
Common shiner	46	27	68	21	60	28	8	4	102	66	20	9	75	23	8	5
Northern redbelly dace	0	0	2	<1	0	0	0	0	0	0	3	1	0	0	0	0
Fathead minnow	1	<1	2	<1	0	0	0	0	0	0	0	0	0	0	0	0
Bluntnose minnow	0	0	1	<1	0	0	2	1	0	0	0	0	0	0	0	0
Blacknose dace	3	2	30	9	0	0	33	18	1	<1	30	13	42	13	50	29
Longnose dace	0	0	41	13	0	0	98	52	0	0	112	50	72	22	68	40
Creek chub	18	11	11	3	3	1	16	9	9	6	3	1	16	5	24	14
Pearl dace	0	0	1	<1	0	0	0	0	0	0	0	0	1	<1	0	0
Cyprinidae (unid. sp.)	2	1	1	<1	0	0	3	2	0	0	0	0	0	0	0	0
Gasterosteidae																
Brook stickleback	8	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ictaluridae																
Black bullhead	1	<1	0	0	80	38	0	0	1	<1	0	0	0	0	0	0
Yellow bullhead	0	0	0	0	0	0	0	0	0	0	1	<1	0	0	0	0
Percidae																
Johnny darter	13	8	0	0	4	2	0	0	2	1	1	<1	1	<1	7	4
Yellow perch	2	1	0	0	1	<1	0	0	1	<1	1	<1	0	0	0	0
Salmonidae																
Brook trout	1	<1	39	12	0	0	0	0	0	0	10	5	78	24	4	2
Umbridae																
Mudminnow	0	0	0	0	16	8	4	2	0	0	0	0	0	0	0	0
Total	169		318		211		188		154		226		325		172	

Analysts, Inc. (1983, 1984a). These results are from field sampling of fish populations in the vicinity of the proposed water discharge site during 1982 and 1983.

The results of chemical analyses of muscle tissue from fish collected in Swamp Creek downstream from County Trunk Highway M are presented in Ecological Analysts, Inc. (1984b). Metal concentrations in 4 northern pike, 6 rock bass, and 5 white suckers collected in the vicinity of the proposed water discharge site are presented in this 1984 report.

Fish Parasites

The occurrence of external parasites was periodically observed on various fish species. Blackspot (the metacercaria of larval flatworms known as strigeids) was the most commonly observed parasite. Frequently, heavy infestations of blackspot were found on yellow perch, brassy minnow, common shiner, fathead minnow, blacknose dace, and northern creek chub from Station A-1 on Hemlock Creek. Lesser levels of parasitism were observed on blacknose dace from Hoffman Creek, and longnose dace and mudminnow from Swamp Creek.

Other parasites or deformities observed on fish included the copepod *Salmincola edwardsii* (gill lice) on brook trout from Hoffman Creek, and deformed or abbreviated opercula on brook trout from Swamp Creek were observed.

Brook Trout Redd Survey

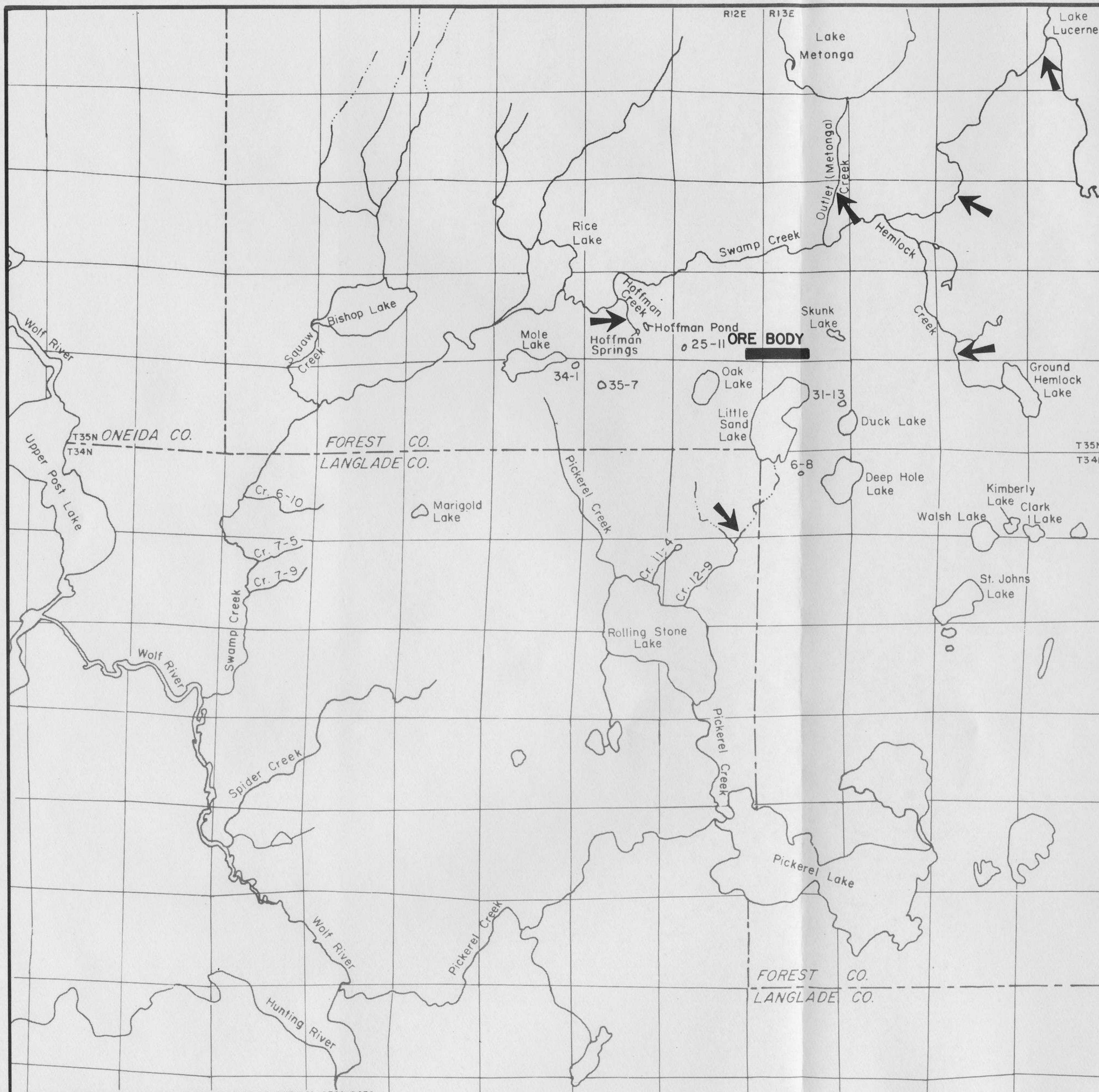
In the autumn, brook trout dig redds (nests) in gravel beds of headwater streams, with areas of ground water flow particularly favored (Benson, 1953; Latta, 1965; Webster and Eiriksdottir, 1976). Because brook trout support a popular and intensive sport fishery in Wisconsin (Brasch et al., 1973), areas important to spawning brook trout were sought in October and November 1977 in Swamp Creek and its tributaries upstream of Rice Lake. Five potential spawning areas were observed, and their locations are depicted on Figure 2.5-4.

A relatively large potential spawning area was observed in Hoffman Creek approximately 210 m (689 feet) upstream of Station E-1 and extended for approximately 50 m (164 feet). This portion of the creek was characterized as having a sand and gravel bottom and observations of seeps and springs suggested a ground water discharge. The area generally consisted of riffles, but small pools formed by instream obstructions such as fallen branches were also found. Aquatic vegetation was composed of *Nasturtium officinale* (watercress), which occurred in moderately sized clumps.

Brook trout typically disperse to downstream areas their first summer of life (Hunt, 1965). The collection of trout less than 50 mm (2 inches) at Station E-1 in June 1977 (Appendix 2.5E, Table E-40) indicates that spawning probably occurred in Hoffman Creek in autumn 1976.

Four other areas bearing qualities similar to those observed in Hoffman Creek were observed in the Swamp Creek drainage basin (Figure 2.5-4). However, these potential spawning areas were small, less than approximately 5 m (10 feet), and isolated by reaches, characterized by soft, silty, muck bottom, that are typically not suitable as trout spawning habitat.

The generally low reproductive potential of brook trout in Swamp Creek is supplemented by the DNR's stocking of 1,000 legal sized 152-mm (6-inch) trout in spring in Swamp Creek at the Keith Siding Road bridge (Theis, 1978).



KEY:

STREAM

25-11 WISCONSIN DNR IDENTIFICATION CODE FOR UNNAMED LAKES

Cr. 11-4 WISCONSIN DNR IDENTIFICATION CODE FOR UNNAMED STREAMS

LOCATION OF POTENTIAL BROOK TROUT SPAWNING AREAS

1 .5 0 1 MILE

1 .5 0 1 KILOMETER

BASE MAP REFERENCE: WISCONSIN DEPARTMENT OF NATURAL RESOURCES, 1972.

EXXON MINERALS COMPANY
CRANDON PROJECT

POTENTIAL BROOK TROUT SPAWNING AREAS

DAMES & MOORE

FIGURE 2.5-4

2.5.2.2 Seepage Lakes

Oak Lake

Oak Lake is located 0.6 km (0.9 mile) from the ore body and has a total area of 20.6 ha (51 acres) and a maximum depth of 14.3 m (47 feet). The shoreline vegetation is predominantly Dry-mesic Northern Hardwoods Forest with the remainder composed of bog, meadow, and shrub wetlands. The littoral substrates were comprised of sand, muck, and gravel, and in the deep central portion of the lake, the substrate was silt and detritus (Table 2.5-8). Station G was located at a depth of approximately 9 m (29.5 feet). The shoreline is undeveloped and no residential structures exist along the lakeshore. Phytoplankton, zooplankton, periphytic algae, aquatic macrophytes, benthic macroinvertebrates, and fish were collected from Oak Lake.

Phytoplankton - Phytoplankton were collected from Oak Lake in March 1977, monthly from May through October 1977 and in March, May, and August 1978. Density and relative abundance of the seven major taxa identified and enumerated are presented in Table 2.5-19. The density and relative abundance of individual taxa from each collection are presented in Appendix 2.5A, Tables A-27 through A-36. The 78 taxa identified are presented in Appendix 2.5A, Table A-59.

In 1977 total phytoplankton density was lowest in March, 493 units/ml, ranged from 828 units/ml to 1,516 units/ml in May, June, July, and October and peaked in August (13,464 units/ml) and September (9,817 units/ml). In 1978, lowest density was again observed in March (339 units/ml). The density in May (2,548 units/ml) was higher than the previous May, and density

TABLE 2.5-19

MEAN DENSITY[a] (units/ml), RELATIVE ABUNDANCE (%), AND DIVERSITY[b]
OF PHYTOPLANKTON COLLECTED AT OAK LAKE - STATION G
MARCH 1977, MAY THROUGH OCTOBER 1977, AND MARCH, MAY, AND AUGUST 1978

	1977														1978					
	MARCH		MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER		MARCH		MAY		AUGUST	
	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%
Bacillariophyceae	51	10	100	12	47	4	12	1	1,164	9	251	3	125	8	53	15	90	11	21	1
Chlorophyceae	42	8	182	22	221	17	279	23	3,723	28	2,181	22	486	32	10	3	0	0	112	3
Chrysophyceae	400	81	487	59	245	19	426	35	7,064	52	6,575	67	856	56	277	82	761	30	1,356	40
Cyanophyceae	0	0	58	7	767	60	500	41	1,380	10	154	2	44	3	0	0	1,476	58	1,918	56
Dinophyceae	0	0	1	<1	1	<1	4	<1	83	1	0	0	5	<1	0	0	0	0	0	0
Euglenophyceae	0	0	0	0	0	0	1	<1	17	<1	654	7	0	0	0	0	21	1	13	<1
Xanthophyceae	0	0	0	0	0	0	0	0	33	<1	1	<1	0	0	0	0	0	0	0	0
Total	493	100	828	100	1,281	100	1,222	100	13,464	100	9,817	100	1,516	100	339	100	2,548	100	3,420	100
Diversity	0.3		0.7		0.7		0.8		0.8		0.6		0.9		0.4		0.7		0.5	

[a]Density is the mean of two replicate samples rounded to the nearest whole number.

[b]Calculated by Shannon-Weaver formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5A, Tables A-27 through A-36.

in August (3,420 units/ml) did not reach the high level observed the previous year.

In 1977 golden-brown algae predominated in March, May, August, and September. Blue-green algae predominated in June and July. In 1978 golden-brown algae predominated in March whereas blue-green algae were most abundant in May and August.

Unidentified Chrysococcus-like algae generally were the common golden-brown algae but Diachros sp. predominated in March 1977. Chroococcus dispersus var. minor was the dominant blue-green alga in June and July 1977, Aphanotheca clathrata predominated in May 1978 and Chroococcus minimus in August 1978.

The average phytoplankton diversity, calculated from the data presented in Table 2.5-19, was 0.6 for Oak Lake. Minimum diversities of 0.3 and 0.4 occurred in March 1977 and March 1978, respectively, whereas a maximum diversity of 0.9 occurred in October 1977.

The mean chlorophyll a concentration recorded from Oak Lake was less than 16 μg/l, ranging from <1 to 53 μg/l (Appendix 2.5F, Table F-1). Peak concentrations occurred in July and September 1977 from both sampling depths. Pheophytin a values for 1978 are reported in Appendix 2.5F, Table F-12.

Zooplankton - Zooplankton samples were collected from Oak Lake in March 1977; monthly from May through October 1977; and during March, May, and August 1978. Zooplankton enumerated from these samples were classified into two crustacean orders, Copepoda and Cladocera, or the phylum Rotatoria, and the mean density and relative abundance of these three major taxa are presented in Table 2.5-20. The density and relative abundance of individual

TABLE 2.5-20

MEAN DENSITY[a] (no./l), RELATIVE ABUNDANCE (%), AND DIVERSITY[b] OF ZOOPLANKTON COLLECTED FROM OAK LAKE - STATION G MARCH 1977, MAY THROUGH OCTOBER 1977, AND MARCH, MAY, AND AUGUST 1978

	1977														1978					
	MARCH		MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER		MARCH		MAY		AUGUST	
	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%
Cladocera	4	2	23	8	8	5	8	3	8	3	6	1	15	3	11	2	2	1	11	12
Copepoda	142	78	227	74	125	76	223	84	167	68	77	15	66	14	139	28	95	49	70	79
Rotatoria	37	20	56	18	31	19	34	13	72	29	435	84	378	82	344	70	96	50	9	10
Total	182		307		164		264		247		518		459		494		194		89	
Diversity	0.8		0.9		0.6		0.7		0.7		0.6		0.5		0.3		0.5		0.7	

[a]Density is the mean of two replicate samples rounded to the nearest whole number.

[b]Calculated by Shannon-Weaver formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5B, Tables B-7 through B-36.

taxa from each collection are presented in Appendix 2.5B, Tables B-27 through B-36. The 27 taxa identified from samples collected throughout the period of investigation are presented in Appendix 2.5B, Table B-59.

In 1977 zooplankton density ranged from 164/1 in June to 518/1 in September. In 1978, density in March, 494/1, was higher than the previous year, 182/1, whereas densities in May, 194/1, and August, 89/1, were lower than corresponding collections in 1977, 307 and 247/1, respectively.

Copepods dominated the collections in March and May through August 1977 and August 1978 comprising 68 to 84 percent of the collections. Rotifers predominated the collections in September and October 1977 and March 1978, comprising 70 to 84 percent of the collections, and were codominant with copepods in May 1978.

Common components of the copepod group were the immature naupliar and copepodite life stages and the adult calanoid *Diaptomus minutus*.

Kellicottia bostoniensis, *K. longispina*, and *Keratella taurocephala* were commonly collected rotifer species.

Zooplankton diversity ranged from 0.3 in March 1978 to 0.9 in May 1977. The monthly values for samples collected in March and May 1978 were lower than for comparable months sampled in 1977 (Table 2.5-20).

Periphyton - Periphyton samples were collected from Oak Lake monthly from May through October 1977 and May and August 1978. The relative abundances of the five major taxa identified are presented in Table 2.5-21. The relative abundance of individual taxa identified from each collection is presented in Appendix 2.5C, Table C-4. A total of 139 taxa were identified and are presented in Appendix 2.5C, Table C-17.

TABLE 2.5-21

RELATIVE ABUNDANCE (PERCENT COMPOSITION)
OF MAJOR TAXA OF PERIPHYTON COLLECTED FROM OAK LAKE - STATION G
MAY THROUGH OCTOBER 1977, AND MAY AND AUGUST 1978

TAXA	1977 MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	1978 MAY	AUGUST
Bacillariophyceae	22	56	52	49	55	85	44	13
Chlorophyceae	30	30	35	15	43	15	26	50
Chrysophyceae	46	0	0	32	0	0	2	30
Cyanophyceae	1	14	12	5	2	0	<1	6
Euglenophyceae	0	0	0	0	0	0	28	<1

Diatoms, green algae and golden-brown algae were most abundant in the collections. The relative abundance of diatoms exceeded 40 percent in all months sampled, except May 1977 and August 1978, and reached a maximum of 85 percent in October 1977. Abundant species of diatoms throughout the study were Tabellaria flocculosa, T. fenestrata, and Frustulia rhomboides var. crussinevira.

The highest relative abundances for the green algae were recorded in September 1977 (43 percent) and August 1978 (50 percent). During the other months sampled, the relative abundances for the green algae ranged from 15 percent in both August and October 1977 to 35 percent in July 1977. Species of Oedogonium were the most abundant green algae during the study.

Golden-brown algae comprised up to 46 percent of the periphyton in May 1977, exhibited similar abundance in August 1977 (32 percent) and 1978 (30 percent) and were absent or found in low abundances in other collections. The unidentified Chrysococcus-like algae were the most abundant golden-brown algae.

Aquatic Macrophytes - Aquatic vegetation was present along the northern, eastern, and southwestern shorelines of Oak Lake in the littoral zone in water ≤1 m (3.3 feet) in depth (Figure 2.5-3). Stands were sparse and were comprised primarily of spike rush (Eleocharis smallii). Water lobelia (Lobelia dortmanna), pipewort (Eriocaulon septangulare), bur reed (Sparganium angustifolium), and rush (Juncus pelocarpus) were also identified but collectively occupied less than 50 percent of all aquatic macrophytes encountered. The DNR also found dwarf milfoil (Myriophyllum tenellum), waterwort (Elatine minima), three-way sedge (Dulichium arundinaceum), and marsh purselane (Ludwigia palustris) (Ramharter, 1982a).

Benthic Macroinvertebrates - Quantitative benthic macroinvertebrate samples were collected from one location in Oak Lake (Station G), and qualitative collections were undertaken during March, May, August, and October 1977 and March, May, and August 1978. The major taxa collected in quantitative sampling and their density and relative abundance are presented in Table 2.5-22. The density and relative abundance of individual taxa collected in each quantitative sample are presented in Appendix 2.5D, Tables D-20 through D-26. The 46 taxa identified in quantitative sampling and the additional 18 taxa identified in qualitative sampling are presented in Appendix 2.5D, Table D-72.

In 1977 total numbers of benthic organisms collected at Oak Lake ranged from 1,172/m^2 in August to 7,741/m^2 in March.

In 1978 densities in March (2,256/m^2) and August (819/m^2) were lower than in corresponding collections in 1977, 7,741 and 1,172/m^2, respectively. Density in May was higher in 1978 (7,226/m^2) than in 1977 (4,956/m^2).

Midges were the predominant benthic organisms collected from Oak Lake during the study. Midges comprised from 63 to 94 percent of the benthic macroinvertebrates collected. Midges from the genera *Tanytarsus* and *Procladius* were most common.

In general, other benthic invertebrates individually comprised less than 7 percent of the total invertebrates collected during any sampling period. The only exception was the Nematoda (roundworms), which comprised 11 (560/m^2), 15 (172/m^2), and 26 (784/m^2) percent of the total benthos in May, August, and October 1977, respectively (Appendix 2.5D, Tables D-21, D-22 and D-23).

TABLE 2.5-22

MEAN DENSITY[a] (no./m^2), RELATIVE ABUNDANCE (%), AND DIVERSITY[b]
OF BENTHIC MACROINVERTEBRATES COLLECTED FROM OAK LAKE, STATION G
MARCH, MAY, AUGUST, AND OCTOBER 1977 AND MARCH, MAY, AND AUGUST 1978

	1977								1978					
	MARCH		MAY		AUGUST		OCTOBER		MARCH		MAY		AUGUST	
	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%
Oligochaeta	52	1	119	2	78	7	164	5	0	0	259	4	43	5
Trichoptera	17	<1	32	1	0	0	0	0	0	0	14	<1	29	4
Chironomidae	7,292	94	4,073	82	879	75	1,896	63	1,968	87	5,862	81	646	79
Gastropoda	0	0	11	<1	0	0	0	0	0	0	14	<1	0	0
Pelecypoda	0	0	0	0	17	1	0	0	0	0	230	3	29	4
All Others[c]	379	5	722	15	198	17	974	32	287	13	848	12	72	9
Total	7,741		4,956		1,172		3,034		2,256		7,226		819	
Number of Replicates	5		5		5		5		3		3		3	
Diversity	0.7		0.7		0.6		0.6		0.7		0.7		0.5	

[a]Density is the mean of three or five replicate samples, as indicated above, rounded to the nearest whole number.

[b]Calculated by Brillouin's formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5D, Tables D-20 through D-26.

[c]Includes Hydracarina, Nematoda, Ostracoda, Megaloptera, and Diptera other than Chironomidae.

The benthic diversity for Oak Lake varied little with a range of 0.5 in August 1978 to 0.7 in March and May 1977 and 1978 (Table 2.5-22).

Taxa collected by the DNR during verification sampling are presented in Appendix 2.5D, Table D-85. The samples were obtained with an Ekman sampler during December 1980 in deep and shallow areas of the lake (Ramharter, 1982a).

Fish - Fish were collected from Oak Lake during May, August, and October 1977, and May and August 1978 by seine, gill net, or electroshocking. Numbers and relative abundances of the species collected are presented in Table 2.5-23. The length-weight data for the 8 species collected are summarized in Appendix 2.5E, Tables E-7 and E-8.

Yellow perch was the most abundant species in Oak Lake in gill net and electroshocking catches. This species comprised from 78 to 100 percent of the gill net catches and from 90 to 95 percent of the electroshocking catches, excluding the October 1977 catch. Electroshocking was conducted around the entire lake in association with DNR staff in October 1977, and although more fish (235) were collected than in other electroshocking collections (70 to 193), yellow perch comprised a similar portion of the catch (96 percent) as in other electroshocking samples (90 to 95 percent). In addition to yellow perch, 7 golden shiner and 2 largemouth bass were collected in October 1977 using the DNR electrofishing gear.

Yellow perch comprised more than 60 percent of the beach seine catches except for August 1978. In that period, golden shiner comprised 80 percent of the fish collected and yellow perch made up only 17 percent. Generally, golden shiner did not comprise more than 7 percent of the catches.

TABLE 2.5-23

NUMBERS AND RELATIVE ABUNDANCE (PERCENT OF TOTAL CATCH) OF FISH COLLECTED BY GILL NET (GN)[a], SEINE (BS)[b], AND ELECTROSHOCKING (ES)
OAK LAKE - STATION G
MAY, AUGUST, OCTOBER 1977 AND MAY, AUGUST 1978

	1977											
	MAY				AUGUST						OCTOBER	
	(BS)		(GN)		(BS)		(GN)		(ES)		(GN)	
SPECIES	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Centrarchidae												
Bluegill	1	1	0	0	0	0	0	0	3	2	0	0
Pumpkinseed	3	3	0	0	2	4	0	0	1	<1	0	0
Largemouth bass	28	31	5	11	8	16	0	0	5	3	1	1
Cyprinidae												
Golden shiner	1	1	3	7	0	0	0	0	1	<1	0	0
Longnose dace	0	0	0	0	0	0	0	0	0	0	1	1
Ictaluridae												
Black bullhead	0	0	1	2	0	0	0	0	0	0	0	0
Yellow bullhead	0	0	1	2	0	0	0	0	0	0	0	0
Percidae												
Yellow perch	58	64	35	78	39	80	48	100	173	95	84	98
Total	91		45		49		48		183		86	

[a]One gill net fished in May, August, October 1977; two fished in May, August 1978; numbers expressed as catch per set.

[b]Minnow seine was used in May 1977, beach haul seine was used at all other times.

TABLE 2.5-23 (continued)

SPECIES	1978											
	MAY						AUGUST					
	(BS)		(GN)		(ES)		(BS)		(GN)		(ES)	
	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Centrarchidae												
Bluegill	10	7	1	1	0	0	7	1	0	0	1	1
Pumpkinseed	2	1	2	2	5	3	16	2	0	0	0	0
Largemouth bass	6	4	8	6	5	3	1	<1	0	0	6	8
Cyprinidae												
Golden shiner	0	0	1	1	5	3	531	80	0	0	1	1
Longnose dace	0	0	0	0	0	0	0	0	0	0	0	0
Ictaluridae												
Black bullhead	0	0	0	0	0	0	0	0	0	0	0	0
Yellow bullhead	0	0	0	0	0	0	0	0	0	0	0	0
Percidae												
Yellow perch	131	88	113	90	163	92	110	17	34	100	70	90
Total	149		125		178		665		34		78	

Largemouth bass was the second most abundant species in the catches. It comprised from 0 to 6 percent of the gill net, from 3 to 8 percent of the electroshocking catches, and from <1 to 31 percent of the beach seine catches. In addition, white sucker was collected by the DNR in verification sampling conducted during September and October 1979 and October 1980 (Ramharter, 1982a). Sampling gear was minnow seine, gill nets, fyke nets, minnow traps, and boom shocker.

Fish Parasites and Deformities - Blackspot was commonly observed on yellow perch and largemouth bass. In addition, the metacercaria of the trematode *Clinostomum marginatum* was observed in yellow perch musculature when tissue was being obtained for chemical analysis. Deformities of yellow perch such as deformed spines and jaw tumors were also observed.

2.5.2.3 Ponds

Three ponds were sampled within the Swamp Creek drainage basin: Pond 25-11, Hoffman Springs, and Hoffman Pond. These ponds are northwest of the ore body (Figure 2.5-1) and are part of the surface drainage pattern of Oak Lake (section 2.4, Surface Water). In general, these ponds are small in area, $\leq$0.6 ha (1.5 acres); shallow, $\leq$0.6 m (2 feet); and are associated with wetlands (Table 2.5-8).

Aquatic Macrophytes

Pond 25-11 - Dense growths of yellow water lily were observed throughout the pond (Figure 2.5-3). The two predominant plant types located in moderate growths along the mud banks of the pond were spike rush (Eleocharis obtusa) and carex (Carex rostrata). Other incidental shoreline vegetation included St. John's-wort (Hypericum majus), beggar's tick (Bidens cernua), manna grass (Glyceria borealis), and smartweed (Polygonum pensylvanicum).

Hoffman Springs - The aquatic vegetation was very sparse throughout the pond. The vegetation that was observed in shoreline areas was bitter cress (Cardamine pensylvanica) and muskgrass (Chara sp.).

Fish

Pond 25-11 - No fish were collected from minnow traps.

Hoffman Springs - Two finescale dace were the only fish collected in minnow traps from Hoffman Springs, Station E-2, in October 1978. The length-weight data are summarized in Appendix 2.5E, Table E-29.

Fish sampling in Hoffman Springs by the DNR in October 1983 yielded the following species and numbers: brook trout (230), pearl dace (85), creek chub (14), common shiner (10), white sucker (9), brassy minnow (4), finescale dace (4), golden shiner (3), mottled sculpin (2), and pumpkinseed (1). Most of the brook trout that were captured had been stocked by the landowner 3 days prior to the DNR investigation (Steuck, 1983).

Hoffman Pond - A total of 328 northern redbelly dace and 53 finescale dace were collected from Hoffman Pond, Station E-3, in October 1978. The length-weight data are summarized in Appendix 2.5E, Table E-28. In addition, mudminnow and brook stickleback were observed in a minnow trap tended by the landowner.

In October 1983, the DNR sampled Hoffman Pond and collected 35 fine-scale dace, 27 creek chubs, 15 bluegill, 8 brook stickleback, and 7 central mudminnows (Steuck, 1983).

2.5.2.4 Ecological Relationships of Swamp Creek Drainage Basin

The hydrologic characteristics of the Swamp Creek drainage basin, including subwatershed contributions from Hemlock Creek, Outlet Creek, and Hoffman Creek, were discussed in section 2.4, Surface Water. During the baseline monitoring studies from 1977 through 1980, stream gages were established to monitor flow rates in Hemlock Creek (SG 6), Outlet Creek (SG 4), Hoffman Creek (SG E), and at seven locations in Swamp Creek (SG 1, SG 2, SG 3, SG 5B, SG 5A, and two USGS stations) (see Figure 2.4-1). During this monitoring period, surface water levels also were recorded in Rice Lake (LG 14). Additional stream gage measurements have been taken in Swamp Creek (April 1982 to date) at County Trunk Highway M by the USGS and at SG 24 (in the vicinity of the proposed water discharge site) by Ecological Analysts, Inc. (1983, 1984b).

As discussed in subsections 2.4.4.1 and 2.4.7, water chemistry of streams in the Swamp Creek drainage basin was generally similar. Data presented in section 2.3, Ground Water, indicate that the same aquifer feeds Rice and Ground Hemlock lakes and the Hemlock-Swamp-Outlet Creek system in the Swamp Creek drainage basin. This evidence includes the water chemistry summary data presented in Table 2.4-22, which indicate that all the above mentioned water bodies have relatively high alkalinity and hardness and neutral pH. This suggests a close relationship between the main ground water aquifer and surface water. Surface water chemistry data for the drainage lakes and streams, when compared to ground water quality, support this relationship. Differences in water chemistry upstream and downstream of Rice Lake were slight.

The water quality data presented in section 2.4 and Appendices 2.4F and 2.4G for the water bodies sampled indicated nutrient and metal concentrations were generally low in Hemlock Creek (Stations A-1 and A-2), Outlet Creek (Station C), and Swamp Creek at stations upstream (B, D, and E) and downstream (Q, S, and V) of Rice Lake (see Figure 2.4-2). Water chemistry data from Rice Lake at stations in the north (N) and south (F) portions of the lake were generally similar. Oak Lake apparently receives no water from the main ground water aquifer, and its water is characterized as soft, neutral to slightly acidic, and clear. Further information on the water quality characteristics of water bodies in the Swamp Creek drainage basin is presented in subsections 2.4.4 and 2.4.7. The Hemlock-Swamp-Outlet Creek system, including Rice Lake, is an area of ground water discharge from the main ground water aquifer (see subsection 2.3.3.3). No ground water recharge occurs in this creek system.

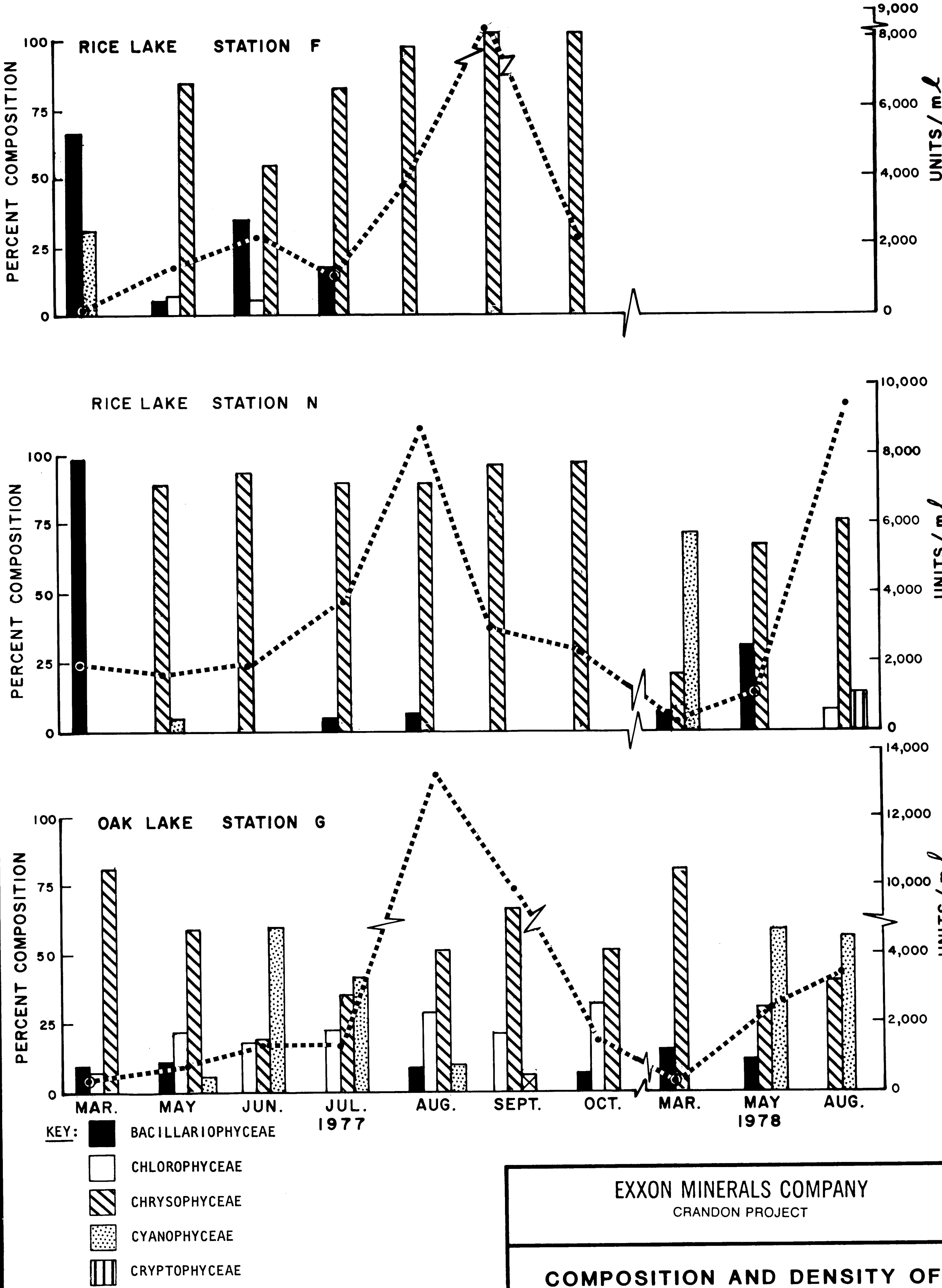
Of the biological components investigated, the periphytic algae samples were generally similar in composition throughout the hard water system. Diatoms generally constitute a major portion of the periphyton (Collins and Weber, 1978) and they comprised 65 percent or more of the periphytic algae collected in Rice Lake and associated streams (Table 2.5-11). In 1977 minimum diatom abundance generally occurred in summer at all stations. In 1978 minimum abundance occurred in August at Station N but minima were not observed in Swamp Creek or Hemlock Creek. The diatoms *Achnanthes minutissima* and *Cocconeis placentula* were the dominant species at Stations D and E. At

Station A-1, A. minutissima was predominant and C. placentula constituted a minor portion of the community. Cocconeis placentula was dominant at Rice Lake.

In samples from Oak Lake, diatoms were less dominant, typically comprising no more than 56 percent of the collections. As was observed at Station N in Rice Lake, a pronounced decrease in diatom abundance was observed in Oak Lake in August 1978 (Table 2.5-21).

Typically phytoplankton density was low in winter and peaked in August or September (Figure 2.5-5). Densities were relatively similar at Rice and Oak lakes throughout the period of investigation. Chlorophyll a levels, an estimate of phytoplankton biomass (Wetzel, 1975), generally were similar in both lakes, which is consistent with the similarity in phytoplankton density. In Rice Lake diatoms were dominant in winter 1977 and golden-brown algae typically dominated the collections other times. In Oak Lake golden-brown algae were abundant but green and blue-green algae were more commonly observed than at Rice Lake.

The zooplankton community exhibited different seasonal patterns in Rice and Oak lakes (Figure 2.5-6). In Rice Lake zooplankton density peaked in June 1977 at both stations and another increase in density was observed during August and September at Station N. In Oak Lake zooplankton density was consistently higher than in Rice Lake and peak density was observed in September and October. Copepods dominated from March through August in Oak Lake and rotifers dominated during September and October 1977, and March 1978. Cladocerans, common in vegetated areas (Pennak, 1978), were considerably more abundant in Rice Lake than in Oak Lake.



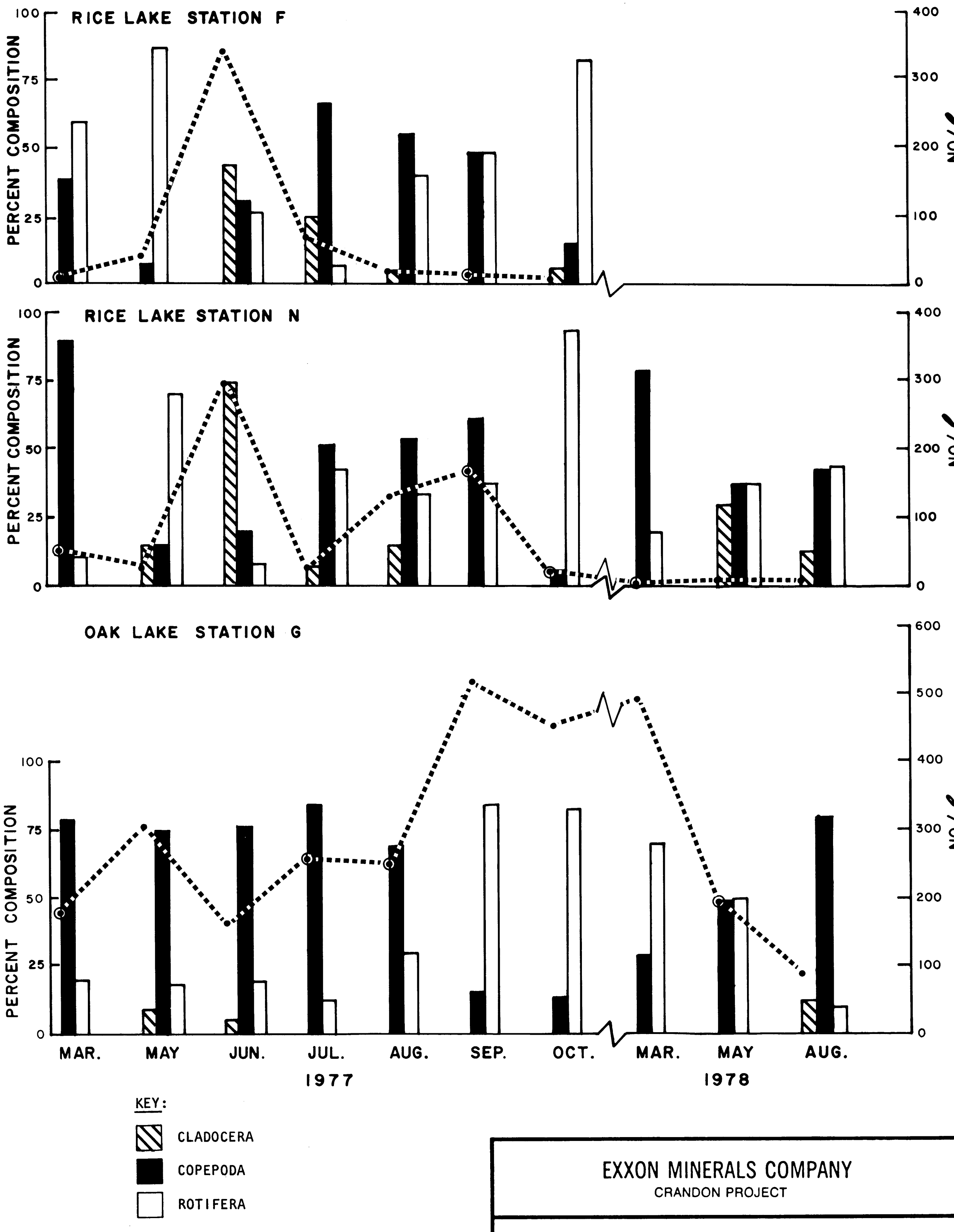
NOTE: PERCENT COMPOSITION OF ORGANISMS COMPRISING 5 PERCENT OR MORE OF THE COLLECTION (HISTOGRAM) IS INDICATED BY THE LEFT VERTICAL AXIS AND TOTAL DENSITY (UNITS/mℓ) (LINE GRAPH) IS INDICATED BY THE RIGHT VERTICAL AXIS.

EXXON MINERALS COMPANY
CRANDON PROJECT

COMPOSITION AND DENSITY OF PHYTOPLANKTON IN RICE AND OAK LAKES

DAMES & MOORE

FIGURE 2.5-5



EXXON MINERALS COMPANY
CRANDON PROJECT

COMPOSITION AND DENSITY OF ZOOPLANKTON IN RICE AND OAK LAKES

NOTE: PERCENT COMPOSITION OF ORGANISMS COMPRISING 5 PERCENT OR MORE OF THE COLLECTION (HISTOGRAM) IS INDICATED BY THE LEFT VERTICAL AXIS AND TOTAL DENSITY (NO./ℓ) (LINE GRAPH) IS INDICATED BY THE RIGHT VERTICAL AXIS.

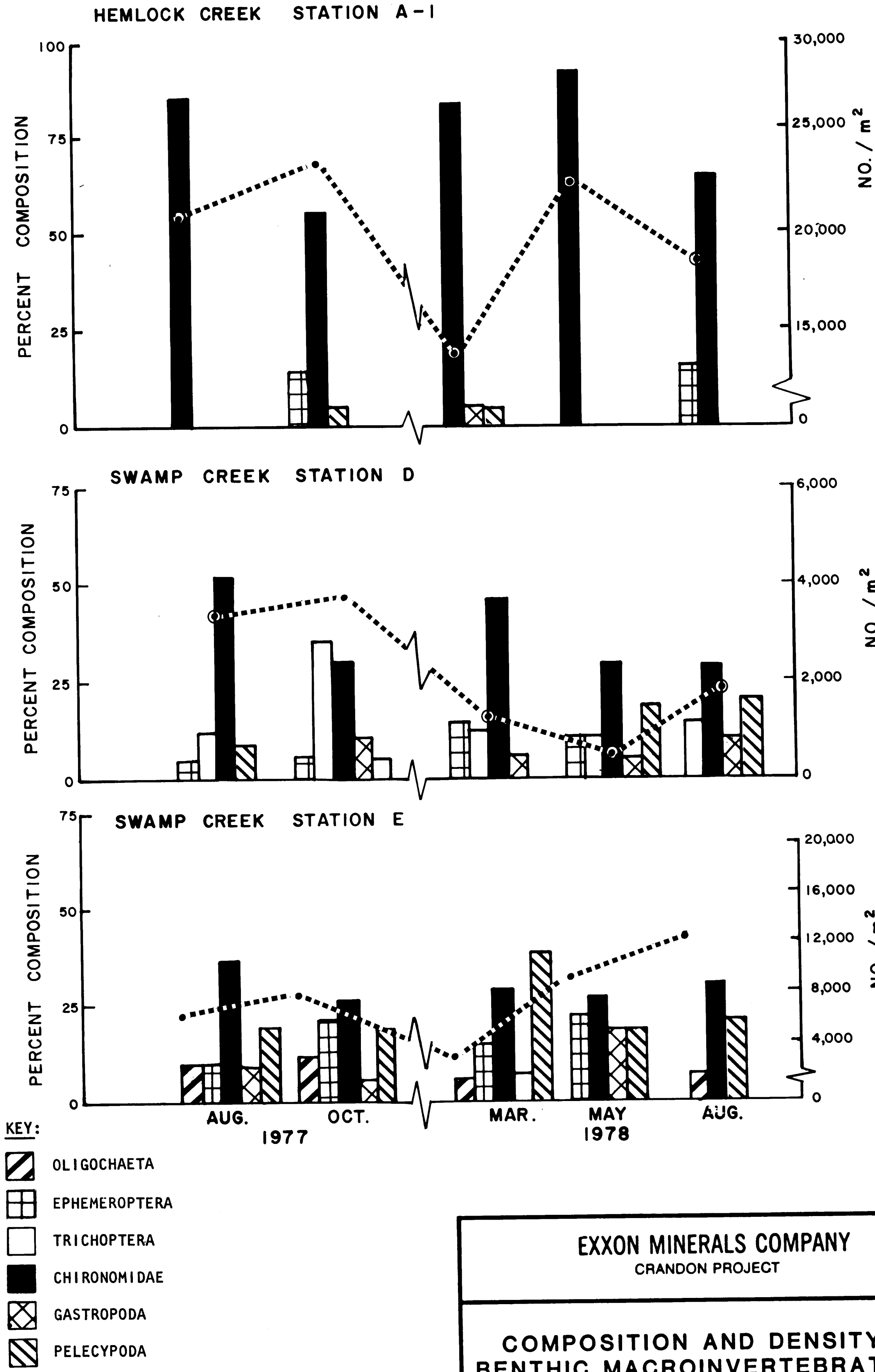
DAMES & MOORE

FIGURE 2.5-6

The distribution of benthic macroinvertebrates and fish varied with habitat, that is, current velocity and substrate composition. At Station A-1, located in a reach characterized by soft, silty substrate and low current velocity, midges dominated the benthos samples comprising over 50 percent of the benthos obtained from August 1977 to August 1978 (Figure 2.5-7). At Station D, located in a reach characterized by high current velocity and a hard gravel and rubble bottom, and Station E, located in a reach with sand and silt substrate, midges were generally dominant, although not to the extent observed at Station A-1. Midges typically occur over a wide range of substrates, but are more productive in soft sediments (Curry, 1965).

Organisms, such as mayflies, clams and snails, infrequently found at Station A-1 were common at Stations D and E. The mayflies *Baetis* sp. and *Stenonema* sp. were common at Station D and characteristically occur in fast flowing water with gravel and rubble substrates (Curry, 1965; Edmunds et al., 1976; Pennak, 1978). *Caenis* sp. and *Hexagenia* sp. were common at Station E and typically occur in silt substrates (DeMarch, 1976). Caddisflies were common at Station D but few were collected at Stations A-1 or E. High numbers of caddisflies are typically associated with larger substrates (Barber and Kevern, 1973).

Numbers of organisms collected by Ekman dredge were consistently higher at Station A-1 than Station E (Figure 2.5-7). Midges, which comprised the major portion of the benthos at Station A-1, are typically found in higher numbers in substrate of finer texture (Wene, 1940). The relationship of benthic communities in Rice Lake and in Swamp Creek upstream and downstream of Rice Lake is discussed in Ecological Analysts, Inc. (1983).



NOTE: PERCENT COMPOSITION OF ORGANISMS COMPRISING 5 PERCENT OR MORE OF THE COLLECTION (HISTOGRAM) IS INDICATED BY THE LEFT VERTICAL AXIS AND TOTAL DENSITY (NO./m²) (LINE GRAPH) IS INDICATED BY THE RIGHT VERTICAL AXIS.

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COMPOSITION AND DENSITY OF BENTHIC MACROINVERTEBRATES IN HEMLOCK AND SWAMP CREEKS

DAMES & MOORE

FIGURE 2.5-7

Rice Lake, which receives drainage primarily from Gliske Creek from the north and Swamp Creek from the east, is part of an extensive wetland system. The lake is shallow, has a dense macrophyte flora, and has a soft peat and muck bottom. Wild rice, which requires a soft, fertile, mud bottom (Muenscher, 1976) and shallow water (Voss, 1972), is abundant and is harvested commercially.

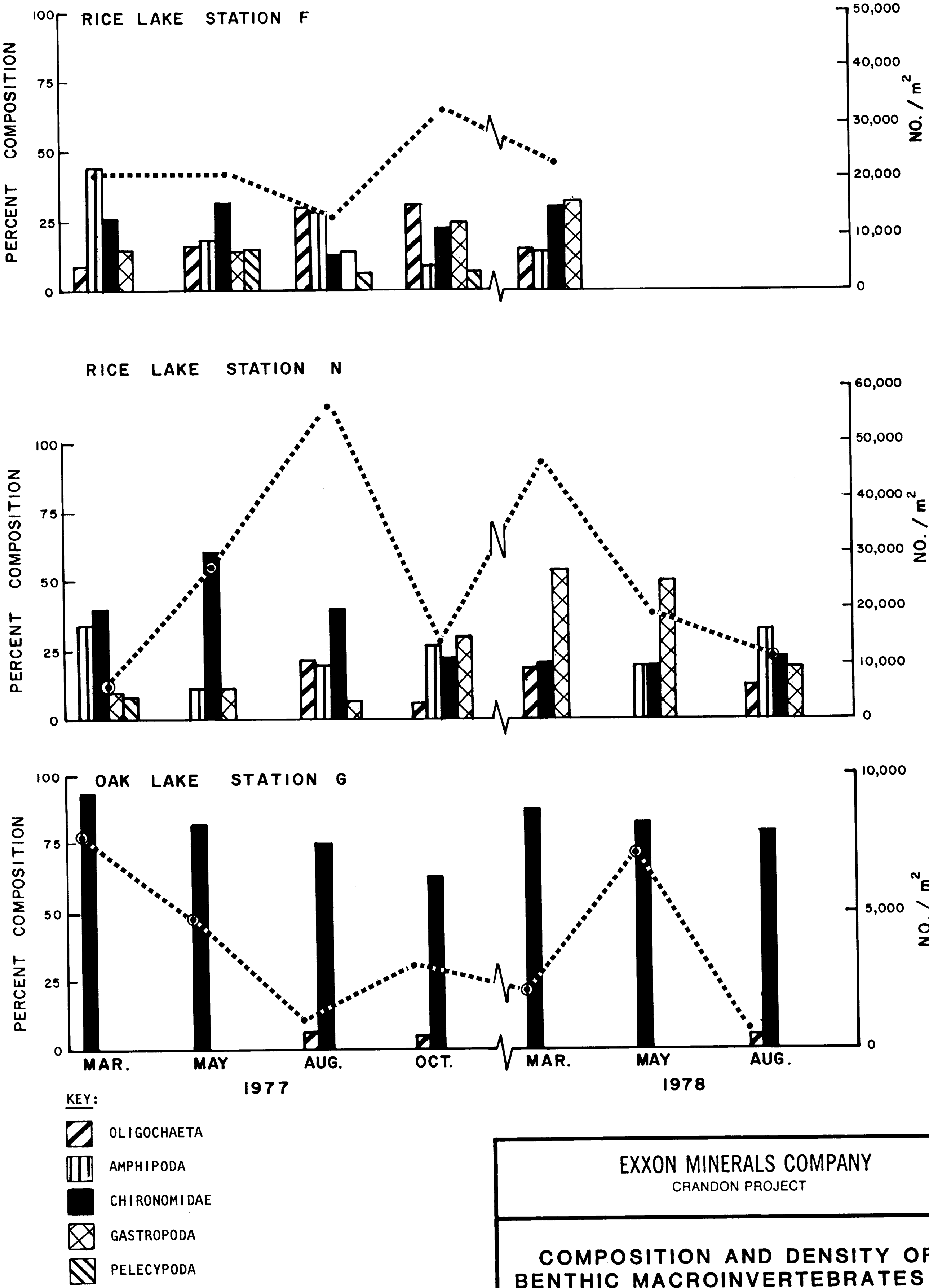
Two Potamogeton species found at Rice Lake, P. zosteriformis and P. friesii, are considered representative of hard water systems (Moyle, 1945; Hellquist, 1975).

Midges were an important component of the benthos samples from Rice Lake (Figure 2.5-8) as well as from reaches of Swamp Creek (Figure 2.5-7). Amphipods and snails were also prominent in Rice Lake which is typically of heavily vegetated areas (Pennak, 1978).

Oak Lake is approximately 14 m (46 feet) in depth and has a relatively narrow littoral zone with a sand substrate. The littoral area supported a macrophyte community consisting of nine species or more, including water lobelia and pipewort which are typical of soft water habitats (Moyle, 1945).

The deeper portions of Oak Lake where benthic samples were obtained consisted of an uniform soft muck substrate. This substrate was colonized primarily by midges which comprised 75 percent or more of each benthic collection (Figure 2.5-8).

The fish species collected at the stream stations were indicative of the different types of habitat encountered. Common shiners, which occur in nearly all creeks in Wisconsin (Becker, 1976), were common in samples from Hemlock and Swamp creeks and were most abundant in the sluggish reaches of



NOTE: PERCENT COMPOSITION OF ORGANISMS COMPRISING 5 PERCENT OR MORE OF THE COLLECTION (HISTOGRAM) IS INDICATED BY THE LEFT VERTICAL AXIS AND TOTAL DENSITY (NO./m²) (LINE GRAPH) IS INDICATED BY THE RIGHT VERTICAL AXIS.

EXXON MINERALS COMPANY
CRANDON PROJECT

COMPOSITION AND DENSITY OF BENTHIC MACROINVERTEBRATES IN RICE AND OAK LAKES

DAMES & MOORE

FIGURE 2.5-8

those creeks represented by Stations A-1, A-2, and B. Northern redbelly dace, which prefer mud-bottomed creeks (Becker, 1976), were codominant with common shiners in samples from Hemlock Creek.

In the riffle area of Swamp Creek, represented by Station D, fish such as longnose dace and blacknose dace that prefer riffles and bottoms consisting of boulders and gravel were predominant in samples.

Brook trout were found in all creeks sampled in the drainage basin and were most abundant in samples from Hoffman Creek. There were indications, such as young fish and the presence of suitable spawning substrate, that reproduction may occur in various areas of the creeks, with the most extensive area in Hoffman Creek. Also, the abundance of brook trout in the creeks is enhanced by annual stocking of adult fish (Theis, 1978).

Mottled sculpin commonly occurred in samples from Hoffman Creek and, along with blacknose dace, longnose dace, and white sucker, was also collected at Station D in Swamp Creek. Sculpin, dace, and white sucker are characteristic of stream areas where salmonids predominate (White, 1973).

A discussion of fish community structure, including potential movements, in Swamp Creek upstream and downstream of Rice Lake and in the Wolf River near the confluence with Swamp Creek is presented in Ecological Analysts, Inc. (1983). In general, fish community structure upstream and downstream of Rice Lake is similar, and all species collected in Rice Lake were present upstream and/or downstream of the lake. Bluegill and brook trout were the only species captured in Rice Lake that were not collected downstream in Swamp Creek during the 1982-83 Aquatic Monitoring Program. Because only 10 northern pike were collected in Rice Lake, the potential is minimal for a major spawning run by this species into Swamp Creek.

Three species (white sucker, shorthead redhorse, and northern pike) have been collected in the Wolf River that have the potential to migrate into Swamp Creek. Both white sucker and shorthead redhorse are apparently present in sufficient numbers to provide a migrating stock; however, the northern pike was present in such low numbers that it seems unlikely this species would migrate into Swamp Creek.

Black bullhead, white sucker, common shiner, northern pike, and brook trout were collected in Rice Lake and the streams. Black bullheads reached their greatest abundance in Rice Lake and were the dominant species in samples from the lake. Typically, black bullheads inhabit lakes and warm water streams of all sizes over a variety of bottom types but prefer habitat with a muddy bottom and weeds (Becker, 1976).

Fish species found in Oak Lake also occurred in Rice Lake and the associated streams, but because of the isolated nature of Oak Lake and relatively uniform habitat, fewer species were collected in Oak (8) than in Rice Lake (15). Yellow perch, the most abundant species in samples from Oak Lake, was relatively uncommon in samples from Rice Lake.

Parasites such as those observed on fish from the Swamp Creek basin are a common malady and their presence is a normal part of the fauna of freshwater esosystems.

Biologically, the Swamp Creek watershed is connected only with the Wolf River watershed. There are no other surface water connections with any other watersheds via lakes or stream that would allow movements of fish, macroinvertebrates, or other forms of aquatic biota between watersheds.

The flow rate of tributary streams to Swamp Creek and Rice Lake is sufficient to support biological populations that could serve as sources for colonization of downstream water bodies.

2.5.3 Pickerel Creek Drainage Basin

The streams of the environmental study area portion of the Pickerel Creek Drainage Basin, Pickerel Creek, Creek 12-9 and Creek 11-4, drain into Rolling Stone Lake (Figure 2.5-1). Pickerel Creek originates in wetlands south of Mole Lake, flows south to Rolling Stone Lake, emerges from the lake and flows south and west to its confluence with the Wolf River. Creek 12-9 originates in wetlands south of Little Sand Lake and receives intermittent flow from the lake. Creek 11-4 originates in a beaver pond north of Rolling Stone Lake.

The major lakes in the environmental study area portion of the basin are Rolling Stone, Duck, Deep Hole, Little Sand, Skunk, Mole, Walsh, and St. Johns. Rolling Stone Lake is the only drainage lake and it receives drainage from three creeks in the environmental study area. The other lakes are seepage lakes, although some intermittent flow occurs from Duck and Deep Hole lakes to Little Sand Lake and subsequently Rolling Stone Lake. A detailed discussion of the surface water drainage is presented in section 2.4, Surface Water.

Surface water bodies selected for investigation of periphyton, benthic macroinvertebrates, fish and fish tissue chemistry were Pickerel Creek, Creek 12-9, Creek 11-4, and Rolling Stone, Little Sand, Duck, Deep Hole, and Skunk lakes. In addition to these components, phytoplankton, zooplankton, and aquatic macrophytes were investigated at these lakes as well as tissue chemistry of aquatic macrophytes and benthic organisms from Little Sand Lake. Ponds 6-8, 31-13, 35-7 and 34-1 in wetland areas were surveyed at the request of the DNR (Brasch, 1977) to investigate aquatic macrophyte and fish species. A summary of the characteristics of these water bodies is presented in Table 2.5-24.

2.5.3.1 Drainage Lakes and Associated Streams

Within the Pickerel Creek drainage basin, water bodies classified as drainage lakes and their associated streams that were included in the aquatic ecology survey are Rolling Stone Lake, Pickerel Creek, and Creeks 12-9 and 11-4.

Gradient of the creeks was typically 6.5 m/km (35 feet/mile) or less (Table 2.5-24). Stream bottom composition was generally muck, but small areas of sand and gravel also occurred. The surface area of Rolling Stone Lake is 272 ha (672 acres) and the bottom is predominantly sand, gravel, and soft muck. Dry-mesic, mesic or wet northern forest was the predominant shoreline vegetation. No residential structures existed along the creeks; however, numerous residences were located along the shoreline of Rolling Stone Lake.

Biological sampling stations were established near reasonably accessible locations containing habitat that was typical of the overall stream or lake system. Samples were collected from Stations M-2 and M-4 located in the northern and southern portions of Rolling Stone Lake, respectively (Figure 2.5-3). Samples were collected in Pickerel Creek from Station M-5, located approximately 0.2 km (0.1 mile) upstream from Rolling Stone Lake. Samples from Creek 12-9 were obtained from Station M-1, approximately 100 m (328 feet) upstream from Rolling Stone Lake. At Creek 11-4, samples were obtained from Station M-3, approximately 0.5 km (0.3 mile) upstream from Rolling Stone Lake.

TABLE 2.5-24

SUMMARY OF CHARACTERISTICS OF THE WATER BODIES IN THE PICKEREL CREEK DRAINAGE BASIN, FROM WHICH BIOLOGICAL SAMPLES WERE OBTAINED[a]

SURFACE WATER CATEGORY/ WATER BODY	DISTANCE AND DIRECTION FROM ORE BODY (km)		DEPTH (m) MEAN	MAX.	MEAN WIDTH (m)	LENGTH (km)	GRADIENT (m/km)	TOTAL SURFACE AREA (ha)	PREDOMINANT SHORELINE VEGETATION[b]	SUBSTRATE CLASSIFICATION
Drainage Lakes and Associated Streams										
Rolling Stone Lake	5.6	South	--[c]	3.7	--	--	--	272	Dry-mesic or Mesic Northern Hardwoods	Sand, muck, detritus, gravel, rubble
Pickerel Creek	4.7	Southwest	0.5	--	2.7	3.8[d]	2.1[d]	20	Wet-mesic or Wet Northern Forest	Detritus, muck
Creek 12-9	2.3	South	<1	--	2.7	2.6	6.5	0.7	Wet-mesic or Wet Northern Forest	Muck, detritus, some sand
Creek 11-4	4.5	Southwest	<1	--	1.5	0.8	5.8	0.1	Wet-mesic or Wet Northern Forest	Sand, detritus
Seepage Lakes										
Little Sand Lake	0.6	South	--	6.4	--	--	--	100	Dry-mesic or Mesic Northern Hardwoods	Silt, detritus, peat, some sand in deep portion. Sand some muck in littoral area
Duck Lake	1.8	Southeast	--	3.0	--	--	--	11	Bog (Shrub/Scrub Wetland)	Muck, peat, detritus, some sand and gravel
Deep Hole Lake	2.4	Southeast	--	3.0	--	--	--	39	Dry-mesic or Mesic Northern Hardwoods	Muck, detritus in deep portion. Sand, gravel, rubble, muck in littoral area
Skunk Lake	0.6	East	--	1.8	--	--	--	2.4	Dry-mesic or Mesic Northern Hardwoods	Muck
Ponds										
Pond 31-13	1.5	Southeast	--	2.1	-- --	--	--	0.9	Bog (Shrub/Scrub Wetland)	--
Pond 6-8	2.4	South	--	4.6	--	--	--	0.2	Wet-mesic or Wet Northern Forest	--
Pond 35-7	3.5	Southwest	--	4.6	--	--	--	1.0	Wet-mesic or Wet Northern Forest	--
Pond 34-1	3.9	West	--	2.1	--	--	--	0.6	Bog (Shrub/Scrub Wetland)	--

[a]See section 2.4, Table 2.4-11, Steuck and Andrews, 1977.

[b]See section 2,6, Figure 2.6-7.

[c]Information not available or not applicable.

[d]Calculated for creek upstream from Rolling Stone Lake, other values for entire length of creek.

The results of sampling in Rolling Stone Lake and associated streams are presented according to the following scheme:

BIOTIC COMPONENT	WATER BODY
Phytoplankton	Rolling Stone Lake
Zooplankton	Rolling Stone Lake
Periphytic Algae	Rolling Stone Lake, Pickerel Creek, Creek 12-9, Creek 11-4
Aquatic Macrophytes	Rolling Stone Lake
Benthic Macroinvertebrates and Fish	Rolling Stone Lake, Pickerel Creek, Creek 12-9, Creek 11-4

Phytoplankton

Rolling Stone Lake - Phytoplankton samples were collected from Rolling Stone Lake at Stations M-2 and M-4 in October 1977 and March, May, and August 1978. Density and relative abundance of the six major taxa identified and enumerated during the study are presented in Table 2.5-25. The density and relative abundance of taxa from each collection are presented in Appendix 2.5A, Tables A-47 through A-50. The 43 genera and species identified at Station M-2 and the 43 genera and species from Station M-4 are presented in Appendix 2.5A, Table A-61.

Densities of phytoplankton were similar at the two Rolling Stone Lake stations. Density per sampling period at Stations M-2 and M-4 ranged from 3,630 units/ml and 3,468 units/ml in May 1978 to 37,323 units/ml and 32,735 units/ml in March 1978, respectively.

Golden-brown algae were the most abundant phytoplankton collected during each sampling period except August 1978 when green algae were dominant. Golden-brown algae comprised over 41 percent of the phytoplankton in all

TABLE 2.5-25

MEAN DENSITY[a] (units/ml), RELATIVE ABUNDANCE (%), AND DIVERSITY[b] OF PHYTOPLANKTON COLLECTED FROM ROLLING STONE LAKE - STATIONS M-2 AND M-4 OCTOBER 1977, MARCH, MAY, AND AUGUST 1978

	1977		1978					
	OCTOBER		MARCH		MAY		AUGUST	
	units/ml	%	units/ml	%	units/ml	%	units/ml	%
Bacillariophyceae								
M-2	51	<1	0	0	327	9	680	3
M-4	170	2	66	<1	453	13	287	1
Chlorophyceae								
M-2	49	<1	0	0	45	1	9,687	42
M-4	30	<1	44	<1	82	2	12,057	47
Chrysophyceae								
M-2	13,509	97	26,640	71	2,761	76	9,462	41
M-4	7,112	81	22,152	68	2,383	69	9,380	37
Cyanophyceaee								
M-2	360	3	10,638	28	363	10	2,790	12
M-4	248	3	10,472	32	3,504	14	3,504	14
Dinophyceae								
M-2	0	0	0	0	24	1	0	0
M-4	0	0	0	0	82	2	0	0
Euglenophyceae								
M-2	0	0	44	<1	111	3	328	1
M-4	1,169	13	0	0	46	1	278	1
Total								
M-2	13,969		37,323		3,630		22,946	
M-4	8,727		32,735		3,468		25,515	
Diversity								
M-2	0.1		0.3		0.6		0.8	
M-4	0.3		0.3		0.7		0.8	

[a]Density is the mean of two replicate samples rounded to the nearest whole number.

[b]Calculated by Shannon-Weaver formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5A, Tables A-47 through A-50.

samples at Station M-2 and over 37 percent in all samples at Station M-4. Unidentified Chrysococcus-like algae were the most abundant forms (see footnote on page 2.5-28).

Green algae and blue-green algae were commonly collected but their peak abundances occurred at different times. Blue-green algae were most abundant in March 1978 and comprised from 3 to 32 percent of the phytoplankton. With the exception of August 1978, green algae comprised less than 2 percent of any collection.

Individual species of green algae and blue-green algae occurred sporadically and none were common. Organisms that comprised the majority of the green algal maximum in August 1978 were, in decreasing order of abundance, an unidentified green coccoid, Ankistrodesmus falcatus, and Oocystis submarina. During other months no species comprised more than 2 percent of any collections. Spirulina laxa was the only blue-green alga that was identified in March 1978; it comprised 28 and 32 percent of the phytoplankton at Stations M-2 and M-4, respectively, and was not found in other collections.

Diatoms comprised from 0 to 9 percent of the phytoplankton at Station M-2 and from <1 to 13 percent at Station M-4. Asterionella formosa, Cocconeis placentula, and Fragilaria sp. were the only diatoms that comprised more than 1 percent of any collection.

Phytoplankton diversity ranged from 0.1 at Station M-2 in October 1977 to 0.8 at both stations in August 1978. In October, when diversity was lowest, golden-brown algae comprised 97 percent of the sample. In August 1978, diversity was highest and no taxon comprised more than 50 percent of the samples.

Mean chlorophyll *a* concentration in Rolling Stone Lake was 20 μg/l and ranged from 10 to 45 μg/l (Appendix 2.5F, Table F-1). Highest values were reported for March 1978 and August 1978 at Stations M-2 and M-4, respectively. Pheophytin *a* values for 1978 are reported in Appendix 2.5F, Table F-12.

Zooplankton

Rolling Stone Lake - Zooplankton samples were collected from Rolling Stone lake at Stations M-2 and M-4 in October 1977 and March, May and August 1978. Density and relative abundance of the major taxa identified and enumerated during the study are presented in Table 2.5-26. The density and relative abundance of taxa from each collection are presented in Appendix 2.5B, Tables B-47 through B-50. The 29 genera and species identified at Station M-2, and the 31 genera and species from Station M-4, are presented in Appendix 2.5B, Table B-61.

Total zooplankton density per sampling period ranged from 1/1 in March 1978 to 488/1 in October 1977 at Station M-2, and from 2/1 in March 1978 to 477/1 in May 1978 at Station M-4. Densities were similar at both stations except in October 1977 when over twice as many organisms were collected at Station M-2 (488/1) than at Station M-4 (226/1).

Copepoda were the most numerous zooplankton enumerated during the investigation ranging from 12 to 99 percent at Station M-2 to 30 to 95 percent at Station M-4. The immature nauplii and cyclopoid copepodites were the most commonly collected copepod life stages. The adult *Diacyclops thomasi* and *Tropocyclops prasinus mexicanus* were the most commonly collected species.

TABLE 2.5-26

MEAN DENSITY[a] (no./l), RELATIVE ABUNDANCE (%), AND DIVERSITY[b] OF ZOOPLANKTON COLLECTED FROM ROLLING STONE LAKE - STATIONS M-2 AND M-4 OCTOBER 1977, MARCH, MAY, AND AUGUST 1978

	1977		1978					
	OCTOBER		MARCH		MAY		AUGUST	
	no./l	%	no./l	%	no./l	%	no./l	%
Cladocera								
M-2	341	70	<1	2	2	<1	4	1
M-4	71	31	<1	2	1	<1	13	3
Copepoda								
M-2	110	22	<1	38	54	12	371	99
M-4	83	37	1	30	240	50	373	95
Rotatoria								
M-2	37	8	1	60	379	87	1	<1
M-4	72	32	1	68	236	49	4	1
Total								
M-2	488		1		434		376	
M-4	226		2		477		390	
Diversity								
M-2	0.4		0.9		0.4		0.6	
M-4	1.0		0.8		0.4		0.8	

[a]Density is the mean of two replicate samples rounded to the nearest whole number.

[b]Calculated by Shannon-Weaver formula (log_{10}) using numbers of organisms presented in Appendix 2.5B, Tables B-47 through B-50. Immature life stages were not included in the calculations.

Rotatoria were second in abundance in the zooplankton collections. Rotifers comprised from <1 to 87 percent of the zooplankton at Station M-2 and from 1 to 68 percent at M-4. *Synchaeta* sp., *Keratella quadrata*, and *Polyarthra* sp. were the most commonly collected organisms.

Cladocerans were most abundant in October 1977 when they comprised 70 (341/1) and 31 (71/1) percent of the respective collections at Stations M-2 and M-4. During other collections, they comprised ≤3 percent of the samples. *Eubosmina tubicen* and *Chydorus sphaericus* were the most common species encountered.

Zooplankton diversity was lowest (0.4) in October 1977 at Station M-2 and at both stations in May 1978 (Table 2.5-26). Diversity was highest (1.0) at Station M-4 in October 1977.

Periphyton

Rolling Stone Lake - Periphytic algae samples were collected from Rolling Stone Lake at Stations M-2 and M-4 during October 1977, and May and August 1978. The relative abundances of the four major taxa are presented in Table 2.5-27. The relative abundances of taxa from each collection are presented in Appendix 2.5C, Table C-6. The 60 genera and species identified at Station M-2, and the 59 genera and species from Station M-4 are presented in Appendix 2.5C, Table C-19.

Diatoms accounted for 78 percent or more of the periphyton community at both stations during the study. August 1978 was the only month of the study in which the average relative abundance of diatoms was less than 90 percent. Although 30 of the total 72 diatoms enumerated were common to both sampling locations, only *Cocconeis placentula* was abundant at both.

TABLE 2.5-27

RELATIVE ABUNDANCE (PERCENT COMPOSITION) OF MAJOR TAXA OF PERIPHYTON COLLECTED FROM CREEK 12-9, CREEK 11-4, PICKEREL CREEK, AND ROLLING STONE LAKE OCTOBER 1977, MAY AND AUGUST 1978

LOCATION/TAXA	1977 OCTOBER	1978 MAY	1978 AUGUST
Rolling Stone Lake (M-2)			
Bacillariophyceae	93	99	88
Chlorophyceae	0	0	3
Chrysophyceae	0	0	7
Cyanophyceae	7	1	1
Rolling Stone Lake (M-4)			
Bacillariophyceae	99	97	78
Chlorophyceae	0	3	<1
Chrysophyceae	0	0	21
Cyanophyceae	1	0	1
Pickerel Creek (M-5)			
Bacillariophyceae	99	98	75
Chlorophyceae	0	0	1
Chrysophyceae	0	0	22
Cyanophyceae	1	2	2
Creek 12-9 (M-1)			
Bacillariophyceae	100	92	54
Chlorophyceae	0	7	1
Chrysophyceae	0	0	45
Creek 11-4 (M-3)			
Bacillariophyceae	100	94	54
Chlorophyceae	0	6	0
Chrysophyceae	0	0	40
Cyanophyceae	0	0	6

Fragilaria pinorata was abundant at Station M-2, and Cymbella cistula, Achnanthes minutissima, and Rhoicosphenia curvata were abundant at Station M-4.

Unidentified Chrysococcus-like algae were the only golden-brown algae enumerated at Stations M-2 and M-4. These algae were collected only in August 1978 and comprised 21 and 7 percent of the periphyton at Stations M-4 and M-2, respectively.

Pickerel Creek - Periphytic algae samples were collected from Pickerel Creek at Station M-5 in October 1977 and May and August 1978. The relative abundances of the four major taxa identified during the study are presented in Table 2.5-27. The relative abundances of taxa from each collection are presented in Appendix 2.5C, Table C-11. The 80 genera and species identified during the study are presented in Appendix 2.5C, Table C-24.

Diatoms accounted for 75 percent or more of the periphyton community. Golden-brown algae, blue-green algae and green algae comprised the remaining periphyton. The highest relative abundance for algae other than diatoms was 22 percent for the golden-brown algae in August 1978. Commonly occurring diatoms were Eunotia curvata, Navicula minima, and Achnanthes lanceolata and A. minutissima. The only golden-brown algae enumerated were unidentified Chrysococcus-like algae, which were encountered only in the August 1978 sample.

Creek 12-9 - Periphytic algae samples were collected at Creek 12-9 (Station M-1) during October 1977 and May and August 1978. The relative abundances of the three major taxa identified during the investigation are presented in Table 2.5-27. The relative abundances of individual taxa from each collection are presented in Appendix 2.5C, Table C-9. The 49 species and genera identified during the investigation are presented in Appendix 2.5C, Table C-22.

Diatoms were the most common algae constituting 100 percent of the sample in October 1977 and subsequently decreasing to a relative abundance of 54 percent of the sample in August 1978. Achnanthes minutissima and Cocconeis placentula were the most abundant diatoms.

Golden-brown algae were encountered only in August 1978 when the unidentified Chrysococcus-like algae and Chrysococcus major comprised 45 percent of the sample.

Creek 11-4 - Periphytic algae samples were collected at Creek 11-4 (Station M-3) during October 1977, and May and August 1978. The relative abundances of the four major taxa identified during the investigation are presented in Table 2.5-27. The relative abundances of taxa from each collection are presented in Appendix 2.5C, Table C-8. The 86 species and genera collected during the investigation are presented in Appendix 2.5C, Table C-21.

During the study, diatoms were the most abundant component of the periphyton. The lowest relative abundance (54 percent) of the diatoms occurred in August 1978, and was associated with a golden-brown algae relative abundance of 40 percent. No diatom was particularly dominant. The most abundant species that were found in every sampling period were: Achnanthes lanceolata, A. minutissima, Nitzschia palea, and Cocconeis placentula.

The only golden-brown algae enumerated were the unidentified Chrysococcus-like forms. These algae exhibited a relative density of 40 percent of the periphyton during August 1978, and were not collected in October 1977 and May 1978.

Aquatic Macrophytes

Rolling Stone Lake - Submersed aquatic vegetation in Rolling Stone Lake was dense, floating vegetation was moderate, and emergent vegetation was sparse (Figure 2.5-3).

The submersed vegetation throughout the lake consisted predominantly of water milfoil (Myriophyllum exalbescens), flatstem pondweed and whitestem pondweed (Potamogeton praelongus) (Wisconsin DNR, 1978). Additional observations in the northern littoral area of the lake between Pickerel Creek and Creek 12-9 (Figure 2.5-3) indicated that these same macrophytes were predominant although coontail and water weed were also common. Vegetation beds near Pickerel Creek included sparse stands of sedge (Carex sp.), whereas shoreline areas adjacent to Creek 12-9 included moderate beds of white water lily (Nymphaea sp.) and yellow water lily (Nuphar sp.). Interspersed within these beds in moderate to sparse occurrence were the floating species star duckweed, big duckweed, and duckweed (Lemna minor). Additional shoreline vegetation between Creeks 11-4 and 12-9 included sparse stands of bulrush (Scirpus sp.).

In addition, the DNR found wild celery (Vallisneria americana), sago pondweed (Potamogeton pectinatus) and bur reed (Sparganium sp.) in Rolling Stone Lake (Ramharter, 1982a).

Benthic Macroinvertebrates

Rolling Stone Lake - Quantitative benthic macroinvertebrate samples were collected from two locations, Stations M-2 and M-4, and qualitative collections were obtained from Rolling Stone Lake in October 1977 and March, May, and August 1978. The seven major taxa collected in quantitative sampling and their density and relative abundance are presented in Table 2.5-28. The density and relative abundance of individual taxa collected in each quantitative sample are presented in Appendix 2.5D, Tables D-34 through D-37. The 75 and 89 individual taxa identified in quantitative sampling at Stations M-2 and M-4, respectively, and the additional 15 taxa identified in qualitative sampling are presented in Appendix 2.5D, Table D-74.

Numbers of benthic organisms collected were consistently higher at Station M-4 than at M-2. At Station M-2 density ranged from 4,698/m^2 in March 1978 to 22,656/m^2 in October 1977 and at Station M-4 from 10,330 to 43,675/m^2 during the same collecting periods.

Snails were the dominant benthic organisms, constituting 30 to 71 percent of the benthic organisms collected at Station M-2 and from 24 to 74 percent at Station M-4. The most abundant snails at both locations were *Amnicola* sp. and *Valvata tricarinata*.

Midges were the second most numerous benthic organisms comprising from 17 to 31 percent of the organisms collected at Stations M-2 and from 7 to 39 percent at Station M-4. *Glyptotendipes* sp., *Chironomus* sp., *Dicrotendipes* sp., and *Endochironomus* sp. were the most common genera.

Worms were abundant only in October 1977 and August 1978 when they comprised from 16 to 27 percent of the benthos. During other sampling

TABLE 2.5-28

MEAN DENSITY[a] (no./m^2), RELATIVE ABUNDANCE (%), AND DIVERSITY[b] OF BENTHIC MACROINVERTEBRATES COLLECTED FROM ROLLING STONE LAKE - STATIONS M-2 AND M-4 OCTOBER 1977 AND MARCH, MAY, AND AUGUST 1978

	1977		1978					
	OCTOBER		MARCH		MAY		AUGUST	
	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%
Oligochaeta								
M-2	3,419	15	29	1	172	1	2,572	15
M-4	5,976	14	115	1	0	0	5,488	24
Amphipoda								
M-2	2,054	9	0	0	29	<1	0	0
M-4	1,494	3	1,020	10	0	0	72	<1
Ephemeroptera								
M-2	86	<1	0	0	0	0	0	0
M-4	474	1	14	<1	0	0	0	0
Trichoptera								
M-2	589	3	144	3	675	6	388	2
M-4	7,787	18	216	2	158	1	43	<1
Chironomidae								
M-2	6,254	28	790	17	2,471	21	5,244	31
M-4	13,634	31	747	7	5,646	39	5,632	24
Gastropoda								
M-2	7,945	35	3,347	71	7,442	65	5,129	30
M-4	10,574	24	7,614	74	7,873	54	9,180	39
Pelecypoda								
M-2	72	<1	58	1	115	1	489	3
M-4	216	<1	115	1	503	3	158	1
All Others[c]								
M-2	2,241	10	330	7	632	5	3,247	19
M-4	3,520	8	488	5	417	3	3,017	13
Total								
M-2	22,656		4,698		11,536		17,068	
M-4	43,675		10,330		14,596		23,590	
Diversity								
M-2	1.1		0.7		0.7		1.0	
M-4	1.2		0.6		0.9		0.9	

[a]Density is the mean of three replicate samples rounded to the nearest whole number.

[b]Calculated by Brillouin's formula (log_{10}) using numbers of organisms presented in Appendix 2.5D, Tables D-34 through D-37.

[c]Includes Hydracarina, Coelenterata, Tricladida, Coleoptera, Alloeocoela, Hirudinea, Ostracoda, Odonata, Nematoda, and Diptera other than Chironomidae.

periods they did not exceed 1 percent of the benthos. The naidids, Dero digitata, Stylaria lacustris, Nais sp., and Pristina leidgi, were the most common worms encountered.

Although densities differed at the two stations, diversity values were similar. Values ranged from 1.1 to 1.2 at Stations M-2 and M-4, respectively, in October 1977 to 0.7 and 0.6 in March 1978 (Table 2.5-28).

Taxa collected by the DNR during verification studies are presented in Appendix 2.5D, Table D-86. The sample was obtained with an Ekman sampler during December 1980 (Ramharter, 1982a).

Pickerel Creek - Quantitative and qualitative benthos collections were obtained from Pickerel Creek (Station M-5) in October 1977 and March, May, and August 1978. The major taxa collected in quantitative sampling and their density and relative abundance are presented in Table 2.5-29. The density and relative abundance of individual taxa collected in each quantitative sample are presented in Appendix 2.5D, Tables D-54 through D-57. The 67 taxa identified in quantitative sampling and the additional 15 taxa identified in qualitative sampling are presented in Appendix 2.5D, Table D-79. Density of organisms ranged from 5,316/m^2 in March 1978 to 9,338/m^2 in May 1978.

Midges were the most abundant benthic organisms in each collection comprising from 34 to 66 percent of the total. Midges from the genera Procladius, Micropsectra, Chironomus, and Tanytarsus were most common.

Worms were the next most abundant organisms and comprised from 9 to 27 percent of the organisms collected. In general, the most commonly collected worms were the immature tubificid forms with or without hair setae.

TABLE 2.5-29

MEAN DENSITY[a] (no./m^2), RELATIVE ABUNDANCE (%) AND DIVERSITY[b] OF BENTHIC MACROINVERTEBRATES COLLECTED FROM PICKEREL CREEK - STATION M-5 OCTOBER 1977 AND MARCH, MAY, AND AUGUST 1978

	1977		1978					
	OCTOBER		MARCH		MAY		AUGUST	
	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%
Oligochaeta	1,997	27	1,063	20	819	9	1,465	16
Isopoda	977	13	1,063	20	646	7	1,983	22
Amphipoda	86	1	359	7	244	3	460	5
Trichoptera	14	<1	0	0	14	<1	115	1
Chironomidae	2,543	34	2,241	42	6,192	66	3,965	45
Gastropoda	14	<1	158	3	72	1	43	<1
Pelecypoda	1,336	18	388	7	905	10	690	8
All Others[c]	474	6	43	1	446	5	187	2
Total	7,442		5,316		9,338		8,907	
Diversity	0.9		1.0		1.0		1.0	

[a]Density is the mean of three replicate samples rounded to the nearest whole number.

[b]Calculated by Brillouin's formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5D, Tables D-54 through D-57.

[c]Includes Nematoda, Hirudinea, Ostracoda, Megaloptera, Hydracarina, Coelenterata, Alloeocoela, and Diptera other than Chironomidae.

Additional worms enumerated from these samples included the tubificids *Aulodrilus pigueti*, *Ilyodrilus templetoni*, *Limnodrilus hoffmeisteri*, and *L. cervix* and the naidids *Slavina appendiculata*, *Nais* sp., *Dero digitata*, and *Pristina leidgi*.

Isopods constituted from 7 to 22 percent of the benthos. Mature specimens that could be identified to the species level were *Asellus racovitzai racovitzai*.

Clams comprised from 7 to 18 percent of the benthos and all specimens were from the family Sphaeriidae. Mature specimens were identified to the genera *Pisidium* and *Sphaerium*.

The benthic diversity was consistent during the investigation with values ranging from 0.9 in October 1977 to 1.0 for the remaining three collection periods (Table 2.5-29).

Creek 12-9 - Quantitative and qualitative benthos collections were obtained from Creek 12-9 (Station M-1) in October 1977 and March, May, and August 1978. The major taxa collected in quantitative sampling and their density and relative abundance are presented in Table 2.5-30. The density and relative abundance of individual taxa collected in each quantitative sample are presented in Appendix 2.5D, Tables D-44 through D-47. The 76 taxa identified in quantitative sampling and the additional 6 taxa identified in qualitative sampling are presented in Appendix 2.5D, Table D-77.

The numbers of organisms enumerated during each sampling period were similar throughout the investigation. Density ranged from $10,516/m^2$ in August 1978 to $14,309/m^2$ in October 1977. The most abundant benthic organisms were midges and clams.

TABLE 2.5-30

MEAN DENSITY[a] ($no./m^2$), RELATIVE ABUNDANCE (%) AND DIVERSITY[b] OF BENTHIC MACROINVERTEBRATES COLLECTED FROM CREEK 12-9 - STATION M-1 OCTOBER 1977 AND MARCH, MAY, AND AUGUST 1978

	1977		1978					
	OCTOBER		MARCH		MAY		AUGUST	
	$no./m^2$	%	$no./m^2$	%	$no./m^2$	%	$no./m^2$	%
Oligochaeta	201	1	144	1	29	<1	345	3
Isopoda	991	7	316	3	129	1	345	3
Amphipoda	158	1	0	0	0	0	0	0
Ephemeroptera	259	2	0	0	0	0	14	<1
Trichoptera	244	2	101	1	14	<1	158	2
Chironomidae	8,433	59	9,554	83	8,706	65	1,408	13
Gastropoda	0	0	0	0	29	<1	43	<1
Pelecypoda	1,192	8	905	8	3,850	29	7,902	75
All Others[c]	2,830	20	517	4	560	4	302	3
Total	14,309		11,536		13,318		10,516	
Diversity	1.1		0.6		0.9		0.8	

[a]Density is the mean of three replicate samples rounded to the nearest whole number.

[b]Calculated by Brillouin's formula (log_{10}) using numbers of organisms presented in Appendix 2.5D, Tables D-44 through D-47.

[c]Includes Nematoda, Hirudinea, Ostracoda, Plecoptera, Megaloptera, Hydracarina, Lepidoptera, and Diptera other than Chironomidae.

Midges comprised from 13 to 83 percent of the collections. Micropsectra sp. was the most abundant midge during the study. Tanytarsus sp., Polypedilum sp., Conchapelopia sp., and Trichocladius sp. also occurred commonly.

All clams collected in the benthic samples from Creek 12-9 were in the family Sphaeriidae; mature specimens were identified to the genera Pisidium and Sphaerium. Clams ranged from 8 to 75 percent of the benthos.

The benthic diversity ranged from 0.6 in March 1978 when midges comprised over 83 percent of the sample to 1.1 in October 1977 when no taxa comprised more than 59 percent of the sample (Table 2.5-30).

Creek 11-4 - Quantitative and qualitative benthos collections were obtained from Creek 11-4 (Station M-3) in October 1977 and March, May, and August 1978.

The major taxa collected in quantitative sampling along with their density and relative abundance are presented in Table 2.5-31. The density and relative abundance of individual taxa collected in each quantitative sample are presented in Appendix 2.5D, Tables D-40 through D-43. The 76 taxa identified in quantitative sampling and the additional 6 taxa identified in qualitative sampling are presented in Appendix 2.5D, Table D-76.

Subsequent to an exceptionally high density of $86,214/m^2$ in October 1977, densities were relatively similar in 1978 ranging from $14,424/m^2$ in August to $20,731/m^2$ in May. The three most abundant benthic groups were worms, isopods, and clams.

Worms comprised from 37 to 69 percent of the benthos enumerated at Creek 11-4. Most of the worms were from the family Tubificidae of which

TABLE 2.5-31

MEAN DENSITY[a] (no./m^2), RELATIVE ABUNDANCE (%) AND DIVERSITY[b] OF BENTHIC MACROINVERTEBRATES COLLECTED FROM CREEK 11-4 - STATION M-3 OCTOBER 1977 AND MARCH, MAY, AND AUGUST 1978

	1977		1978					
	OCTOBER		MARCH		MAY		AUGUST	
	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%
Oligochaeta	59,866	69	6,336	37	11,091	54	8,692	60
Isopoda	14,223	16	6,810	40	4,741	23	704	5
Amphipoda	158	<1	560	3	115	1	14	<1
Ephemeroptera	14	<1	0	0	115	1	0	0
Trichoptera	29	<1	0	0	14	<1	0	0
Chironomidae	718	1	1,537	9	2,873	14	1,020	7
Gastropoda	172	<1	72	<1	14	<1	14	<1
Pelecypoda	9,295	11	1,437	8	1,465	7	3,606	25
All Others[c]	1,738	2	216	1	302	1	374	3
Total	86,214		16,967		20,731		14,424	
Diversity	0.6		0.8		0.9		0.7	

[a]Density is the mean of three replicate samples rounded to the nearest whole number.

[b]Calculated by Brillouin's formula (log_{10}) using numbers of organisms presented in Appendix 2.5D, Tables D-44 through D-47.

[c]Includes Nematoda, Hirudinea, Ostracoda, Plecoptera, Megaloptera, Hydracarina, Lepidoptera, and Diptera other than Chironomidae.

the immature forms with or without hair setae and Tubifex tubifex were most common.

Isopods constituted from 5 to 40 percent of the total benthos enumerated from Creek 11-4. All isopods enumerated were from the genus *Asellus* and adults were identified to *A. racovitzai racovitzai*.

Clams, represented exclusively by the family Sphaeriidae, comprised from 7 to 25 percent of the benthos collected. Mature specimens were identified to the genera *Sphaerium* and *Pisidium*.

Benthic diversity for Creek 11-4 ranged from 0.6 in October 1977 to 0.9 in May 1978 (Table 2.5-31).

Fish

Rolling Stone Lake - Fish were collected from Rolling Stone Lake (Stations M-2 and M-4) during October 1977 and May and August 1978. Numbers and relative abundance of the species collected are presented in Table 2.5-32. The length-weight data for the 11 species collected are summarized in Appendix 2.5E, Tables E-11 and E-12.

Yellow perch was the most abundant species collected in all samples, except in the fyke net catch of May 1978. It comprised 59 percent or more of the electrofishing catches in May and August 1978, was codominant with golden shiner in the October 1977 gill net catch, and was the only species collected in minnow traps in May 1978.

Other commonly occurring fish species were white sucker, black bullhead and members of the centrarchid (sunfish) family, particularly bluegill, pumpkinseed, and black crappie. Fish species characterized as "game fish" such as largemouth bass, northern pike and walleye were captured in low numbers in most sampling periods.

TABLE 2.5-32

NUMBERS AND RELATIVE ABUNDANCE (PERCENT OF TOTAL CATCH) OF FISH COLLECTED BY FYKE NET (FN)[a], GILL NET (GN), MINNOW TRAPPING (MT) AND ELECTROSHOCKING (ES) ROLLING STONE LAKE - STATIONS M-2 AND M-4 OCTOBER 1977 AND MAY AND AUGUST 1978

	1977		1978													
	OCTOBER		MAY										AUGUST			
	(GN)		(FN)		(GN)		(ES)		(MT)		(ES)[b]		(FN)		(ES)	
SPECIES	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Catostomidae																
White sucker	1	3	3	30	1	25	3	3	0	0	3	17	2	3	2	2
Centrarchidae																
Pumpkinseed	0	0	0	0	0	0	1	1	0	0	0	0	11	19	11	11
Bluegill	0	0	4	40	0	0	15	15	0	0	7	39	5	9	8	8
Largemouth bass	0	0	0	0	0	0	1	1	0	0	0	0	0	0	3	3
Black crappie	0	0	1	10	0	0	1	1	0	0	3	17	2	3	1	1
Cyprinidae																
Golden shiner	15	38	0	0	0	0	0	0	0	0	0	0	2	3	5	5
Common shiner	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3
Esocidae																
Northern pike	7	18	0	0	2	50	0	0	0	0	1	6	0	0	2	2
Ictaluridae																
Black bullhead	1	3	2	20	0	0	0	0	0	0	1	6	24	41	4	4
Percidae																
Yellow perch	15	38	0	0	1	25	78	79	7	100	0	0	12	21	59	59
Walleye	0	0	0	0	0	0	0	0	0	0	3	17	0	0	2	2
Total	39		10		4		99		7		18		58		100	

[a]One fyke net was fished in May 1978; two were fished in August 1978.

[b]Supplemental electroshocking collection along western shoreline; yellow perch were selectively not collected.

Pickerel Creek - Fish were collected from Pickerel Creek (Station M-5) during October 1977 and May and August 1978. Numbers and relative abundance of the six species collected are presented in Table 2.5-33. The length-weight data are summarized in Appendix 2.5E, Tables E-20 and E-21.

Brook trout and mottled sculpin were the most abundant species and each comprised an average 26 percent of the catches. Brook trout were collected in all three sampling periods but no more than six individuals were captured in any one collection. Mottled sculpin were collected in May and August 1978, and no more than six individuals were captured in any one collection. No fish were collected in the minnow trap set in May 1978.

Creek 12-9 - Fish were collected from Creek 12-9 (Station M-1) during October 1977 and May and August 1978. Numbers and relative abundance of the seven species collected are presented in Table 2.5-34. The length-weight data are summarized in Appendix 2.5E, Tables E-15 and E-16.

Mottled sculpin was the most abundant species comprising from 17 to 86 percent of the catches and was the only species collected during each sampling period. Game fish collected at this station included largemouth bass, black bullhead, yellow perch and brook trout.

In addition, mudminnow was collected by the DNR in verification sampling (Ramharter, 1982a).

Creek 11-4 - Fish were collected from Creek 11-4 (Station M-3) during October 1977 and May and August 1978. Numbers and relative abundance of the 15 species collected are presented in Table 2.5-35. The length-weight data are summarized in Appendix 2.5E, Tables E-13 and E-14.

TABLE 2.5-33

NUMBERS AND RELATIVE ABUNDANCE (PERCENT OF TOTAL CATCH)
OF FISH COLLECTED BY ELECTROSHOCKING
PICKEREL CREEK - STATION M-5
OCTOBER 1977 AND MAY AND AUGUST 1978

	1977		1978			
	OCTOBER		MAY*		AUGUST	
	no.	%	no.	%	no.	%
Catostomidae						
White sucker	0	0	0	0	5	12
Centrarchidae						
Largemouth bass	1	50	0	0	0	0
Cottidae						
Mottled sculpin	0	0	6	75	1	2
Percidae						
Yellow perch	0	0	0	0	28	70
Salmonidae						
Brook trout	1	50	1	12	6	15
Umbridae						
Mudminnow	0	0	1	12	0	0
Total	2		8		40	

*Three additional mottled sculpin were collected in supplemental electroshocking in May.

TABLE 2.5-34

NUMBERS AND RELATIVE ABUNDANCE (PERCENT OF TOTAL CATCH)
OF FISH COLLECTED BY ELECTROSHOCKING
CREEK 12-9 - STATION M-1
OCTOBER 1977 AND MAY AND AUGUST 1978

	1977		1978			
	OCTOBER		MAY		AUGUST	
	no.	%	no.	%	no.	%
Centrarchidae						
Largemouth bass	2	33	0	0	0	0
Cottidae						
Mottled sculpin	1	17	6	86	2	22
Cyprinidae						
Blacknose shiner	1	17	0	0	0	0
Ictaluridae						
Black bullhead	0	0	1	14	0	0
Percidae						
Iowa darter	0	0	0	0	1	11
Yellow perch	2	33	0	0	5	56
Salmonidae						
Brook trout	0	0	0	0	1	11
Total	6		7		9	

TABLE 2.5-35

NUMBERS AND RELATIVE ABUNDANCE (PERCENT OF TOTAL CATCH)
OF FISH COLLECTED BY MINNOW TRAP (MT) AND ELECTROSHOCKING (ES)
CREEK 11-4 - STATION M-3
OCTOBER 1977 AND MAY AND AUGUST 1978

	1977		1978					
	OCTOBER		MAY				AUGUST	
	(ES)		(ES)		(MT)		(ES)	
SPECIES	no.	%	no.	%	no.	%	no.	%
Centrarchidae								
Bluegill	3	11	0	0	0	0	0	0
Largemouth bass	4	15	0	0	0	0	0	0
Cyprinidae								
Brassy minnow	1	4	59	4	40	17	0	0
Blacknose shiner	0	0	37	3	4	2	0	0
Northern redbelly dace	3	11	1030	78	164	71	105	88
Finescale dace	0	0	1	<1	0	0	0	0
Fathead minnow	2	7	156	12	12	5	9	8
Northern creek chub	11	41	0	0	0	0	0	0
Pearl dace	0	0	3	<1	0	0	0	0
Gasterosteidae								
Brook stickleback	0	0	32	2	11	5	1	1
Percidae								
Iowa darter	0	0	0	0	0	0	2	2
Johnny darter	1	4	0	0	0	0	0	0
Yellow perch	2	7	0	0	0	0	0	0
Umbridae								
Mudminnow	0	0	6	<1	0	0	3	2
Total	27		1324		231		120	

Cyprinids were dominant in the electrofishing and minnow trap catches. Seven species of cyprinids were collected, and the northern redbelly dace, which comprised from 11 to 88 percent of electrofishing samples, was the most abundant species in all collecting periods. Fathead minnow, which comprised from 7 to 12 percent of the electrofishing catches, was the only other species collected in every sampling period. Game fish included bluegill, largemouth bass and yellow perch.

Additional species collected by the DNR in verification sampling were yellow perch, black crappie, and mottled sculpin (Ramharter, 1982a).

Fish Parasites

Blackspot was observed infrequently on northern pike from Rolling Stone Lake and redbelly dace from Creek 11-4.

Brook Trout Redd Survey

Areas that appeared suitable for spawning brook trout were sought in the three northern tributary streams of Rolling Stone Lake in October 1978. One marginally suitable spawning area was located in Creek 12-9 (Figure 2.5-4). The substrate in this reach of the creek was characterized by sand, gravel and rubble with some indication of ground water discharge such as seeps and springs. The creek in this area flowed through uplands into a lowland area and the stream character was primarily riffles. One brook trout was collected during the investigation by electrofishing, which suggests that brook trout production in Creek 12-9 is minimal.

2.5.3.2 Seepage Lakes

Within the Pickerel Creek drainage basin water bodies classified as seepage lakes included in the aquatic ecology studies are Little Sand, Duck, Deep Hole, and Skunk. These lakes range in surface area from 2.4 ha (5.9 acres), Skunk Lake, to 100 ha (248 acres), Little Sand Lake (Table 2.5-24). The lake bottoms are primarily muck except for sand and gravel in the littoral area of Little Sand Lake. Except for Duck Lake, which is largely surrounded by bog vegetation, and Deep Hole Lake, which has moderate growths of bog vegetation, the predominant shoreline vegetation around the seepage lakes is Dry-mesic Northern Hardwoods.

The shorelines of the lakes, except for portions of Little Sand Lake, are undeveloped and no residential structures exist. Residences at Little Sand Lake are located primarily along the northern and western shorelines. Phytoplankton, zooplankton, periphytic algae, aquatic macrophytes, benthic macroinvertebrates and fish were investigated at all four seepage lakes.

The approximate depths at which plankton and quantitative benthic macroinvertebrate samples were obtained are presented below:

LAKE/STATION	DEPTH (m)
Little Sand	
H	3.2
I	3.4
Duck	
K	2.0
Deep Hole	
L	2.0
Skunk	
J	1.0

Phytoplankton

Little Sand Lake - Phytoplankton samples were collected from Stations H and I in Little Sand Lake in March 1977, monthly from May through October 1977, and in March, May, and August 1978. An additional grab sample was collected in July 1977 from the western shoreline when a red coloration of the water occurred. Density and relative abundance of the seven major taxa identified and enumerated during the study are presented in Table 2.5-36. Density and relative abundance of taxa identified from individual collections are presented in Appendix 2.5A, Tables A-17 through A-26. The 81 genera and species identified at Station H and the 70 genera and species from Station I are presented in Appendix 2.5A, Table A-58.

In 1977 density at Station H ranged from 10 units/ml in March to 4,665 units/ml in September and at Station I from 10 units/ml to 5,871 units/ml in the same months. With the exception of August 1977, densities were generally similar between stations.

In 1978 densities were considerably higher than during corresponding months in 1977. At Station H density ranged from 363 units/ml in March to 30,025 units/ml in August and at Station I from 110 to 33,321 units/ml in the same months.

Overall, golden-brown algae, blue-green algae, and green algae were most abundant. Golden-brown algae were dominant (>85 percent of the collection) in May 1977 and March and May 1978 at both stations. In August 1977 they comprised 76 percent of the community at Station H but only 10 percent at Station I. In October 1977 they comprised 68 percent of the community at Station I, but only 37 percent at Station H in October 1977.

TABLE 2.5-36

MEAN DENSITY[a] (units/ml), RELATIVE ABUNDANCE (%) AND DIVERSITY[b]
OF PHYTOPLANKTON COLLECTED AT LITTLE SAND LAKE - STATIONS H AND I
MARCH 1977, MAY THROUGH OCTOBER 1977, AND MARCH, MAY, AND AUGUST 1978

	1977														1978					
	MARCH		MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER		MARCH		MAY		AUGUST	
	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%
Bacillariophyceae																				
H	1	8	25	2	1	<1	11	<1	2	<1	15	<1	27	8	2	1	47	1	0	0
I	1	11	5	<1	3	1	0	0	2	2	14	<1	13	2	1	1	59	1	38	<1
Chlorophyceae																				
H	<1	1	27	2	207	59	870	27	174	18	433	9	167	49	1	<1	0	0	494	2
I	<1	1	28	2	262	52	613	30	51	61	430	7	181	29	1	1	0	0	570	2
Chrysophyceae																				
H	<1	<1	1,556	93	60	17	412	13	720	76	362	8	128	37	354	97	4,160	88	1,729	6
I	0	0	1,475	95	81	16	261	13	8	10	136	2	421	68	108	98	5,144	87	2,166	6
Cyanophyceae																				
H	0	0	52	3	77	22	1,931	60	39	4	3,844	82	17	5	0	0	0	0	27,802	93
I	0	0	32	2	141	28	1,133	56	20	24	5,279	90	6	1	0	0	378	6	30,517	92
Dinophyceae																				
H	9	90	8	<1	9	3	0	0	8	1	5	<1	1	<1	6	2	0	0	0	0
I	9	88	7	<1	15	3	8	<1	2	3	0	0	2	<1	0	0	15	<1	0	0
Euglenophyceae																				
H	0	0	0	0	0	0	0	0	0	0	6	<1	0	0	0	0	495	11	0	0
I	0	0	0	0	1	<1	0	0	<1	<1	0	0	0	0	0	0	294	5	0	0
Xanthophyceae																				
H	0	0	0	0	0	0	0	0	2	<1	0	0	1	<1	0	0	0	0	0	0
I	0	0	0	0	0	0	0	0	0	0	13	<1	0	0	0	0	15	<1	0	0
Total																				
H	10	100	1,668	100	353	100	3,223	100	944	100	4,665	100	342	100	363	100	4,702	100	30,025	100
I	10	100	1,517	100	504	100	2,015	100	84	100	5,871	100	622	100	110	100	5,905	100	33,321	100
Diversity																				
H	0.5		0.5		1.0		0.6		0.5		0.4		1.0		0.1		0.5		0.2	
I	0.3		0.4		0.9		0.6		1.0		0.3		0.6		0.1		0.5		0.2	

[a]Density is the mean of two replicate samples rounded to the nearest whole number.

[b]Calculated by Shannon-Weaver formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5A, Tables A-17 through A-26.

Unidentified Chrysococcus-like algae were the dominant forms. Other commonly occurring forms were Dinobryon sertularia, D. divergens, and D. bavaricum.

Blue-green algae exhibited exceptionally high density in August 1978 (>30,000 units/ml), which was 5 to 6 times higher than densities enumerated in other sampling periods. Blue-green algae were the most abundant phytoplankton in July and September 1977 and August 1978 at both stations when they comprised 56 to 93 percent of the samples. In other sampling periods they comprised 24 percent or less of the collections. Merismopedia tenuissima was the most abundant blue-green algal species.

Green algae were the most abundant group in June 1977 at both stations, at Station I in August 1977, and Station H in October 1977. An unidentified coccoid was the most abundant of the green algae and Selenastrum minutum was commonly present.

An additional whole water sample was collected from a near-shore area in July 1977 where local residents noted a red coloration in the water. A single euglenoid member, Phacus pyrum, was identified from this sample. The algae occurred in the shallow water area along the northwestern shoreline and appeared to be responsible for the red coloration noted in that area.

The lowest diversity (0.1) occurred at both stations in March 1978 when the unidentified Chrysococcus-like algae comprised most of the sample (Table 2.5-36). The highest diversity (1.0) occurred at Station H in June and October 1977 and at Station I in August 1977 when no single taxon comprised more than 61 percent of the collections.

The mean chlorophyll a concentration calculated from all samples taken in Little Sand Lake was <11 and 10 μg/l at Stations H and I, respectively (Appendix 2.5F, Table F-2). Pheophytin a values for 1978 are reported in Appendix 2.5F, Table F-12.

Duck Lake - Phytoplankton samples were collected from Duck Lake in October 1977, March 1978, and monthly from May through October 1978. Density and relative abundance of the seven major taxa identified and enumerated during the study are presented in Table 2.5-37. The density and relative abundance of taxa from individual collections are presented in Appendix 2.5A, Tables A-9 through A-16. The 36 genera and species identified are presented in Appendix 2.5A, Table A-57.

In 1978 numbers of phytoplankton were lowest in March, 983 units/ml, progressively increased to 23,918 units/ml in July, then declined to 2,830 units/ml in October. Density in October 1978 (2,830 units/ml) was considerably lower than the number collected in October 1977 (16,922 units/ml).

Golden-brown algae dominated the phytoplankton collections. Members of this class were the most abundant forms in every sampling period except May 1978 when blue-green algae were the most abundant. Unidentified Chrysococcus-like algae were dominant and comprised 95 percent of the golden-brown algae collected.

Green algae were collected in every sampling period except May 1978 and comprised up to a maximum of 44 percent (July 1978). Commonly occurring green algal species were Oocystis submarina and Selenastrum minutum and unidentified members of the family Spondylomoraceae.

Blue-green algae comprised 50 percent of the organisms enumerated in May 1978 but were 4 percent or less during the other sampling periods. The only blue-green algae in May were genera of the family Chroococcaceae.

TABLE 2.5-37

MEAN DENSITY[a] (units/ml), RELATIVE ABUNDANCE (%), AND DIVERSITY[b] OF PHYTOPLANKTON FROM DUCK LAKE - STATION K OCTOBER 1977, MARCH 1978, AND MAY THROUGH OCTOBER 1978

	1977		1978													
	OCTOBER		MARCH		MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	
	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%
Bacillariophyceae	38	4	0	0	12	<1	0	0	0	0	0	0	0	<0	16	1
Chlorophyceae	5	<1	60	6	0	0	3,324	29	10,511	44	2,194	10	496	3	93	3
Chrysophyceae	16,408	97	852	87	1,869	38	8,243	71	13,322	56	20,080	89	14,388	93	2,537	90
Cyanophyceae	0	0	5	<1	2,446	50	0	0	0	0	33	<1	89	1	101	4
Dinophyceae	465	3	0	0	390	8	0	0	86	<1	166	1	97	1	43	2
Euglenophyceae	0	0	66	7	150	3	43	<1	0	0	0	0	344	2	40	1
Xanthophyceae	5	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	16,922		983		4,867		11,610		23,918		22,473		15,413		2,830	
Diversity	0.2		0.3		0.5		0.4		0.4		0.2		0.3		0.3	

[a]Density is the mean of two replicate samples rounded to the nearest whole number.

[b]Calculated by Shannon-Weaver formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5A, Tables A-9 through A-16.

Diversity values were low and ranged from 0.2 in October 1977 and August 1978 to 0.5 in May 1978 (Table 2.5-37).

The mean chlorophyll a concentration calculated for all Duck Lake samples was 9 μg/l and ranged from 2 μg/l in June 1977 to 19 μg/l in October 1978 (Appendix 2.5F, Table F-2). Values exhibited a bimodal distribution with high values in spring and late summer/autumn and low mid-summer levels. Pheophytin a values for 1978 are reported in Appendix 2.5F, Table F-12.

Deep Hole Lake - Phytoplankton samples were collected from Deep Hole Lake in October 1977, March 1978, and monthly from May through October 1978. Density and relative abundance of the seven major taxa identified and enumerated during the study are presented in Table 2.5-38. The density and relative abundance of taxa from individual collections are presented in Appendix 2.5A, Tables A-1 through A-8. The 55 genera and species identified are presented in Appendix 2.5A, Table A-56.

In 1978 phytoplankton density was lowest in March, 768 units/ml, increased to 16,194 units/ml in May, then progressively decreased to 4,758 units/ml in August. In September density increased to 11,710 units/ml then decreased to 9,102 units/ml in October. Density in October 1978 was considerably higher than in October 1977 (1,205 units/ml).

Golden-brown algae was the most abundant class of algae in all sampling periods (≥72 percent) except March, May, and June 1978 when green algae or blue-green algae predominated. Golden-brown algae were represented primarily by unidentified Chrysococcus-like forms. Other common golden-brown algae were Dinobryon sertularia, Chrysococcus major, and Mallomonas acaroides.

TABLE 2.5-38

MEAN DENSITY[a] (units/ml), RELATIVE ABUNDANCE (%) AND DIVERSITY[b] OF PHYTOPLANKTON COLLECTED AT DEEP HOLE LAKE - STATION L OCTOBER 1977, MARCH 1978, AND MAY THROUGH OCTOBER 1978

	1977		1978													
	OCTOBER		MARCH		MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	
	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%
Bacillariophyceae	7	1	1	<1	40	<1	0	0	43	1	27	1	15	<1	11	<1
Chlorophyceae	74	6	577	75	16	<1	13,992	90	1,309	16	428	9	2,649	23	608	7
Chrysophyceae	1,124	93	184	24	5,995	37	1,375	9	3,602	44	4,199	88	8,392	72	8,440	93
Cyanophyceae	0	0	2	<1	9,739	60	38	<1	3,295	40	93	2	59	<1	0	0
Dinophyceae	0	0	0	0	0	0	0	0	11	<1	3	<1	43	<1	0	0
Euglenophyceae	0	0	4	<1	404	2	120	1	0	0	8	<1	552	5	43	<1
Total	1,205		768		16,194		15,525		8,258		4,758		11,710		9,102	
Diversity	0.1		0.3		0.5		0.3		0.6		0.3		0.5		0.5	

[a]Density is the mean of two replicate samples rounded to the nearest whole number.

[b]Calculated by Shannon-Wiener formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5A, Tables A-1 through A-8.

Green algae was the most numerous class in March and June 1978, when it comprised 75 and 90 percent, respectively, of the collections. Common green algae were _Oocystis_ _submarina_, _Selenastrum_ _minutum_, and _Ankistrodesmus_ _folcatus_ var. _acicularis_.

Blue-green algae was the most abundant algal class in May 1978 when it constituted 60 percent of the sample. Blue-green algae were dominated by unidentified members of the family Chroococcaceae and _Merismopedia_ _tenuissima_.

The minimum diversity of 0.1 occurred in October 1977 when the unidentified _Chrysococcus_-like algae comprised 93 percent of the sample (Table 2.5-38). The maximum diversity of 0.6 occurred in July 1978, when no class comprised more than 44 percent of the sample.

The mean chlorophyll _a_ concentration recorded from Deep Hole Lake was ≤4 µg/l, and ranged from <1 to 10 µg/l (Appendix 2.5F, Table F-2). The highest mean concentration of 6.5 µg/l (mean of 2 replicates) occurred in October 1978. Pheophytin _a_ values for 1978 are reported in Appendix 2.5F, Table F-12.

Skunk Lake - Phytoplankton samples were collected from Station J in Skunk Lake monthly from June to October 1977. Density and relative abundance of the six major taxa identified and enumerated during the study are presented in Table 2.5-39. Density and relative abundance of taxa identified from individual collections are presented in Appendix 2.5A, Tables A-51 through A-55. The 41 genera and species identified are presented in Appendix 2.5A, Table A-62.

TABLE 2.5-39

MEAN DENSITY[a] (units/ml), RELATIVE ABUNDANCE (%) AND DIVERSITY[b] OF PHYTOPLANKTON COLLECTED AT SKUNK LAKE - STATION J JUNE THROUGH OCTOBER 1977

	1977									
	JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	
	units/ml	%	units/ml	%	units/ml	%	units/ml	%	units/ml	%
Bacillariophyceae	37	<1	14	<1	60	1	48	<1	7	1
Chlorophyceae	1,177	16	1,456	25	729	7	125	1	25	4
Chrysophyceae	6,210	84	4,341	75	9,176	91	15,478	98	532	93
Cyanophyceae	12	<1	0	0	96	1	76	<1	4	1
Euglenophyceae	0	0	0	0	0	0	0	0	1	<1
Xanthophyceae	0	0	0	0	0	0	0	0	1	<1
Total	7,436		5,811		10,060		15,727		571	
Diversity	0.2		0.3		0.2		0.1		0.2	

[a]Density is the mean of two replicate samples rounded to the nearest whole number.

[b]Calculated by Shannon-Weaver formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5A, Tables A-51 through A-55.

Phytoplankton density in Skunk Lake ranged from 571 units/ml in October to 15,727 units/ml in September 1977.

Golden-brown algae comprised 75 percent or more of each sample. The most abundant golden-brown algal species were unidentified Chrysococcus-like algae.

Green algae was second in abundance, comprising from 1 to 25 percent of the phytoplankton collected. Ankistrodesmus falcatus was the most common green alga in June and July (92 and 97 percent of the assemblage, respectively) but was uncommon in subsequent collections. Dictyosphaerium pulchellum, Elakatothrix gelatinosa and Scenedesmus brasiliensis were common green algal species in various periods from August through October 1977.

Primarily because of the dominance of the unidentified golden-brown Chrysococcus-like algae, diversity values were low, ranging from 0.1 to 0.3. The highest diversity value occurred in July 1977 when golden-brown algae were lowest in abundance (75 percent of the collection).

The mean chlorophyll a level calculated from all samples was <81 μg/l (Appendix 2.5F, Table F-1). Values ranged from <1 μg/l in June 1977 to 395 μg/l in March 1978. During March 1978 when the highest chlorophyll a level was recorded, the phytoplankton samples were collected at a depth of approximately 0.5 m (1.6 feet). The ice cover at the sampling location was approximately 30.5 cm (12 inches) in thickness. There was patchy snow cover, which varied across the lake. Pheophytin a values for 1978 are reported in Appendix 2.5F, Table F-12.

Zooplankton

Little Sand Lake - Zooplankton samples were collected from Little Sand Lake (Stations H and I) during March 1977, and monthly from May through October 1977 and March, May, and August 1978. Density and relative abundance of the three major taxa are presented in Table 2.5-40. Density and relative abundance of taxa identified from each collection are presented in Appendix 2.5B, Tables B-17 through B-26. The 25 and 30 genera and species identified at Stations H and I, respectively, are presented in Appendix 2.5B, Table B-58.

The lowest density of zooplankton occurred in March 1978 at both stations, 66/l at Station H and 75/l at Station I. The highest density was observed in June 1977 at Station H (419/l) and in May 1977 at Station I (293/l). Generally, collections in corresponding periods in 1977 and 1978 were similar.

Copepods were the most numerous zooplankton at both stations. This subclass comprised 47 percent or more of each collection. The copepods were primarily comprised of immature nauplii and calanoid copepodites, and adult *Diaptomus minutus*. Other adult species included *Diacyclops thomasi* and *Mesocyclops edax*.

Rotifers were the second most abundant group at Little Sand Lake and comprised from 18 to 47 percent of the monthly samples. *Keratella taurocephala* was the primary rotifer identified.

Except for June 1977, cladocera never comprised more than 15 percent of the zooplankton community. In June, cladocerans represented 20 percent of the zooplankton sample at Station I, with their highest density (44/l). Cladocerans commonly found in the sample were *Diaphanosoma leuchtenbergianum*, *Eubosmina tubicen*, and *Daphnia dubia*.

TABLE 2.5-40

MEAN DENSITY[a] (no./l), RELATIVE ABUNDANCE (%), AND DIVERSITY[b]
OF ZOOPLANKTON COLLECTED FROM LITTLE SAND LAKE - STATIONS H AND I
MARCH 1977, MAY THROUGH OCTOBER 1977, AND MARCH, MAY AND AUGUST 1978

	1977														1978					
	MARCH		MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER		MARCH		MAY		AUGUST	
	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%
Cladocera																				
H	<1	<1	0	0	40	9	15	7	7	2	39	12	13	8	1	1	5	2	13	9
I	<1	<1	2	1	44	20	14	8	13	6	22	9	9	4	1	1	2	1	25	15
Copepoda																				
H	73	82	225	59	195	47	148	72	162	57	159	47	100	59	37	56	196	60	104	72
I	102	64	209	71	123	54	120	65	132	57	128	55	100	49	39	52	132	69	100	61
Rotatoria																				
H	16	18	156	41	184	44	42	21	118	41	139	41	55	33	28	43	127	39	28	19
I	57	36	82	28	59	26	50	27	87	38	84	36	95	47	35	46	57	30	40	24
Total																				
H	90		381		419		205		287		338		168		66		329		145	
I	159		293		226		185		233		234		205		75		192		164	
Diversity																				
H	0.5		0.5		0.7		0.4		0.4		0.5		0.5		0.6		0.5		0.6	
I	0.6		0.8		0.7		0.5		0.4		0.5		0.6		0.7		0.6		0.6	

[a]Density is the mean of two replicate samples rounded to the nearest number.

[b]Calculated by Shannon-Weaver formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5B, Tables B-17 through B-26. Immature life stages were not included in the calculations.

Zooplankton diversity was similar at Stations H and I and ranged from 0.4 in August 1977 at both locations and in July at Station H to 0.8 in May at Station I (Table 2.5-40).

Duck Lake - Zooplankton samples were collected from Duck Lake (Station K) during October 1977, March 1978, and monthly from May through October 1978. Density and relative abundance of the three major taxa are presented in Table 2.5-41. Density and relative abundance of taxa identified from each collection are presented in Appendix 2.5B, Tables B-9 through B-16. The 30 genera and species identified are presented in Appendix 2.5B, Table B-57.

In 1978, zooplankton density ranged from 25/1 in May to 419/1 in August. Density in October 1978 was considerably less than in October 1977.

Rotifers were the most abundant organisms in all sampling periods except July and August 1978 when copepods were dominant. Rotifer abundance ranged from 12 percent in July 1978 to 99 percent in March 1978. *Keratella taurocephala* was the most abundant species. Individuals from the genera *Polyarthra* and *Synchaeta* were also common.

Copepods were highest in density in July (187/1) and August 1978 (283/1) when they comprised 65 and 68 percent of the respective collections. The greatest abundance of cladocerans was observed in June 1978 when they comprised 43 percent (116/1) of the sample.

Among the copepods, the nauplii were the most common forms and the most abundant adult form was the cyclopoid *Mesocyclops edax*. *Eubosmina tubicen*, *Holopedium gibberum* and *Diaphanosoma leuchtenbergianum* were the most common cladoceran species.

TABLE 2.5-41

MEAN DENSITY[a] (no./l), RELATIVE ABUNDANCE (%), AND DIVERSITY[b] OF ZOOPLANKTON COLLECTED AT DUCK LAKE - STATION K OCTOBER 1977, MARCH 1978, AND MAY THROUGH OCTOBER 1978

	1977		1978													
	OCTOBER		MARCH		MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	
	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%
Cladocera	14	2	1	1	4	16	116	43	65	23	73	17	4	4	13	11
Copepoda	3	<1	1	1	1	6	22	8	187	65	283	68	4	4	9	8
Rotatoria	772	98	143	99	19	79	133	49	36	12	63	15	86	92	88	80
Total	789		145		25		272		288		419		94		110	
Diversity	0.2		0.3		0.7		0.6		0.5		0.7		0.1		0.3	

[a]Density is the mean of two replicate samples rounded to the nearest whole number.

[b]Calculated by Shannon-Weaver formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5B, Tables B-9 through B-16. Immature life stages were not included in the calculations.

Zooplankton diversity ranged from a low of 0.1 in September to a high of 0.7 recorded for both May and August (Table 2.5-41).

Deep Hole Lake - Zooplankton samples were collected from Deep Hole Lake (Station L) in October 1977, March 1978, and monthly from May through October 1978. Density and relative abundance of the three major taxa are presented in Table 2.5-42. The density and relative abundance of taxa from each collection are presented in Appendix 2.5B, Tables B-1 through B-8. The 28 genera and species identified are presented in Appendix 2.5B, Table B-56.

In 1978, density ranged from 68/1 in March to 512/1 in September. Density in October 1978 (234/1) was less than in October 1977 (693/1).

Rotifers were the most numerous of all zooplankton in October 1977, and June, August, September and October 1978 comprising from 59 to 84 percent of the collection. Keratella cochlearis and K. taurocephala were the most common rotifers collected.

Copepods were the most abundant organisms in March (72 percent) and May (62 percent) 1978 but comprised no more than 35 percent of any sample during the other sampling periods. Of the copepods, the immature naupliar form was the most abundant, and the cyclopoid and calanoid copepodites and the adult calanoid Diaptomus minutus were frequently identified but were never abundant. Cladocera were most abundant in July 1978 (40 percent) but generally did not comprise more than 26 percent of any sample. Although no single cladoceran species occurred in all of the samples, Eubosmina tubicen, Daphnia dubia, and Holopedium gibberum were the most common species.

TABLE 2.5-42

MEAN DENSITY[a] (no./l), RELATIVE ABUNDANCE (%), AND DIVERSITY[b] OF ZOOPLANKTON COLLECTED AT DEEP HOLE LAKE - STATION L OCTOBER 1977, MARCH 1978 AND MAY THROUGH OCTOBER 1978

	1977		1978													
	OCTOBER		MARCH		MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	
	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%
Cladocera	110	16	<1	<1	8	7	20	16	44	40	15	5	61	12	61	26
Copepoda	51	7	49	72	73	62	31	25	40	35	30	11	58	11	19	8
Rotatoria	532	77	19	28	37	31	73	59	28	25	231	84	394	77	154	66
Total	693		68		118		124		112		275		512		234	
Diversity	0.7		0.6		1.0		0.9		0.8		0.6		0.6		0.9	

[a]Density is the mean of two replicate samples rounded to the nearest whole number.

[b]Calculated by Shannon-Weaver formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5B, Tables B-1 through B-8. Immature life stages were not included in the calculations.

Zooplankton diversity ranged from a low of 0.6 in March to a high of 1.0 in May (Table 2.5-42). From the maximum in May, diversity decreased through the summer months to 0.6 in September before increasing to 0.9 in October 1978.

Skunk Lake - Monthly zooplankton samples were collected from Skunk Lake (Station J) from June through October 1977. Density and relative abundance of the three major taxa identified are presented in Table 2.5-43. Density and relative abundance of taxa identified from each collection are presented in Appendix 2.5B, Tables B-51 through B-55. The 29 taxa identified are presented in Appendix 2.5B, Table B-62.

The density of zooplankton was highest in July 1977 (1,293/l) but declined in subsequent months to a low of 35/l in October 1977.

Rotifers were the most abundant organisms in all samples and comprised from 47 to 88 percent of the organisms enumerated. *Conochilus unicornis* was the most numerous rotifer identified and represented 90 percent of the total rotifers during the study. Other rotifers identified were *Keratella quadrata* and *K. taurocephala*.

The density of copepods was highest in June when 434/l (43 percent) were enumerated and lowest in October when 3/l (8 percent) were collected. Immature nauplii were the major component of Copepoda present. Other commonly collected copepods were calanoid copepodites and the adult calanoid *Diaptomus leptopus*.

The temporal distribution of cladocerans was irregular. This group comprised 2 percent or less (9/l) of the population in June, July and August but 24 percent (26/l) and 46 percent (16/l) in September and October,

TABLE 2.5-43

MEAN DENSITY[a] (no./l), RELATIVE ABUNDANCE (%), AND DIVERSITY[b] OF ZOOPLANKTON COLLECTED FROM SKUNK LAKE - STATION J JUNE THROUGH OCTOBER 1977

	JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER	
	no./l	%	no./l	%	no./l	%	no./l	%	no./l	%
Cladocera	7	1	9	1	6	2	26	24	16	46
Copepoda	434	43	150	12	88	28	17	16	3	8
Rotatoria	569	56	1,134	88	218	70	68	61	16	47
Total	1,010		1,293		311		112		35	
Diversity	0.5		<0.1		0.1		0.7		0.8	

[a]Density is the mean of two replicate samples rounded to the nearest whole number.

[b]Calculated by Shannon-Weaver formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5B, Tables B-51 through B-55. Immature life stages were not included in the calculations.

respectively. Chydorus sphaericus and Daphnia sp. were the numerically important cladocerans.

Zooplankton diversity ranged from a low of <0.1 in July 1977 to a high of 0.8 in October 1977 (Table 2.5-43).

Periphyton

Little Sand Lake - Periphytic algae samples were collected from Little Sand Lake (Stations H and I) monthly from May through October 1977 and May and August 1978. The relative abundances of the six major taxa identified during the study are presented in Table 2.5-44. The relative abundances of taxa from each collection is presented in Appendix 2.5C, Table C-3. The 147 genera and species identified at Station H and the 116 taxa collected at Station I are presented in Appendix 2.5C, Table C-16.

Diatoms were generally the dominant periphytic algal forms collected at Little Sand Lake. Diatoms comprised 53 percent or more of the periphytic algae except during summer and fall when diatoms decreased at times to 7 to 32 percent of the samples at Stations H and I, respectively. Only one diatom, Tabellaria flocculosa, was consistently abundant at Little Sand Lake. Other common forms found at both stations were T. fenestrata, Frustulia rhomboides var. saxonica, and Eunotia curvata.

Green algae were commonly collected in the periphytic community at both stations. Green algae were most abundant at Station H in June 1977 (41 percent) and at Station I in October 1977 (66 percent) Abundant green algal forms were Oedogonium sp. and Mougeotia sp.

Golden-brown algae typically ranged from 0 to 17 percent but on three occasions (Station H in July 1977 and both stations in August 1978)

TABLE 2.5-44

RELATIVE ABUNDANCE (PERCENT COMPOSITION) OF MAJOR TAXA OF PERIPHYTON COLLECTED FROM DEEP HOLE LAKE, DUCK LAKE, LITTLE SAND LAKE, AND SKUNK LAKE MAY THROUGH OCTOBER 1977 AND MAY THROUGH OCTOBER 1978

	1977						1978					
LOCATION/TAXA	MAY	JUNE	JULY	AUG	SEP	OCT	MAY	JUNE	JULY	AUG	SEP	OCT
Little Sand Lake (H)												
Bacillariophyceae	53	55	8	60	22	63	62	--	--	7	--	--
Chlorophyceae	29	41	27	38	15	29	34	--	--	13	--	--
Chrysophyceae	17	0	61	1	2	0	4	--	--	72	--	--
Cyanophyceae	1	4	4	1	61	6	0	--	--	7	--	--
Euglenophyceae	0	0	0	0	0	0	0	--	--	1	--	--
Xanthophyceae	0	0	0	0	0	3	0	--	--	0	--	--
Little Sand Lake (I)												
Bacillariophyceae	61	73	56	52	77	32	68	--	--	18	--	--
Chlorophyceae	11	21	25	43	13	66	20	--	--	22	--	--
Chrysophyceae	16	0	7	3	1	2	13	--	--	58	--	--
Cyanophyceae	12	6	11	2	9	<1	0	--	--	3	--	--
Duck Lake (K)												
Bacillariophyceae	--	--	--	--	--	22	51	70	34	37	32	64
Chlorophyceae	--	--	--	--	--	50	49	20	11	15	20	28
Chrysophyceae	--	--	--	--	--	0	<1	8	14	37	28	2
Cyanophyceae	--	--	--	--	--	1	0	2	40	8	7	1
Euglenophyceae	--	--	--	--	--	0	0	<1	0	<1	13	5
Xanthophyceae	--	--	--	--	--	0	0	0	0	2	0	0
Dinophyceae	--	--	--	--	--	27	0	0	0	0	0	0
Deep Hole Lake (L)												
Bacillariophyceae	--	--	--	--	--	69	60	66	42	34	43	51
Chlorophyceae	--	--	--	--	--	31	9	16	48	29	36	32
Chrysophyceae	--	--	--	--	--	<1	30	17	4	33	9	5
Cyanophyceae	--	--	--	--	--	0	<1	1	6	4	2	11
Euglenophyceae	--	--	--	--	--	0	0	0	0	0	10	2
Dinophyceae	--	--	--	--	--	0	0	0	0	<1	0	0
Skunk Lake (J)												
Bacillariophyceae	--	83	25	28	98	87	--	--	--	--	--	--
Chlorophyceae	--	14	3	17	2	9	--	--	--	--	--	--
Chrysophyceae	--	0	72	56	0	0	--	--	--	--	--	--
Cyanophyceae	--	3	1	<1	<1	4	--	--	--	--	--	--

-- Indicates no sample collected.

their abundance increased to 58 to 72 percent of the community. The most common golden-brown algae were the unidentified Chrysococcus-like algae and Chrysococcus major.

Blue-green algae were found in all collections except May 1978. With the exception of September 1977, when 61 percent of the sample at Station H was composed of blue-green algae, this group comprised 12 percent or less of the collections.

Duck Lake - Periphytic algae samples were collected from Duck Lake during October 1977 and monthly from May through October 1978. The relative abundances of the seven major taxa are presented in Table 2.5-44. The relative abundances of taxa from each collection are presented in Appendix 2.5C, Table C-2. The 94 taxa identified are presented in Appendix 2.5C, Table C-15.

Diatoms dominated the periphytic algal community in June and October 1978 comprising 70 and 64 percent of the collections, respectively. Diatom abundance was similar to that of green algae in May 1978, and blue-green algae in August and September 1978. Tabellaria fenestrata was the most abundant diatom and T. flocculosa was commonly collected but in low abundance.

Green algae were most abundant in October 1977 (50 percent) and May 1978 (49 percent). At other times their relative abundance did not exceed 28 percent of the collections. Oedogonium sp. and Ulothrix sp. were the most abundant green algal forms.

Golden-brown algae comprised 37 and 28 percent of the community in August and September 1978, respectively, but other times did not exceed 14 percent. Blue-green algae comprised 40 percent of the collection in July

1978 but did not exceed 8 percent during any other sampling periods. Common golden-brown algae included an unidentified Chrysococcus-like algae and Chrysococcus major. Hapalosiphon flexuosus was the most common blue-green algal species.

Deep Hole Lake - Periphytic algae samples were collected from Deep Hole Lake during October 1977 and monthly from May through October 1978. The relative abundance of the six major taxa identified during the study is presented in Table 2.5-44. The relative abundance of taxa from each collection is presented in Appendix 2.5C, Table C-1. The 128 genera and species identified are presented in Appendix 2.5C, Table C-14.

Diatoms, green algae, and golden-brown algae were the predominant groups of periphytic algae. Diatoms were most abundant (43 to 69 percent) in spring and autumn. However, they were similar in abundance to green algae in July 1978 and to green algae and blue-green algae in August 1978. The most abundant diatom species was Tabellaria flocculosa, and T. fenestrata was commonly collected.

Green algae generally were second in abundance to diatoms throughout the study. The most common green algal form encountered was the genus Oedogonium. The primary forms of golden-brown algae were the unidentified Chrysococcus-like algae.

Skunk Lake - Periphytic algae samples were collected from Skunk Lake monthly from June through October 1977. The relative abundances of the four major taxa identified during the investigation are presented in Table 2.5-44. The relative abundances of taxa from each collection are presented in Appendix 2.5C, Table C-7. The 64 genera and species identified are presented in Appendix 2.5C, Table C-20.

Diatoms were the most abundant periphytic algal class collected in June, September and October 1977 comprising over 80 percent of these samples. However, their abundance decreased to <30 percent of the July and August collections. The most abundant diatom was Nitzschia palea. Other common forms were Frustulia rhomboides var. saxonica, Tabellaria flocculosa and T. fenestrata.

Golden-brown algae comprised 72 and 56 percent of the July and August samples, respectively. The collections primarily consisted of unidentified Chrysococcus-like algae.

Aquatic Macrophytes

Little Sand Lake - Aquatic macrophyte vegetation in Little Sand Lake was located primarily along shoreline areas in water depths to 1 m (3.3 feet) (Figure 2.5-3). The pondweed Potamogeton epihydrus, which occurred sparsely throughout the lake, was typically found at depths >1 m (3.3 feet).

Aquatic macrophyte beds in the shallow areas along the northern, eastern, and southwestern shore areas, characterized primarily by sandy substrates, were dominated by spike rush. This spike rush comprised approximately 75 percent of the vegetative cover in these areas. Other species common in these areas were: yellow water lily (Nuphar variegatum and N. rubrodiscus), waterwort (Elatine triandra), narrow-leaved bur reed (Sparganium angustifolium), mud rush (Juncus pelocarpus), water lobelia, and bulrush (Scirpus torreyi). Vegetation along the northeastern shoreline area that had primarily silt-organic substrate was characterized by yellow water lily (Nuphar rubrodiscus), bur reed (Sparganium fluctuans), and pondweed (Potamogeton epihydrus). Common species in the southeastern portion of the lake were watershield (Braseinia schreberi), arrowhead (Sagittaria graminea), yellow water lily (N. rubrodiscus), pipewort, and fluctuating bur reed (Sparganium fluctuans).

Sparsely occurring macrophytes, including the white water lily (Nymphaea tuberosa) and bur reed (Sparganium angustifolium), were observed in the southwestern area of the lake at a water depth of 1.2 m (4 feet).

Additional species found by the DNR were spike rush (Eleocharis smallii), quillwort (Isoetes spp.), three-way sedge, water hemlock (Cicuta bulbifera), and dwarf milfoil (Ramharter, 1982a).

Deep Hole Lake - The primary areas of vegetation in the littoral zone of Deep Hole Lake extended from the shoreline to a depth of 1 m (3.3 feet) (Figure 2.5-3). Common aquatic macrophyte species, in order of apparent relative abundance, were arrowhead (Sagittaria latifolia), spike rush (Eleocharis smallii), yellow water lily (Nuphar variegatum), and pondweed (P. epihydrus). These species were observed in moderate stands in all areas along the northern, western, southwestern and eastern shorelines. Bur reed (Sparganium fluctuans) and cattail were observed in sparse stands along parts of the southern and eastern lake shoreline areas. The only aquatic macrophyte found at depths >1 m (>3.3 feet) was the pondweed, which occurred infrequently.

Nonwoody vegetation found in shoreline wetland areas was commonly comprised of cut grass (Leersia oryzoides), manna grass (Glyceria canadensis), and sedges (Scirpus cyperinus, Carex rostrata, and Dulichium arundinaceum). Less common species in these areas included beggar's tick and marsh St. John's-wort (Triadenum fraseri).

Additional species found by the DNR were arrowhead (Sagittaria sp.), bladderwort (Utricularia vulgaris), water arum (Calla palustris), water lobelia, pipewort, rush, Juncus pelocarpus, waterwort (Elatine minima), and quillwort (Isoetes echinospora) (Ramharter, 1982a).

Duck Lake - Aquatic macrophytes are primarily limited to sparse growths in southern and northwestern areas of Duck Lake (Figure 2.5-3). Species that were found in these areas and that comprised approximately 75 percent of the macrophyte community were yellow water lily (Nuphar variegatum) and bur reed (Sparganium fluctuans). Water arum was also observed but was limited in abundance.

Other species occurring in sparse stands were pipewort and water lily (Nymphaea sp.). Pipewort was observed along the southern portions of the lake shore, and the water lily primarily along the northwestern shore. A moss mat composed of Drepanocladus exannulatus overlaid the sediment over most of the lake.

Uprooted vegetation that consisted primarily of pondweed (Potamogeton confervoides), a species listed as threatened in Wisconsin, was found along the east and southeast shoreline in July 1980. The identification of this species was made by Dr. H. Iltis of Madison, Wisconsin from several intact specimens. In addition to the lake vegetation survey in 1978, littoral areas of the lake were searched in July and October 1980 from a canoe and the deep portions in October 1980 utilizing snorkel and scuba gear, specifically to locate this rooted aquatic plant. No rooted specimens were found.

Additional species found by the DNR in verification studies were white water lily (Nymphaea tuberosa), pipewort, pondweed (Potamogeton epihydrus), manna grass (Glyceria canadensis), three-way sedge, sedge (Carex limosa), pitcher plant (Sarracenia purpurea), bog cinquefoil (Potentilla palustris), iris (Iris versicolor), small bur reed (Sparganium minima), quillwort (Isoetes sp.), Nitella sp., and arrowhead (Sagittaria sp.) (Ramharter, 1982a).

Skunk Lake - Generally, aquatic vegetation occurred in moderate stands throughout the lake but was most abundant along shoreline areas (Figure 2.5-3). The vegetation was primarily pondweed (Potamogeton sp.) and yellow water lily (Nuphar variegatum). Shoreline areas were characterized by moderate growths of spike rush.

Additional species reported by the DNR in Skunk Lake were three-way sedge (Dulichium arundinaceum), Robbin's pondweed (Potamogeton robbinsii), bulrush (Scirpus sp.), cattail (Typha latifolia), bladderwort (Utricularia sp.), sphagnum moss (Sphagnum sp.), leatherleaf (Chamaedaphne calyculata), and water moss (Drepnocladus sp.) (Druckenmiller, 1983).

Benthic Macroinvertebrates

Little Sand Lake - Benthic macroinvertebrates were collected at two locations, Stations H and I, in Little Sand Lake during March, May, August, and October 1977 and March, May, and August 1978. The seven major taxa collected in quantitative sampling and their density and relative abundance are presented in Table 2.5-45. The density and relative abundance of individual taxa are presented in Appendix 2.5D, Tables D-13 through D-19. The 67 taxa identified in quantitative sampling from Station H and 73 from Station I as well as the additional 14 taxa identified in qualitative sampling are presented in Appendix 2.5D, Table D-71.

TABLE 2.5-45

MEAN DENSITY[a] (no./m^2), RELATIVE ABUNDANCE (%), AND DIVERSITY[b] OF BENTHIC MACROINVERTEBRATES COLLECTED FROM LITTLE SAND LAKE - STATIONS H AND I MARCH, MAY, AUGUST, AND OCTOBER 1977 AND MARCH, MAY, AND AUGUST 1978

	1977								1978					
	MARCH		MAY		AUGUST		OCTOBER		MARCH		MAY		AUGUST	
	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%
Oligochaeta														
H	207	2	940	6	241	1	940	2	86	<1	1,020	4	747	12
I	293	1	302	2	207	2	681	2	345	2	158	1	431	6
Amphipoda														
H	103	1	0	0	9	<1	9	<1	0	0	0	0	14	<1
I	26	<1	0	0	0	0	0	0	0	0	0	0	0	0
Ephemeroptera														
H	9	<1	17	<1	0	0	181	<1	0	0	14	<1	0	0
I	34	<1	0	0	0	0	17	<1	0	0	0	0	0	0
Trichoptera														
H	681	6	431	3	578	3	733	2	402	2	618	2	460	7
I	1,388	6	621	4	724	8	940	2	776	5	718	6	517	8
Chironomidae														
H	11,154	91	12,896	86	12,913	77	36,411	91	21,895	93	24,854	87	4,597	71
I	22,119	91	13,327	91	6,232	72	27,774	72	13,418	90	9,582	77	5,057	74
Gastropoda														
H	0	0	0	0	0	0	0	0	0	0	0	0	158	2
I	0	0	0	0	0	0	0	0	14	<1	0	0	0	0
Pelecypoda														
H	17	<1	172	1	216	1	0	0	0	0	0	0	0	0
I	0	0	86	1	52	1	95	<1	29	<1	58	<1	287	4
All Others[c]														
H	95	1	534	4	2,741	16	1,690	4	1,221	5	1,911	7	503	8
I	517	2	353	2	1,388	16	8,904	23	287	2	1,968	16	546	8
Total														
H	12,266		14,990		16,697		39,962		23,604		28,417	100	6,479	
I	24,377		14,688		8,603		38,411		14,870		12,485	100	6,838	
Number of Replicates	5		5		5		5		3		3		3	
Diversity														
H	0.8		0.9		1.1		1.0		1.0		1.0		1.0	
I	1.0		0.9		1.1		1.0		1.0		1.1		0.8	

[a]Density is the mean of three or five replicate samples, as indicated above, and rounded to the nearest whole number.

[b]Calculated by Brillouin's formula (log_{10}) using numbers of organisms presented in Appendix 2.5D, Tables D-13 through D-19.

[c]Includes Tricladida, Hirudinea, Hydracarina, Zygoptera, Coelenterata, Nematoda, Anisoptera, Neuroptera, Ostracoda, and Diptera other than Chironomidae.

Density of benthic organisms in 1977 ranged from 12,266/m^2 in March to 39,962/m^2 in October at Station H and from 8,603/m^2 in August to 38,411/m^2 in October at Station I. In May and October density at both stations was similar but considerable variation occurred in March and August.

In 1978 density ranged from 6,479/m^2 in August to 28,417/m^2 in May at Station H and from 6,838/m^2 in August to 14,870/m^2 in March at Station I. Densities in 1978 generally corresponded to densities observed in 1977.

Midges were the most abundant benthic macroinvertebrates collected at both sampling locations, comprising over 70 percent of the benthos collected during each sampling period. Common and abundant midges were *Pseudochironomus* sp., *Tanytarsus* sp., and *Procladius* sp.

Other organisms that were common but never exceeded 12 percent of the benthos community were worms and caddisflies. Of the worms enumerated, no single species exceeded 4 percent of the total benthos during any one period. At both sampling locations, the common naidids were *Nais* sp. and *Dero digitata*. Less common and irregularly occurring naidid forms included *Stylaria fossularis*, *Slavina appendiculata* and *Vejdovskyella comata*. Immature forms were the most common tubificids recorded throughout the study.

No caddisfly species exceeded 8 percent of the total benthos identified at any location for any collection period. This group was composed primarily of *Polycentropus* sp., which comprised from 75 to 95 percent of the caddisflies collected from both sampling locations during any sampling period.

Benthic diversity ranged from 0.8 at Station H in March 1977 and Station I in August 1978 to 1.1 at Station H in August 1977 and Station I in August 1977 and May 1978 (Table 2.5-45).

Taxa collected by the DNR during verification studies are presented in Appendix 2.5D, Table D-84. Samples were obtained with an Ekman grab in deep and shallow portions of the lake during October 1979 (Ramharter, 1982a).

Duck Lake - Benthic macroinvertebrates were identified from quantitative samples and qualitative collections from Duck Lake during May, August, and October 1977 and March, May, and August 1978. The five major taxa collected in quantitative sampling and their density and relative abundance are presented in Table 2.5-46. The density and relative abundance of individual taxa are presented in Appendix 2.5D, Tables D-7 through D-12. The 53 taxa identified in quantitative sampling and the additional 12 taxa identified in qualitative sampling are presented in Appendix 2.5D, Table D-70.

In 1977, benthic density was highest in May, 20,192/m^2, and subsequently decreased to 3,879/m^2 in October. In 1978, the previous year's trend of high spring density was not observed and density ranged from 3,549/m^2 in August to 6,609/m^2 in May.

Worms dominated in August and October 1977 and August 1978 comprising 45 to 75 percent of the collections. During the other sampling periods worms comprised from 18 to 41 percent. Naidid worms, including *Nais* sp., *Vejdovskyella comata*, and *Dero digitata*, were generally abundant but immature tubificid forms, as well as *Aulodrilus pigueti* occurred regularly at low densities.

TABLE 2.5-46

MEAN DENSITY[a] (no./m^2), RELATIVE ABUNDANCE (%), AND DIVERSITY[b] OF BENTHIC MACROINVERTEBRATES COLLECTED FROM DUCK LAKE - STATION K MAY, AUGUST, AND OCTOBER 1977 AND MARCH, MAY, AND AUGUST 1978

	1977						1978					
	MAY		AUGUST		OCTOBER		MARCH		MAY		AUGUST	
	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%	no./m^2	%
Oligochaeta	8,340	41	9,568	65	1,738	45	1,695	37	1,221	18	2,672	75
Amphipoda	0	0	0	0	0	0	0	0	0	0	14	<1
Ephemeroptera	43	<1	86	1	316	8	101	2	532	8	29	1
Trichoptera	690	3	690	5	216	6	718	16	934	14	273	8
Chironomidae	9,633	48	3,146	21	1,293	33	1,695	37	2,916	44	287	8
All Others[c]	1,487	7	1,250	8	316	8	359	8	1,006	15	273	8
Total	20,192		14,740		3,879		4,569		6,609		3,549	
Number of Replicates	2		2		3		3		3		3	
Diversity	1.0		0.9		0.9		0.8		1.1		0.8	

[a]Density is the mean of two or three replicate samples, as indicated above, rounded to the nearest whole number.

[b]Calculated by Brillouin's formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5D, Tables D-7 through D-12.

[c]Includes Nematoda, Anisoptera, Hydracarina, Ostracoda, Zygoptera, and Diptera other than Chironomidae.

Midges were the most abundant organisms in May 1977 and 1978 comprising 48 and 44 percent of the respective collections. Midges were codominant with worms in March 1978 comprising 37 percent of the collections. During the remaining sampling periods midges comprised from 8 to 21 percent of the collections. Tanytarsus sp. was the most abundant midge and Polypedilum sp., Chironomus sp., and Conchapelopia sp. were also commonly collected.

Other benthic groups that occurred throughout the study were caddisflies and mayflies that comprised up to 16 and 8 percent, respectively, of the benthic community. The two most common caddisflies were Polycentropus sp. and Oxyethira sp., while Caenis sp. was the most abundant mayfly.

Individual diversity values ranged from 0.8 in March and August 1978 to 1.1 in May 1978 (Table 2.5-46).

Taxa collected by the DNR during verification studies are presented in Appendix 2.5D, Table D-83. Samples were obtained with an Ekman grab in deep and shallow portions of the lake during October 1979 (Ramharter, 1982a).

Deep Hole Lake - Quantitative and qualitative benthic macroinvertebrate samples were collected from Deep Hole Lake in May, August, and October 1977 and March, May, and August 1978. The six major taxa collected in quantitative sampling and their density and relative abundance are presented in Table 2.5-47. Density and relative abundance of genera and species collected in each quantitative sample are presented in Appendix 2.5D, Tables D-34 through D-37. The 69 taxa identified in quantitative sampling and the 21 additional taxa identified in qualitative sampling are presented in Appendix 2.5D, Table D-69.

TABLE 2.5-47

MEAN DENSITY[a] (no./m²), RELATIVE ABUNDANCE (%), AND DIVERSITY[b] OF BENTHIC MACROINVERTEBRATES COLLECTED FROM DEEP HOLE LAKE - STATION L
MAY, AUGUST, AND OCTOBER 1977 AND MARCH, MAY, AND AUGUST 1978

	1977						1978					
	MAY		AUGUST		OCTOBER		MARCH		MAY		AUGUST	
	no./m²	%	no./m²	%	no./m²	%	no./m²	%	no./m²	%	no./m²	%
Oligochaeta	101	1	776	5	589	3	58	1	431	3	1,078	18
Amphipoda	29	<1	0	0	0	0	0	0	0	0	14	<1
Ephemeroptera	0	0	0	0	0	0	14	<1	29	<1	0	0
Trichoptera	144	1	1,013	7	991	4	101	1	273	2	675	11
Chironomidae	9,726	87	11,422	74	19,079	82	9,367	89	11,034	77	2,543	42
Pelecypoda	761	7	991	6	675	3	330	3	991	7	675	11
All Others[c]	474	4	1,142	7	1,839	8	632	6	1,494	10	1,020	17
Total	11,235		15,344		23,173		10,502		14,252		6,005	
Number of Replicates	3		2		3		3		3		3	
Diversity	0.8		1.0		1.0		0.9		1.0		1.1	

[a]Density is the mean of two or three replicate samples, as indicated above, rounded to the nearest whole number.

[b]Calculated by Brillouin's formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5D, Tables D-34 through D-37.

[c]Includes Nematoda, Anisoptera, Alloeocoela, Hydracarina, Zygoptera, Hirudinea, Coleoptera, and Diptera other than Chironomidae.

In 1977, density ranged from $11,235/m^2$ in May to $23,173/m^2$ in October. In 1978, density was lowest in August ($6,005/m^2$) and highest in May ($14,252/m^2$).

Midges were the most abundant benthic macroinvertebrates enumerated, comprising 42 to 89 percent of the benthos collected. Overall, the most common and abundant midge was Tanytarsus sp., which was recorded in all sampling periods. Microtendipes sp., Procladius sp., and Pseudochironomus sp. also were found regularly.

Other groups that were collected in moderate densities included worms, caddisflies, and clams.

Worms comprised 5 percent or less of the benthos during all sampling periods except August 1978, when worms comprised 18 percent of the total benthos. Common forms were immature tubificids with hair setae, Nais sp., and Stylaria fossularis.

Monthly values of benthic diversity ranged from 0.8 in May 1977 to 1.1 in August 1978 (Table 2.5-47).

Taxa collected by the DNR during verification studies are presented in Appendix 2.5D, Table D-82. Samples were obtained with an Ekman grab in deep and shallow portions of the lake during October 1979 (Ramharter, 1982a).

Skunk Lake - Benthic macroinvertebrates were collected from Skunk Lake in May and August 1977. The three major taxa collected in quantitative sampling and their density and relative abundance are presented in Table 2.5-48. Density and relative abundance of individual taxa are presented in Appendix 2.5D, Tables D-38 and D-39. The 20 taxa identified from quantitative sampling and an additional 2 taxa identified in qualitative sampling are presented in Appendix 2.5D, Table D-75.

TABLE 2.5-48

MEAN DENSITY[a] (no./m^2), RELATIVE ABUNDANCE (%), AND DIVERSITY[b] OF BENTHIC MACROINVERTEBRATES COLLECTED FROM SKUNK LAKE - STATION J MAY AND AUGUST 1977

	MAY		AUGUST	
	no./m^2	%	no./m^2	%
Oligochaeta	560	29	2,263	14
Chironomidae	733	38	14,223	86
Pelecypoda	108	6	22	<1
All Others[c]	539	28	108	1
Total	1,940		16,615	
Diversity	0.6		0.3	

[a]Density is the mean of two replicate samples, rounded to the nearest whole number.

[b]Calculated by Brillouin's formula (log_{10}) using numbers of organisms presented in Appendix 2.5D, Tables D-38 and D-39.

[c]Includes Hydracarina, Nematoda, and Diptera other than Chironomidae.

Densities of organisms were considerably higher in August (16,615/m^2) than in May (1,940/m^2). The increase in density was largely from abundance of midge flies and worms. The dominant midge in May was *Psectrocladius* sp., which comprised 21 percent of the sample. In August *Chironomus* sp. was the dominant midge, comprising 81 percent of the sample. *Dero digitata* was the dominant worm in both collections.

Diversity was higher in May (0.6), when no single taxon comprised more than 25 percent of the sample (Table 2.5-48). The low value, 0.3, corresponded to the dominance (86 percent of the sample) of one taxon, Chironomidae.

Fish

Little Sand Lake - Ten species of fish, representing the families Catostomidae, Centrarchidae, Esocidae, Ictaluridae, and Percidae, were collected in Little Sand Lake during May, August, and October 1977 and May and August 1978. Length-weight data for the fish collected are summarized in Appendix 2.5E, Tables E-5 and E-6.

Yellow perch, yellow bullhead, and bluegill were collected in all months sampled and generally were the most abundant species in Little Sand Lake (Table 2.5-49). Yellow perch were the most abundant species in the gill net catches, except in October 1977, comprising 67 to 100 percent of the samples and in electroshocking samples comprising 42 to 87 percent. Yellow bullhead comprised 2 to 49 percent and bluegill 1 to 72 percent (16 per net set) of the fyke net catches.

Other species collected were black crappie, largemouth bass, walleye, and northern pike. Although black crappie and largemouth bass

	1978															
	MAY								AUGUST							
	(BS)		(GN)		(FN)		(ES)		(BS)		(GN)		(FN)		(ES)	
	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Catostomidae																
White sucker	0	0	0	0	0	0		0	0	0	1	33	0	0	0	0
Centrarchidae																
Bluegill	0	0	0	0	1	1	0	0	13	30	0	0	34	45	14	10
Pumpkinseed	0	0	0	0	0	0	3	5	21	48	0	0	7	9	39	29
Black crappie	0	0	0	0	14	20	2	3	0	0	0	0	0	0	0	0
Largemouth bass	0	0	0	0	0	0	0	0	4	9	0	0	5	7	9	7
Esocidae																
Northern pike	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0
Ictaluridae																
Black bullhead	0	0	0	0	2	3	1	2	0	0	0	0	0	0	0	0
Yellow bullhead	0	0	0	0	51	73	2	3	0	0	0	0	26	35	16	12
Percidae																
Walleye	0	0	0	0	2	3	0	0	0	0	0	0	0	0	0	0
Yellow perch	4	100	25	96	0	0	54	87	6	14	2	67	3	4	56	42
Total	4		26		70		62		44		3		75		134	

TABLE 2.5-49

NUMBERS AND RELATIVE ABUNDANCE (PERCENT OF TOTAL CATCH)
OF FISH COLLECTED BY GILL NET (GN)[a], FYKE NET (FN)[b], SEINING (BS)[c], AND
ELECTROSHOCKING (ES)
LITTLE SAND LAKE - STATIONS H AND I
MAY, AUGUST, AND OCTOBER 1977 AND MAY, AND AUGUST 1978

	1977																			
	MAY						AUGUST								OCTOBER					
	(BS)		(GN)		(FN)		(BS)		(GN)		(FN)		(ES)		(BS)		(GN)		(FN)	
	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Catostomidae																				
White sucker	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Centrarchidae																				
Bluegill	2	4	0	0	10	12	20	21	0	0	78	72	1	4	1	100	0	0	3	4
Pumpkinseed	25	44	0	0	3	4	35	36	0	0	23	21	1	4	0	0	0	0	1	1
Black crappie	0	0	0	0	9	11	0	0	0	0	0	0	2	7	0	0	0	0	29	41
Largemouth bass	4	7	0	0	0	0	12	12	0	0	5	5	0	0	0	0	0	0	0	0
Esocidae																				
Northern pike	0	0	0	0	0	0	0	0	1	5	0	0	0	0	0	0	0	0	0	0
Ictaluridae																				
Black bullhead	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	1	1
Yellow bullhead	0	0	0	0	15	18	0	0	1	5	2	2	5	19	0	0	0	0	34	49
Percidae																				
Walleye	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	100	0	0
Yellow perch	26	46	170	100	44	54	29	30	18	90	1	<1	17	63	0	0	0	0	2	3
Total	57		170		82		96		20		109		27		1		2		70	

[a]Two gill nets were fished.

[b]One fyke net was fished in May and August 1977; two were fished in October 1977 and May and August 1978.

[c]Minnow net was used May 1977; beach haul seine was used other times.

comprised small percentages (≤14 percent) of any collection, they were collected in most sampling periods. Walleye and northern pike occurred infrequently and made up 5 percent or less of the catches.

Electrofishing in October 1977 by the DNR (Theis, 1978) yielded higher numbers of fish (217) than electrofishing samples for the baseline studies (27 to 134). However, the DNR sampled the entire lake perimeter, whereas baseline sampling was conducted for approximately 0.5 hour (see subsection 2.5.1), which encompassed approximately one-half of the lake perimeter. The assemblage of fish collected by the DNR was similar to other baseline electrofishing samples. Fish collected and their percent of catch were: bluegill, 8; pumpkinseed, 4; black crappie, 4; largemouth bass, <1; northern pike, <1; black bullhead, <1; yellow bullhead, 12; and yellow perch, 71.

Additional fish species collected by the DNR in verification sampling were mudminnow, northern pike, and Iowa darter (Ramharter, 1982a). Samples were obtained with fyke nets, minnow seines, and boom electrofisher in May, September, and October 1979, and October 1980.

Duck Lake - Yellow perch, black bullhead, and mudminnow were collected from Duck Lake in May, August and October 1977 and May and August 1978 surveys (Table 2.5-50). Length-weight data for the fish collected are summarized in Appendix 2.5E, Tables E-3 and E-4. Yellow perch, which comprised 73 percent or more of the gill net catches, was the only species caught in minnow traps and it comprised 87 percent of the electroshocking samples. Black bullheads were a minor portion of the catches in 1977 (2 to 27 percent) and none were collected in 1978. Mudminnows were collected in low numbers in October 1977 and August 1978.

TABLE 2.5-50

NUMBERS AND RELATIVE ABUNDANCE (PERCENT OF TOTAL CATCH) OF FISH COLLECTED BY GILL NET (GN)[a], MINNOW TRAP (MT)[b], AND ELECTROSHOCKING (ES)
DUCK LAKE - STATION K
MAY, AUGUST, AND OCTOBER 1977 AND MAY AND AUGUST 1978

	1977						1978							
	MAY		AUGUST		OCTOBER		MAY				AUGUST			
	(GN)		(GN)		(GN)		(GN)		(MT)		(GN)		(ES)	
SPECIES	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Ictaluridae														
Black bullhead	12	27	1	2	1	2	0	0	0	0	0	0	0	0
Percidae														
Yellow perch	32	73	53	98	45	96	453	100	528	100	61	100	26	87
Umbridae														
Mudminnow	0	0	0	0	1	2	0	0	0	0	0	0	4	13
Total	44		54		47		453		528		61		30	

[a]One gill net was fished in May and August 1977 and May 1978; two nets were fished in October 1977 and August 1978.

[b]Three minnow traps were fished.

No additional fish species were collected by the DNR in verification sampling (Ramharter, 1982a). Fish sampling consisted of gill netting and fyke netting in October 1979 and 1981.

Deep Hole Lake - Walleye, yellow perch, white sucker and golden shiner were the only species collected in Deep Hole Lake during May, August, and October 1977 and May and August 1978 surveys (Table 2.5-51). Length-weight data for the species collected are summarized in Appendix 2.5E, Tables E-1 and E-2. Yellow perch, the most abundant species in all collections, comprised 75 percent or more of the gill net catches, and 67 percent or more of the electroshocking samples. Walleye comprised minor portions of the electroshocking and gill net catches. No fish were caught in minnow traps fished in May 1978.

Additional fish species collected by the DNR in verification sampling were mudminnow and bluegill (Ramharter, 1982a). Fish sampling was conducted in September and October 1979 utilizing minnow seine, fyke nets, gill nets and boom shocker.

Skunk Lake - No fish were collected by minnow trapping (May 1977) or modified streamside electroshocking (May 1978) in Skunk Lake. Also no fish were collected by the DNR in verification sampling in September 1979 (Ramharter, 1982a).

2.5.3.3 Ponds

Four ponds were sampled within the Pickerel Creek drainage basin: the unnamed ponds 31-13, 6-8, 35-7, and 34-1 (Table 2.5-24). These ponds are southeast to southwest and within 3.9 km (2.4 miles) of the ore body

TABLE 2.5-51

NUMBERS AND RELATIVE ABUNDANCE (PERCENT OF TOTAL CATCH)
OF FISH COLLECTED BY GILL NET (GN)* AND ELECTROSHOCKING (ES)
DEEP HOLE LAKE - STATION L
MAY, AUGUST, AND OCTOBER 1977 AND MAY AND AUGUST 1978

	1977						1978							
	MAY		AUGUST		OCTOBER		MAY				AUGUST			
	(GN)		(GN)		(GN)		(ES)		(GN)		(ES)		(GN)	
SPECIES	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Catostomidae														
White sucker	0	0	0	0	0	0	0	0	1	6	0	0	0	0
Cyprinidae														
Golden shiner	0	0	0	0	0	0	0	0	0	0	2	4	0	0
Percidae														
Walleye	0	0	2	3	1	5	9	33	3	19	1	2	3	4
Yellow perch	13	100	62	97	19	95	18	67	12	75	51	94	65	96
Total	13		64		20		27		16		54		68	

*One gill net was fished in May and August 1977; two nets were fished in October 1977 and May and August 1978.

(Figure 2.5-1). Pond 31-13 is in wetlands associated with Duck Lake, Pond 6-8 is in wetlands associated with Deep Hole Lake, and ponds 34-1 and 35-7 are in wetlands associated with Mole Lake. Macrophytes were surveyed and fish collections were undertaken in all four ponds.

Aquatic Macrophytes

Pond 31-13 - Moderate to sparse vegetation growths in Pond 31-13 included bladderwort and yellow water lily (Nuphar variegatum) (Figure 2.5-3). Other sparsely occurring shoreline and wetland vegetation included sedges (Carex oligosperma and C. limosa) and pitcher plant (Sarracenia sp.).

Pond 6-8 - Aquatic macrophytes observed in moderate stands in Pond 6-8 were yellow water lily (Nuphar variegatum) throughout the pond and water arum along the shoreline and adjacent wetland areas (Figure 2.5-3). Other vegetation occurring in moderate to sparse stands along the shoreline included white water lily, and the sedges Dulichium arundinaceum and Carex limosa. Common nonwoody, riparian vegetation, which contained a variety of plant types associated with bog areas, included primrose (Lysimaehia terrestris), beggar's tick (Bidens comosa), marsh cinquefoil, iris, marsh St. John's-wort, sundew (Drosera sp.), and pitcher plant.

Pond 35-7 - Yellow water lily (Nuphar variegatum) was observed in moderate to dense growths throughout Pond 35-7 (Figure 2.5-3). Other macrophytes occurring moderately to sparsely in limited areas along shoreline or marginal wetland areas were as follows: cattail, water arum, pondweed (Potamogeton epihydrus), the sedges Carex lacustris, C. crawfordii and C. comosa, and the grass Muhlenbergia glomerata.

Additional species found by the DNR in verification studies were muskgrass, (*Chara* sp.), water hemlock, and pitcher plant (*Sarracenia purpurea*) (Ramharter, 1982a).

Pond 34-1 - The aquatic vegetation located within and along the shoreline of Pond 34-1 included sparse growths of bladderwort (*Utricularia vulgaris* var. *americana*), coontail, water arum, bulrush (*Scirpus cyperinus*), and duckweed (*Lemna* ef. *minor*) (Figure 2.5-3). Wetland vegetation occurring in moderate abundance included marsh bluebell (*Campanula aparinodes* var. *grandiflora*) and water hemlock.

Additional species found by the DNR in verification studies were pitcher plant (*Sarracenia purpurea*), yellow water lily (*Nuphar variegatum*), and water hemlock (Ramharter, 1982a).

Fish

Pond 31-13 - No fish were collected in minnow traps set in Pond 31-13.

Pond 6-8 - Two mudminnows were the only fish collected by minnow trapping in Pond 6-8 in 1977. The length-weight data for these fish are summarized in Appendix 2.5E, Table E-25.

Pond 35-7 - Fish collected from Pond 35-7 in 1977, along with the number collected, and the percent of the catch are: finescale dace, 344 (75 percent); fathead minnow, 59 (13 percent); bluntnose minnow, 55 (12 percent); and brook stickleback 1 (<1 percent).

Pond 34-1 - One brook stickleback was the only fish collected from minnow traps set in Pond 34-1 in 1977. Length-weight measurements for this fish are summarized in Appendix 2.5E, Table E-26.

2.5.3.4 Ecological Relationships of Pickerel Creek Drainage Basin

The hydrologic characteristics of the Pickerel Creek drainage basin, including subwatershed contributions from Pickerel Creek, Creek 11-4, and Creek 12-9 to Rolling Stone Lake, are discussed in section 2.4, Surface Water. Also, the flow contribution of Rolling Stone Lake and tributaries to Pickerel Creek at East Shore Road is presented in section 2.4.

As discussed in subsection 2.4.7, water chemistry of streams in the Swamp Creek and Pickerel Creek drainage basins was similar. Evidence is presented in section 2.3, Ground Water, that suggests that the main ground water aquifer in the site area feeds Rice and Ground Hemlock lakes and the Hemlock-Swamp-Outlet Creek system in the Swamp Creek drainage basin, and Rolling Stone Lake, Pickerel Creek, and Creeks 12-9 and 11-4 in the Pickerel Creek drainage basin. The water quality parameters measured for Rolling Stone Lake typically were within the range of water quality values reported from Pickerel Creek (above Rolling Stone Lake), Creek 12-9, and Creek 11-4.

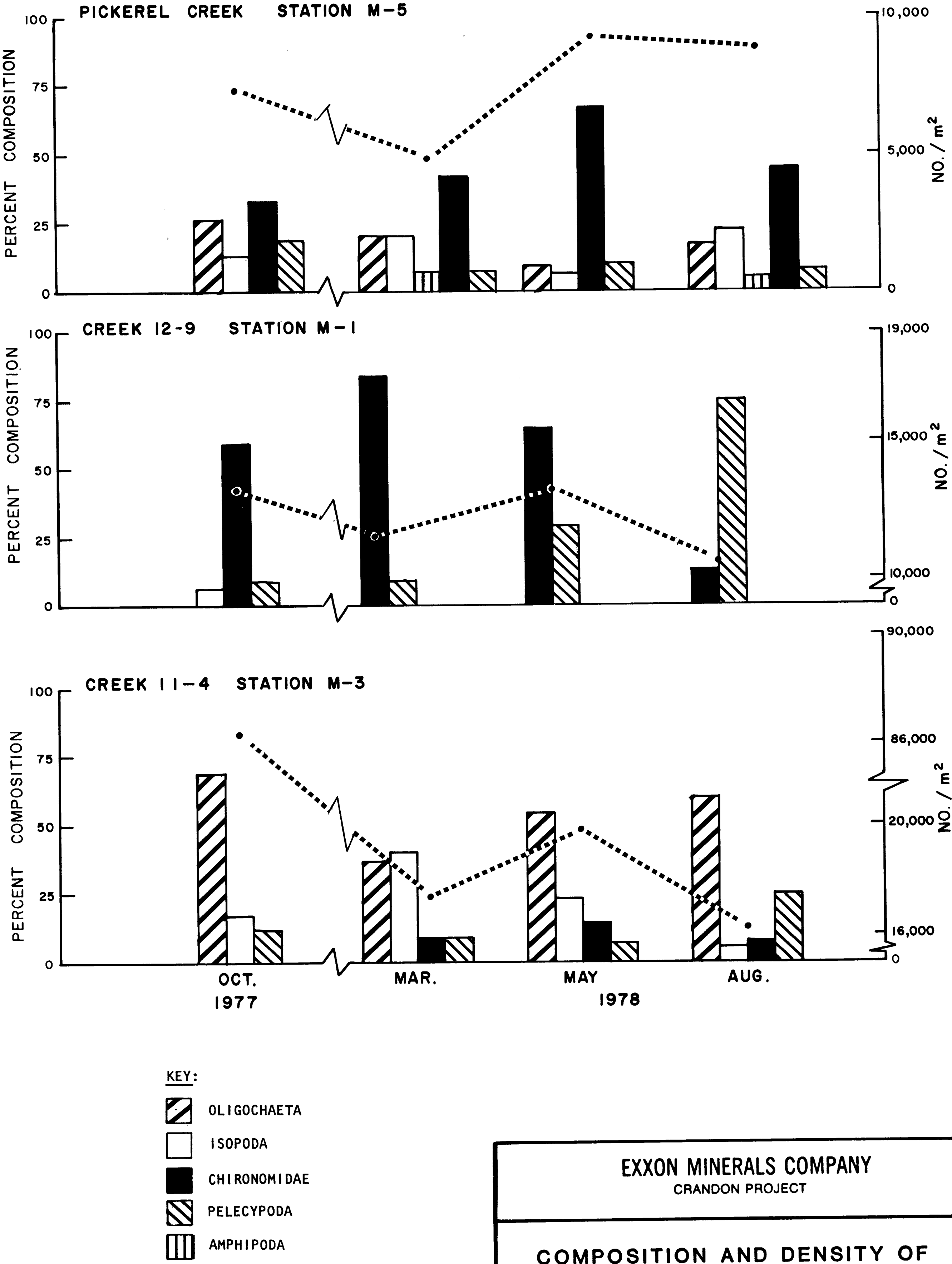
The water quality data presented in section 2.4 and Appendices 2.4F and 2.4G for the water bodies sampled indicated nutrient and metal concentrations were generally low in Pickerel Creek (Station M-5), Creek 11-4 (Station M-3), and Creek 12-9 (Station M-1), and there was minimal contribution to Rolling Stone Lake. Water chemistry data from Rolling Stone Lake at stations in the north (M-2) and south (M-4) portions of the lake were generally similar, indicating that the lake is well mixed. Further information on the water quality characteristics of water bodies in the Pickerel Creek drainage basin is presented in subsections 2.4.5 and 2.4.7.

The southwest portion of the site area, including Pickerel Creek, Creeks 11-4 and 12-9, and Rolling Stone Lake, is primarily an area of ground water discharge from the main ground water aquifer (see subsection 2.3.3.3).

The periphytic algae samples were relatively similar in the tributaries to Rolling Stone Lake. Diatoms comprised over 90 percent of the October 1977 and May 1978 collections and decreased in August when golden-brown algae increased in abundance in all three creeks (Table 2.5-27). However, slight differences in dominant species were observed. In samples from Pickerel Creek the diatoms Eunotia curvata, Navicula minima, Achnanthes lanceolata, and A. minutissima were dominant, at Creek 12-9 Achnanthes lanceolata dominated and at Creek 11-4 A. minutissima and Cocconeis placentula were the dominant species. Golden-brown algae were represented almost exclusively by unidentified Chrysococcus-like algae in all creeks.

Substrates differed slightly among the creeks and the composition of the benthic macroinvertebrate samples reflected these differences. In Pickerel Creek and Creek 12-9, which had bottom substrates of soft muck and detritus, midges were typically most abundant in the samples (Figure 2.5-9). In Creek 11-4 where the bottom substrate was primarily composed of sand with some detritus, worms were most abundant. Wene (1940) reported that midge density is directly related to the texture of the substrate with finer textured substrates supporting higher densities of midges.

The fish samples in Pickerel Creek and Creek 12-9 were most similar in that few species were collected, 6 and 7 respectively, and mottled sculpin,



NOTE: PERCENT COMPOSITION OF ORGANISMS COMPRISING 5 PERCENT OR MORE OF THE COLLECTION (HISTOGRAM) IS INDICATED BY THE LEFT VERTICAL AXIS AND TOTAL DENSITY (NO./m^2) (LINE GRAPH) IS INDICATED BY THE RIGHT VERTICAL AXIS.

EXXON MINERALS COMPANY
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COMPOSITION AND DENSITY OF BENTHIC MACROINVERTEBRATES IN PICKEREL CREEK AND CREEKS 12-9 AND 11-4

FIGURE 2.5-9

brook trout and yellow perch were common. In Creek 11-4, 15 species were captured during the investigation, however, no brook trout or mottled sculpin were collected during this investigation and members of the Cyprinidae (minnow family) were dominant.

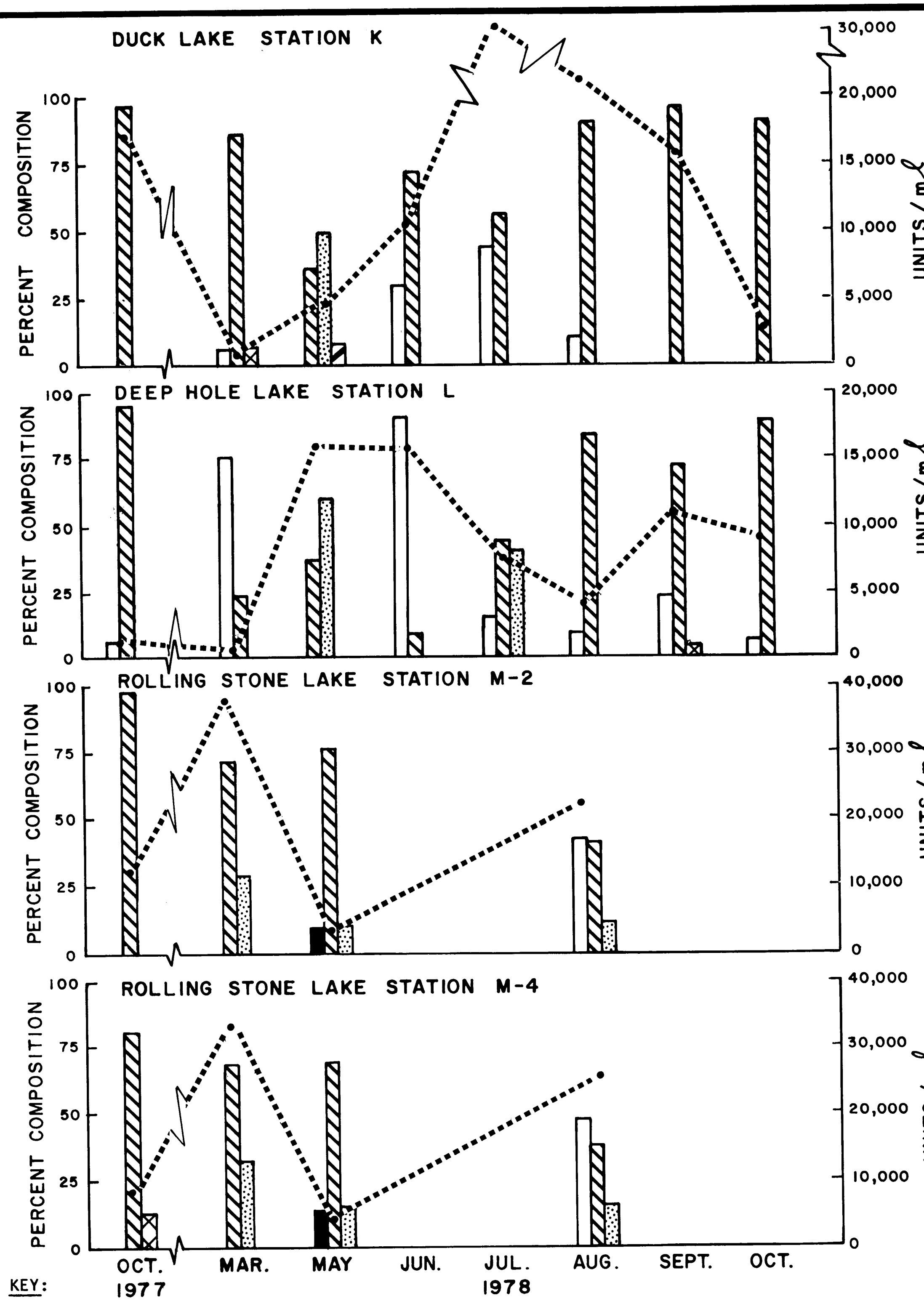
The apparent absence of species such as brook trout and mottled sculpin that dwell in cool, clear streams (Becker, 1976) and the predominance of pond dwelling species such as northern redbelly dace and fathead minnow (Becker, 1976) in Creek 11-4 can be attributed to the alteration in stream habitat caused by the beaver dams. Changes in stream habitat caused by beaver dams can result in increased water temperatures in summer often beyond the tolerance of brook trout, and can isolate fish from spawning grounds. The beaver has been cited as the cause of a serious decline in brook trout in some northern Wisconsin streams where most tributaries with springs have been dammed (Brasch et al., 1973).

Rolling Stone Lake, a ground water discharge lake, receives surface water flow from Pickerel Creek, Creeks 12-9 and 11-4, and the main ground water aquifer. The lake water is characterized as moderately hard, neutral in pH and light brown in color (section 2.4, Surface Water). Deep Hole, Duck, Little Sand, and Skunk lakes act to recharge the ground water and appear to receive no water from the main ground water. The water in these lakes is characterized as soft, slightly acidic and clear to light brown in color. Skunk Lake has no surface water discharge but intermittent surface water flow occurs from Duck Lake and Deep Hole to Little Sand Lake and then Creek 12-9 (section 2.4, Surface Water).

As presented in section 2.4, Surface Water, Little Sand Lake has the clearest water, has little bog vegetation along its shoreline, and is the least bog-like of the seepage lakes. Duck Lake had dark brown stained water and sphagnum moss, which is typical of bog lakes (Boelter and Verry, 1977), was the dominant shoreline vegetation for approximately 75 percent of the shoreline. Deep Hole Lake had sphagnum growths, although less extensive than Duck Lake, and the brown stained water characteristic of bogs but the pH was typically higher (6.0) than either Little Sand Lake (5.4) or Duck Lake (5.0). Although Skunk Lake had some bog-like characteristics such as brown stained waters and relatively low pH, no sphagnum growths were observed.

Distinct seasonal patterns of phytoplankton composition and abundance in samples from lakes in the Pickerel Creek drainage basin were not evident because of the variability from lake to lake and year to year. However, two characteristics were reasonably consistent: a seasonal pattern of relatively low winter densities and relatively high summer densities, and diatoms were relatively uncommon. Peaks occurred in Duck Lake in July 1978, in Little Sand Lake in September 1977 and August 1978, and in Skunk Lake in September 1977 (Figures 2.5-10 and 2.5-11). Exceptions were Deep Hole Lake in which phytoplankton peaks were observed in May and September 1978 and Rolling Stone Lake with peaks in March and August 1978.

At Little Sand Lake golden-brown algae were abundant in May 1977 and 1978, both blue-green algae and green algae dominated from June through September 1977. At Skunk Lake golden-brown algae predominated throughout the period of investigation, from June through October 1977. At Duck and Deep Hole lakes, golden-brown algae predominated in autumn and were more abundant in March and May at Duck Lake than in Deep Hole Lake. At Rolling Stone Lake, golden-brown algae predominated in all months except August 1977 when green algae were codominant with golden-brown algae.



KEY:

- BACILLARIOPHYCEAE
- CHLOROPHYCEAE
- CHRYSOPHYCEAE
- CYANOPHYCEAE
- DINOPHYCEAE
- EUGLENOPHYCEAE

NOTE: PERCENT COMPOSITION OF ORGANISMS COMPRISING 5 PERCENT OR MORE OF THE COLLECTION (HISTOGRAM) IS INDICATED BY THE LEFT VERTICAL AXIS AND TOTAL DENSITY (UNITS/mℓ) (LINE GRAPH) IS INDICATED BY THE RIGHT VERTICAL AXIS.

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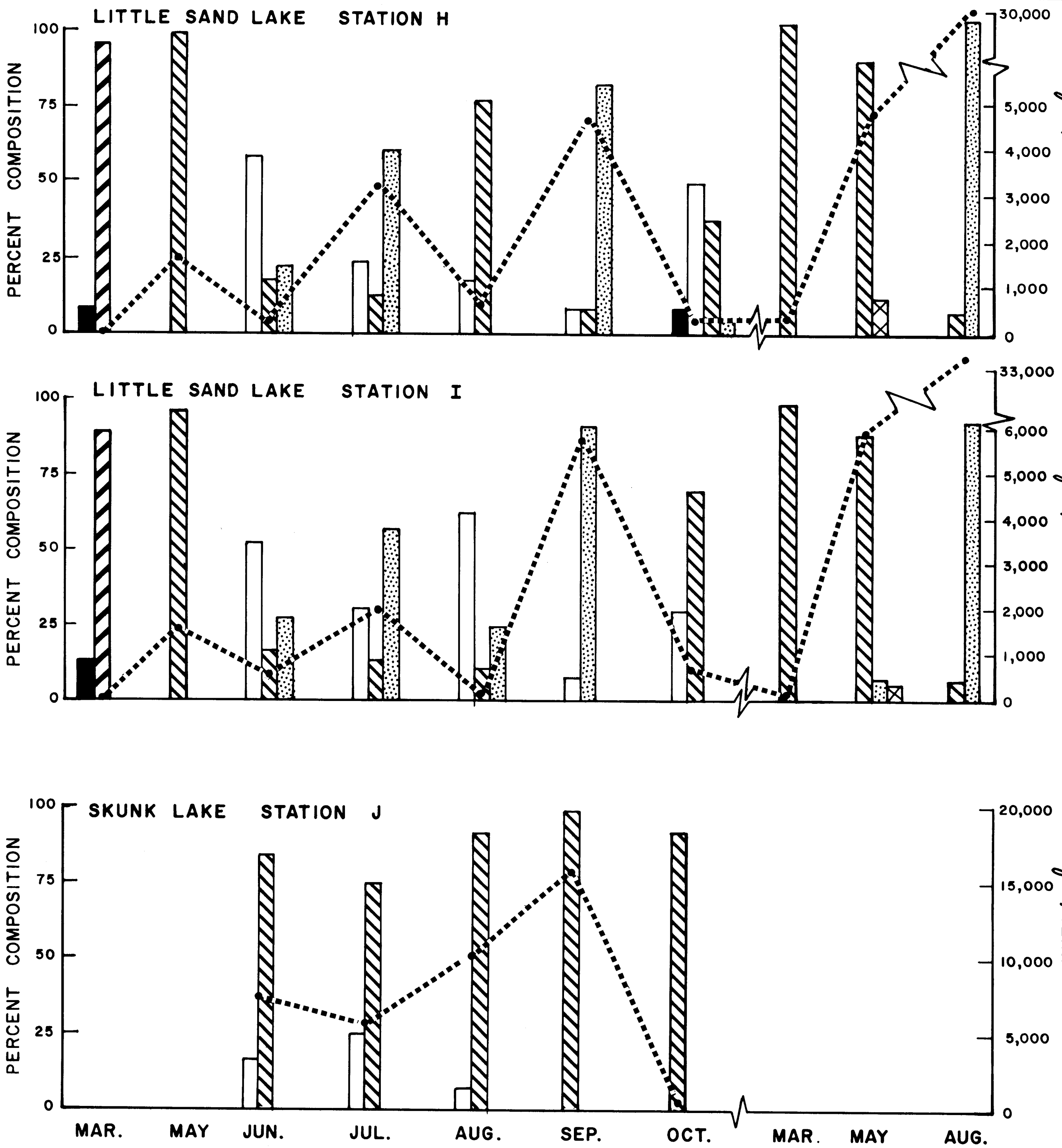
COMPOSITION AND DENSITY OF PHYTOPLANKTON IN DUCK, DEEP HOLE AND ROLLING STONE LAKES

DAMES & MOORE

FIGURE 2-5-10



KEY:

- BACILLARIOPHYCEAE
- CHLOROPHYCEAE
- CHRYSOPHYCEAE
- CYANOPHYCEAE
- DINOPHYCEAE
- EUGLENOPHYCEAE

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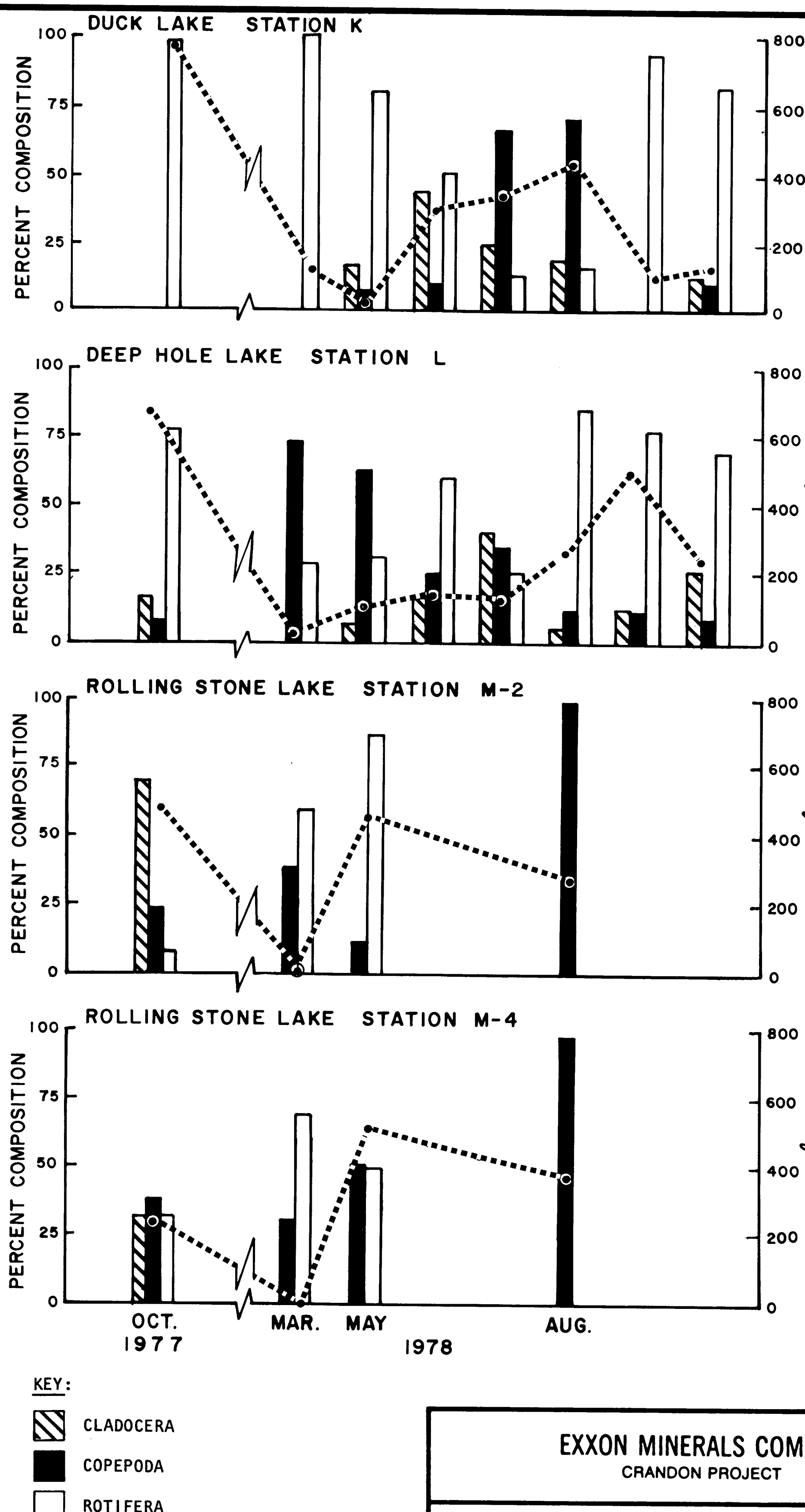
COMPOSITION AND DENSITY OF PHYTOPLANKTON IN LITTLE SAND AND SKUNK LAKES

DAMES & MOORE

FIGURE 2.5-11

Seasonal patterns of zooplankton density typically consisted of low levels in winter samples and elevated levels in spring and autumn samples (Figures 2.5-12 and 2.5-13). However, in Duck and Deep Hole lakes, spring pulses were not observed in 1978 and an autumn pulse was not observed in 1977. Highest zooplankton densities were observed at Skunk (>1,000/l during June and July 1977), Duck (789/l during October 1977) and Deep Hole (693/l during October 1977) lakes, and rotifers comprised most of these collections. Also, rotifers were dominant in these bog-like lakes during most of the other collection periods. Rotifers typically are the most abundant group of zooplankton in bog lakes (Welch, 1963). Except for Skunk Lake, *Keratella taurocephala* was perennially present and abundant in samples from Duck, Deep Hole, and Little Sand lakes. *Keratella taurocephala* has been reported by Hutchinson (1967) as an inhabitant of somewhat acid waters and by Roff and Kwiatkowski (1977) to be dominant in several highly acid northern lakes. Although *Brachionus calyciflorus* and *B. patulus* were represented in low densities, they were only identified from Rolling Stone Lake samples. Alhstrom (1940) stated that the genus *Brachionus* appears to be confined to waters with pH above 6.6 and is typically absent from acid waters.

Periphytic algae samples were generally dominated by diatoms in all lakes and the greatest dominance was consistently observed in samples from Rolling Stone Lake (Tables 2.5-27 and 2.5-44). As was observed in the creeks, the proportion of diatoms decreased in August 1978 in all lakes and in Skunk Lake during 1977, but this decrease was less apparent during 1977 in Little Sand Lake. The abundance of diatoms in periphyton in contrast to their low occurrence in phytoplankton (Figures 2.5-10 and 2.5-11) is typical. Most of freshwater diatoms are sessile (Hutchinson, 1967) and generally constitute a major portion of the periphytic community (Collins and Weber, 1978).



NOTE: PERCENT COMPOSITION OF ORGANISMS COMPRISING 5 PERCENT OR MORE OF THE COLLECTION (HISTOGRAM) IS INDICATED BY THE LEFT VERTICAL AXIS AND TOTAL DENSITY (NO./ℓ) (LINE GRAPH) IS INDICATED BY THE RIGHT VERTICAL AXIS.

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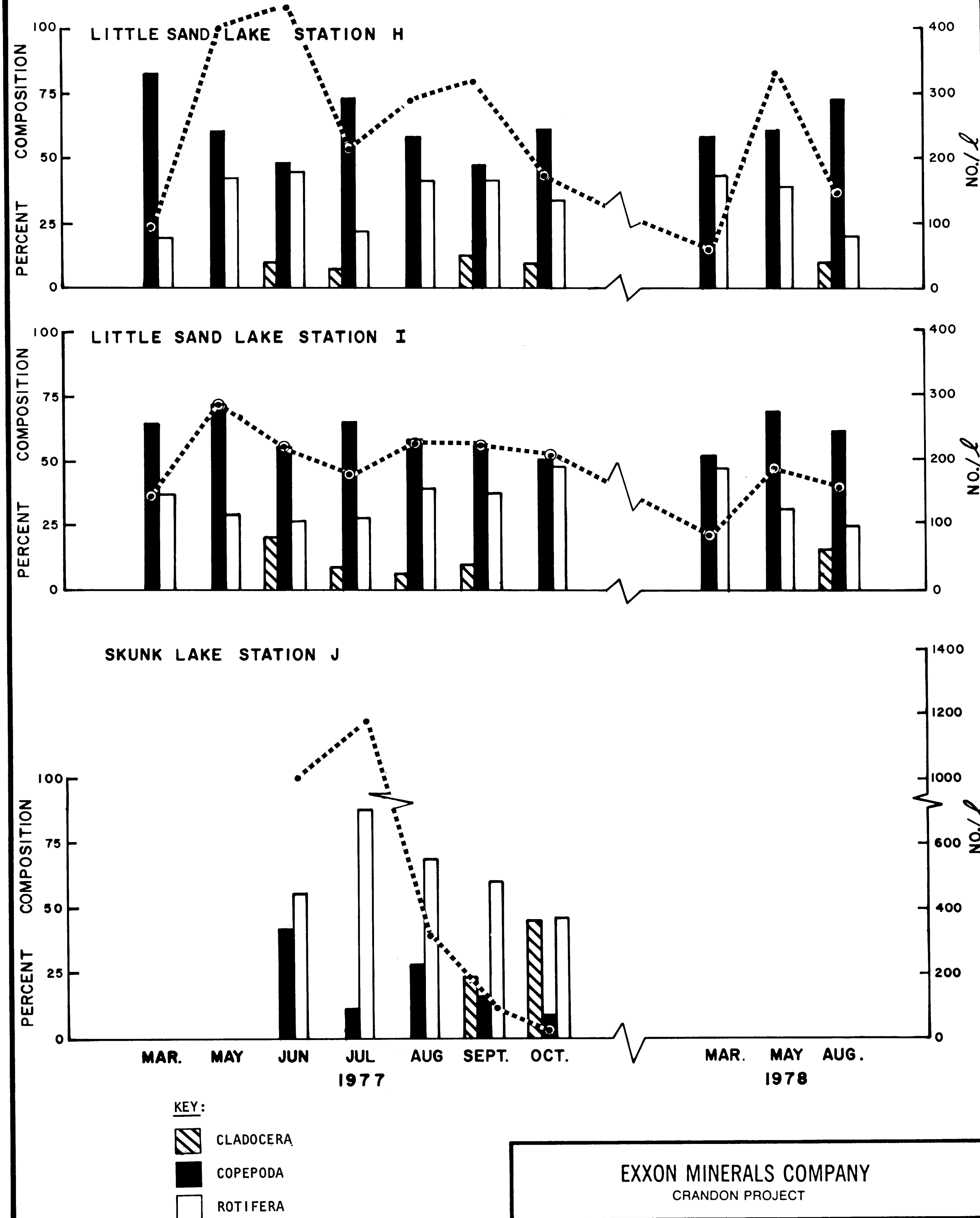
COMPOSITION AND DENSITY OF ZOOPLANKTON IN DUCK, DEEP HOLE, AND ROLLING STONE LAKES

DAMES & MOORE

FIGURE 2.5-12



NOTE: PERCENT COMPOSITION OF ORGANISMS COMPRISING 5 PERCENT OR MORE OF THE COLLECTION (HISTOGRAM) IS INDICATED BY THE LEFT VERTICAL AXIS AND TOTAL DENSITY (NO./ℓ) (LINE GRAPH) IS INDICATED BY THE RIGHT VERTICAL AXIS.

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COMPOSITION AND DENSITY OF ZOOPLANKTON IN LITTLE SAND AND SKUNK LAKES

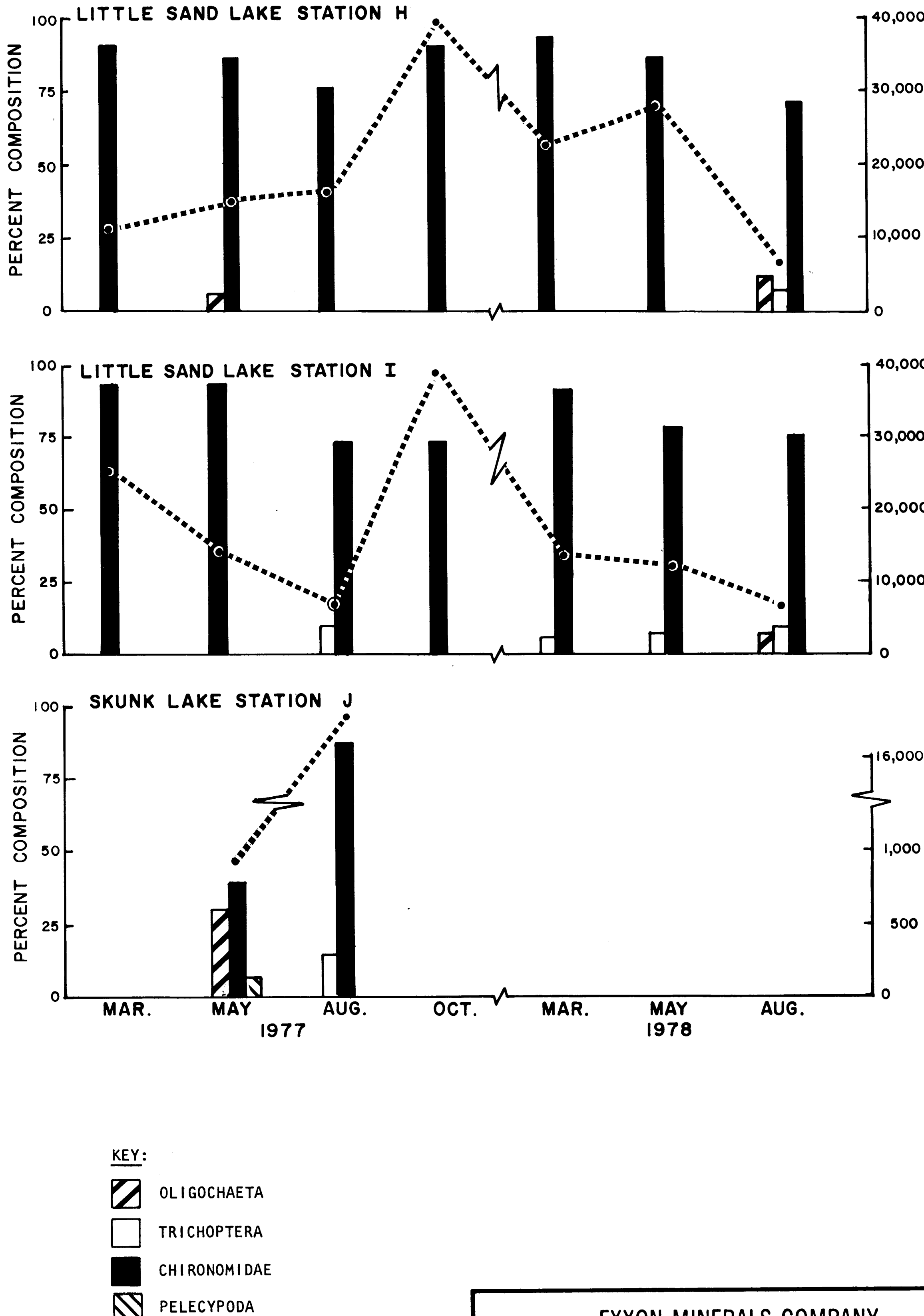
DAMES & MOORE

FIGURE 2.5-13

Cocconeis placentula was the dominant periphytic diatom in samples from Rolling Stone Lake and *Tabellaria flocculosa* and *T. fenestrata* were dominant in the soft water lakes (Little Sand, Duck, and Deep Hole). In Skunk Lake, the dominant diatom was *Nitzschia palea*, which is considered to be very tolerant of organic enrichment (Palmer, 1969). The high levels of ammonia, organic nitrogen, total phosphate and orthophosphate (section 2.4, Surface Water) and chlorophyll *a* in Skunk Lake, relative to other lakes in the drainage basin, are consistent with the abundance of this tolerant organism.

Aquatic macrophyte communities in the drainage and seepage lakes also differed apparently because of water chemistry and morphometry characteristics. Rolling Stone Lake is a relatively shallow, hard water lake with a sand and muck bottom that is largely littoral. The seepage lakes contain soft water and were also largely littoral. Aquatic macrophytes in Rolling Stone Lake were abundant and several species present, water milfoil, flatstem pondweed, whitestem pondweed, and coontail, are typical of hard water lakes (Moyle, 1945; Hellquist, 1980). Aquatic macrophytes typical of soft water bodies (Moyle, 1945; Hellquist, 1980) that occurred only in the seepage lakes are water lobelia, bur reed, pipewort, water arum, and the pondweeds *Potamogeton epihydrus* and *P. pusilis*.

Midges were a common component of the benthos samples from all lakes and were numerically dominant in Little Sand, Skunk, and Deep Hole lakes (Figures 2.5-14 and 2.5-15). Worms were typically dominant in Duck Lake and snails in Rolling Stone Lake. Densities in all lakes except Duck and Skunk (sampled during May and August only) were highest during October 1977. At Duck Lake density was highest during May 1977. The midge *Chironomus* sp., common in Skunk and Rolling Stone lakes, is typical of organic detritus



NOTE: PERCENT COMPOSITION OF ORGANISMS COMPRISING 5 PERCENT OR MORE OF THE COLLECTION (HISTOGRAM) IS INDICATED BY THE LEFT VERTICAL AXIS AND TOTAL DENSITY (NO./m^2) (LINE GRAPH) IS INDICATED BY THE RIGHT VERTICAL AXIS.

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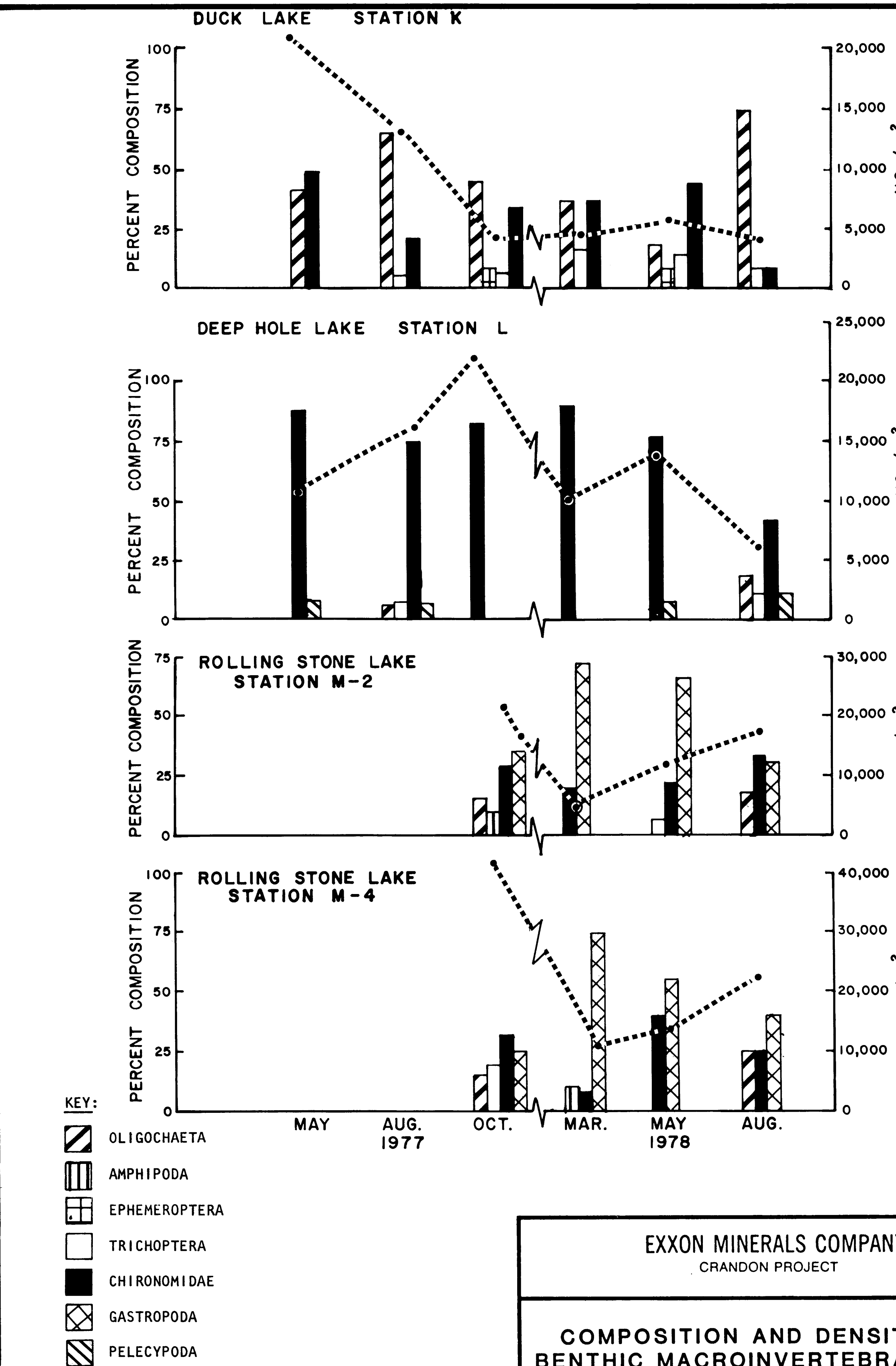
COMPOSITION AND DENSITY OF BENTHIC MACROINVERTEBRATES IN LITTLE SAND AND SKUNK LAKES

DAMES & MOORE

FIGURE 2.5-14



NOTE: PERCENT COMPOSITION OF ORGANISMS COMPRISING 5 PERCENT OR MORE OF THE COLLECTION (HISTOGRAM) IS INDICATED BY THE LEFT VERTICAL AXIS AND TOTAL DENSITY (NO./m²) (LINE GRAPH) IS INDICATED BY THE RIGHT VERTICAL AXIS.

EXXON MINERALS COMPANY
CRANDON PROJECT

COMPOSITION AND DENSITY OF BENTHIC MACROINVERTEBRATES IN DUCK, DEEP HOLE, AND ROLLING STONE LAKES

DAMES & MOORE | FIGURE 2.5-15

substrates and areas subject to dissolved oxygen depletion (Brundin, 1956), conditions observed at both of these lakes (section 2.4, Surface Water). The midge Tanytarsus sp. is less able to survive periods of dissolved oxygen depletion than Chironomus sp. (Brundin, 1956) and was common in Duck, Deep Hole, and Little Sand lakes.

Fish sampling indicated that lakes with bog-like properties contained fewer fish species than other lakes within the drainage basin. In Duck and Deep Hole lakes, 3 and 4 species, respectively, were found. No fish were collected in Skunk Lake. Low dissolved oxygen concentrations, such as those detected in the winter of 1977-1978 (section 2.4, Surface Water), probably account for the absence of fish. In Rolling Stone and Little Sand lakes, 11 and 10 species, respectively, were collected. Yellow perch was the dominant species in samples from all the lakes of the Pickerel Creek drainage basin.

Black bullheads were common in samples from Little Sand and Rolling Stone lakes and occurred in low numbers in samples from Duck Lake. This species was common in Deep Hole Lake prior to the chemical eradication of fish in 1970 (Wendt, 1970). Chemical eradication was conducted to establish the lake for walleye rearing. Yellow bullheads were found only in Little Sand Lake and were consistently more abundant than black bullheads. Walleye occurred in Deep Hole, Little Sand, and Rolling Stone lakes. The latter two lakes are regularly stocked and some reproduction occurred in Rolling Stone Lake (Wisconsin DNR, 1971). Use of Deep Hole Lake by the DNR as a walleye rearing area was discontinued after one stocking because of difficulties in removing yearling fish because of debris such as logs, boulders, branches on the lake bottom (Wendt, 1978).

Two species (white sucker and northern pike) collected in Rolling Stone Lake could potentially migrate to tributary streams, such as Pickerel Creek and Creeks 11-4 and 12-9, for spawning. However, the absence of these species in fish collections from these tributary streams during spring 1978 suggests no movement of these species from Rolling Stone Lake.

Parasites such as those observed on fish from Pickerel Creek basin are a common malady and their presence is a normal part of the fauna of freshwater ecosystems.

There is no linkage for aquatic species between the Pickerel Creek watershed and any adjacent watersheds except the Wolf River (see subsection 2.4.3). No surface water connections exist with any other watersheds via lakes or streams that would allow movements of fish, macroinvertebrates, or other forms of aquatic biota between watersheds.

The flow rate in tributary streams to Rolling Stone Lake is sufficient to support biological populations that could serve as sources for colonization of downstream water bodies.

2.5.4 Wolf River

The Wolf River originates at Pine Lake in Forest County and flows south and east to Lake Poygan in Winnebago County. The principal tributaries above the town of Langlade, Wisconsin are Swamp Creek, Pickerel Creek, Hunting River, Lily River and Nine Mile Creek. Major impoundments in this same reach of river are Little Rice Lake and Upper Post and Lower Post lakes (section 2.4, Surface Water; Figure 2.4-3). The majority (95 percent) of the shoreline above Langlade is wooded and wild but residential structures exist along Pine Lake and Upper Post and Lower Post lakes (Steuck et al., 1977).

A summary of characteristics of the Wolf River is presented in Table 2.5-52. From its source to the town of Pearson, the river has a generally flat gradient, 0.7 m/km (3.7 feet/mile), reflecting the large areas of lakes and wetlands through which it flows. Below Pearson the character of the river begins to change and the gradient becomes steeper, 1.9 m/km (9.8 feet/mile), and several rapids are found in this stretch of river.

Samples were collected at the Wolf River at Station Y, located upstream from the confluence with Swamp Creek, and Station Z, located downstream of the confluence with Pickerel Creek (Figure 2.5-1).

Periphyton - Periphytic algae samples were collected from the Wolf River, Stations Y and Z, during October 1977 and May, July, and October 1978. The relative abundances of the four major taxa identified during the study are presented in Table 2.5-53. The relative abundances of taxa from each collection are presented in Appendix 2.5C, Table C-13. The 94 taxa identified from Station Y and the 95 taxa from Station Z are presented in Appendix 2.5C, Table C-26.

Periphytic algal communities were generally similar at the two Wolf River stations. Diatoms accounted for 94 to 100 percent of each sample except in August 1978 when their relative abundance decreased to 17 and 37 percent at Stations Y and Z, respectively. *Cocconeis placentula*, *Fragilaria pinnata*, and *Achnanthes minutissima* were the most abundant diatoms at both stations.

In August 1978, golden-brown algae, which generally accounted for 5 percent or less of any collection, comprised 58 and 62 percent of the

TABLE 2.5-52

SUMMARY* OF CHARACTERISTICS OF THE WOLF RIVER ABOVE LANGLADE, WISCONSIN

Distance and Direction from Ore Body (km)	12.2 Southwest
Drainage Basin Area (km^2)	1,191
Mean Depth (m)	0.6
Mean Width (m)	45
Length (km)	98.97
Gradient (m/km)	1.2
Total Surface Area (ha)	479.93
Predominant Shoreline Vegetation	Wet-mesic and wet northern forest and aspen
Sediment Composition	Sand, gravel, silt, detritus, peat

*See section 2.4, Table 2.4-20.

TABLE 2.5-53

RELATIVE ABUNDANCE (PERCENT COMPOSITION) OF
MAJOR TAXA OF PERIPHYTON COLLECTED FROM THE WOLF RIVER, STATIONS Y AND Z
OCTOBER 1977 THROUGH OCTOBER 1978

TAXA	1977 OCTOBER	1978 MAY	1978 AUGUST	1978 OCTOBER
Bacillariophyceae				
Y	96	98	17	100
Z	99	100	37	94
Chlorophyceae				
Y	0	0	19	0
Z	1	0	1	<1
Chrysophyceae				
Y	0	1	58	0
Z	0	0	62	5
Cyanophyceae				
Y	4	0	6	0
Z	0	0	<1	<1

samples at Stations Y and Z, respectively. The unidentified *Chrysococcus*-like algae were the only golden-brown algae collected.

Benthic Macroinvertebrates - Benthic macroinvertebrates were collected at two locations, Stations Y and Z in March, May, August and October 1978. The eight major taxa collected in quantitative sampling and their density and relative abundance are presented in Table 2.5-54. The density and relative abundance of individual taxa identified during the study are presented in Appendix 2.5D, Tables D-65 through D-68. The 81 and 100 taxa obtained in quantitative sampling and the additional 9 and 13 taxa obtained in qualitative sampling at Stations Y and Z, respectively, are presented in Appendix 2.5D, Table D-81.

Densities of benthic organisms ranged from 1,896 to 19,036/m^2 at Station Y and 5,373 to 12,959/m^2 at Station Z. Benthic macroinvertebrates from several different groups were irregular in abundance, although they were common throughout the study. These groups included snails, midges, worms, and clams.

Snails accounted for 13 to 48 percent of the benthos at Station Y and from 13 to 58 percent at Station Z. All of the 13 taxa identified, except *Promenetus exacuous*, which was collected only at Station Y, were collected at both sampling stations on the Wolf River. *Amnicola* sp. was the most common and abundant snail collected at both stations.

Midges comprised 0 to 37 percent of the total benthos enumerated from Station Y and from 1 to 28 percent at Station Z. Densities of midges at Station Y ranged from 0 in October 1978 to 2,471/m^2 in August 1978, and densities at Station Z ranged from 43/m^2 in October 1978 to 2,399/m^2 in

TABLE 2.5-54

MEAN DENSITY[a] (no./m²), RELATIVE ABUNDANCE (%), AND DIVERSITY[b] OF BENTHIC MACROINVERTEBRATES COLLECTED FROM WOLF RIVER - STATIONS Y AND Z MARCH, MAY, AUGUST, AND OCTOBER 1978

	MARCH		MAY		AUGUST		OCTOBER	
	no./m²	%	no./m²	%	no./m²	%	no./m²	%
Oligochaeta								
Y	273	1	2,644	31	101	2	29	2
Z	72	1	1,149	13	3,664	28	1,394	26
Isopoda								
Y	0	0	29	<1	0	0	0	0
Z	0	0	0	0	0	0	0	0
Amphipoda								
Y	675	4	1,552	18	0	0	0	0
Z	0	0	646	8	72	1	101	2
Ephemeroptera								
Y	58	<1	14	<1	14	<1	0	0
Z	0	0	29	<1	503	4	0	0
Trichoptera								
Y	302	2	72	1	43	1	0	0
Z	29	<1	460	5	560	4	58	1
Chironomidae								
Y	2,126	11	2,126	25	2,471	37	0	0
Z	503	8	2,399	28	2,313	18	43	1
Gastropoda								
Y	9,180	48	1,135	13	1,437	22	345	18
Z	3,692	58	1,135	13	1,940	15	1,925	36
Pelecypoda								
Y	1,034	5	388	5	2,284	34	1,078	57
Z	1,623	26	129	2	1,451	11	359	7
All Others[c]								
Y	5,387	28	618	7	287	4	445	24
Z	445	7	2,644	21	2,457	19	1,494	28
Total								
Y	19,036	100	8,577	100	6,637	100	1,896	100
Z	6,364	100	8,591	100	12,959	100	5,373	100
Diversity								
Y	0.6		1.0		0.7		0.6	
Z	0.6		1.0		1.1		0.9	

[a]Density is the mean of three replicate samples.

[b]Calculated using Brillouin's formula ($\log_{10}$) using numbers of organisms presented in Appendix 2.5D, Tables D-65 through D-68.

[c]Includes Coelenterata, Tricaldida, Alloeocoela, Nemertea, Nematoda, Hirudinea, Hydracarina, Anisoptera, Zygoptera, Hemiptera, Lepidoptera, Coleoptera, and Diptera other than Chironomidae.

May 1978. Individual genera of midges varied in abundance and occurrence throughout the period of investigation. Organisms that comprised 5 percent or more of a collection were Cladotanytarsus sp., Polypedilum sp., and Trissocladius sp. at Station Y and Rheotanytarsus sp., Tanytarsus sp., and Stictochironomus sp. at Station Z.

Worms comprised from 1 to 31 percent of the total benthos enumerated at Station Y and from 1 to 28 percent at Station Z. The immature tubificid form without hair setae was the most abundant worm at both stations during the study except May and July at Station Z. The naidids Nais sp. and Slavina appendiculata were most abundant in May whereas the naidid Uncinais uncinata was most abundant in July.

Clams comprised from 5 to 57 percent of the benthos collected at Station Y and from 2 to 26 percent at Station Z. All pelecypods collected from both Stations Y and Z were from the family Sphaeriidae; mature specimens were identified to the genera Sphaerium and Pisidium.

Diversity values ranged from 0.6 at both stations in March and at Station Y in October to 1.1 at Station Z in August (Table 2.5-54).

Aquatic Macrophytes - Aquatic macrophytes and vascular plants along the adjacent stream banks were inventoried in Swamp Creek and the Wolf River in June 1983. The relative abundance of rooted aquatic vegetation was higher in the upstream portion of Swamp Creek and was reduced in the downstream segment and in the Wolf River (Table 2.5-55). The most abundant species throughout Swamp Creek and the Wolf River were water-weed (Anacharis canadensis), arrowhead (Sagittaria sp.), bur-reed (Sparganium sp.), and pondweed (Potamogeton epihydrus and P. praelongus). Several small scattered

TABLE 2.5-55

RELATIVE ABUNDANCE OF VASCULAR PLANTS IDENTIFIED IN SWAMP CREEK AND THE WOLF RIVER AND ALONG ADJACENT STREAM BANKS JUNE 1983

LOCATION/TAXA	RELATIVE ABUNDANCE[a]	LOCATION/TAXA	RELATIVE ABUNDANCE[a]
Stream Bottom - Above Discharge		Adjacent Stream Banks - Above Discharge	
Sagittaria sp.[b]	A	Alnus rugosa	A
Certatophyllum demersum	M	Cornus stolonifera	M
Potamogeton praelongus	A	Salix sericea	A
Spriodella polyrhiza	S	Carex stricta	A
Anacharis canadensis	A		
Vallisneria americana	S		
Stream Bottom - Below Discharge		Adjacent Stream Banks - Below Discharge	
Anacharis canadensis	A	Carex stricta	A
Sagittaria sp.[b]	A	Carex lacustris	A
Eleocharis palustris	M	Alnus rugosa	A
Campanula aparinoides	S	Salix sericea	A
Nuphar variegatum	M	Cornus stolonifera	M
Scripus validus	M	Cicuta maculata[c]	S
Utricularia vulgaris	S	Typha latifolia	S
Spirodella polyrhiza	S	Viburnum cassinoides	M
Sparganium americanum	A	Ribes lacustre	M
Potamogeton epihydrus[b]	M	Myrica gale	M
Potamogeton praelongus	A	Trillium cernum	S
Rumex orbiculatus	M	Galium asprellum	M
Ludwigia palustris	M	Spiraea tomentosa	M
Myriophyllum heterophyllum	S	Onoclea sensibilis	M
Glyceria borealis	S	Thalictrum dasycarpum	M
		Picea mariana	A
		Larix laricina	M
		Prunus serotina	M
		Amelanchier arborea	M
		Fraxinus nigra	M
		Acer rubrum	M
		Spiraea alba	M
		Caltha palustris	M
		Acer saccharinum	M
		Betula papyrifera	S
		Abies balsamea	M
		Pinus sylvestris	S
		Pinus resinosa	S
		Populus balsamifera	S
		Phalaris arundinacea	M
		Calamagrostis canadensis	M

[a] A = abundant, M = moderately abundant, S = sparse.

[b] Submersed leaves.

[c] Basal leaves.

patches of northern manna grass (Glyceria borealis) were also present in the lower portion of Swamp Creek in the floating leaf form. No wild rice beds were identified.

Total areal coverage of the bottom by rooted vascular plants ranged from approximately 80 percent in some areas upstream of County Trunk Highway K to 20 percent in portions of the downstream segment of Swamp Creek. Plant species composition of the bottom and adjacent bank of Swamp Creek and the Wolf River was typical for the existing substrate and flow conditions.

Fish - Fish were collected by electroshocking at both Stations Y and Z in May, August, and October 1978 (Table 2.5-56). The length-weight data are summarized in Appendix 2.5E, Table E-24.

Common species were white sucker, shorthead redhorse, and common shiner, which comprised up to 27 percent of the fish collected and occurred in every sampling period except August at Station Z. Black bullheads were also common but were not found in the August sampling at either station.

In August at Station Z no fish were captured during electroshocking collections and only small minnows, creek chub, hornyhead chub, common shiner, and an unidentified shiner were collected along the shore by dip net. White sucker, shorthead redhorse, common shiner, rock bass, yellow perch, black crappie, and hornyhead chub were collected by electroshocking conducted at the mouth of the Hunting River, which is located approximately 200 m (656 feet) downstream from Station Z. At the time of sampling, fish apparently avoided this area of the Wolf River for a more suitable area because dissolved oxygen concentrations, measured concurrently with fish sampling, were low, 1.4 mg/l at Station Z, and higher, 5.6 mg/l, at the mouth of the Hunting River (section 2.4, Surface Water).

TABLE 2.5-56

NUMBERS AND RELATIVE ABUNDANCE (PERCENT OF TOTAL CATCH)
OF FISH COLLECTED BY ELECTROSHOCKING, WOLF RIVER - STATIONS Y AND Z
MAY, AUGUST, AND OCTOBER 1978

	MAY				AUGUST		OCTOBER			
	(Y)		(Z)		(Y)*		(Y)		(Z)	
SPECIES	no.	%	no.	%	no.	%	no.	%	no.	%
Catostomidae										
White sucker	7	21	10	10	1	12	7	7	18	27
Northern hog sucker	0	0	2	2	0	0	0	0	0	0
Shorthead redhorse	3	9	6	6	2	25	2	2	1	1
Centrarchidae										
Rock bass	0	0	13	13	0	0	0	0	9	13
Pumpkinseed	0	0	0	0	0	0	3	3	1	1
Bluegill	0	0	1	1	0	0	0	0	0	0
Smallmouth bass	1	3	0	0	0	0	2	2	1	1
Black crappie	1	3	8	8	0	0	0	29	0	0
Cyprinidae										
Brassy minnow	1	3	0	0	0	0	0	0	0	0
Hornyhead chub	0	0	17	17	0	0	3	3	3	4
Golden shiner	0	0	0	0	0	0	1	<1	0	0
Common shiner	1	3	22	22	3	38	2	2	9	13
Blacknose shiner	0	0	0	0	0	0	1	<1	0	0
Bluntnose minnow	0	0	0	0	2	25	2	12	0	0
Creek chub	0	0	1	1	0	0	0	0	0	0
Esocidae										
Northern pike	0	0	0	0	0	0	1	<1	1	1
Ictaluridae										
Black bullhead	14	41	7	7	0	0	5	15	17	25
Yellow bullhead	5	15	1	1	0	0	6	6	2	3
Tadpole madtom	0	0	2	2	0	0	1	<1	1	1
Percidae										
Johnny darter	0	0	0	0	0	0	2	2	0	0
Yellow perch	1	3	9	9	0	0	4	14	4	6
Total	34		99		8		102		67	

*No fish were collected in sampling at Station Z.

No additional fish species were collected by the DNR in verification sampling (Ramharter, 1982a).

2.5.5 Ecological and Hydrological Relationships

The ore body is situated on the watershed divide between the Swamp Creek and Pickerel Creek drainage basins. Water enters these basins as precipitation or ground water flow and leaves by evapotranspiration and stream flow, which is generally in a southwesterly direction to the Wolf River. Storage within the basins occurs in lakes, wetlands, and ground water aquifers. Within the environmental study area, the highest potentiometric level of the main ground water aquifer, believed to be a ground water recharge area, generally corresponds with a high topographic elevation between Little Sand Lake and Hemlock Creek, and ground water flows outward in all directions (section 2.3, Ground Water). Water percolating down through the soils in this area appears to leach calcareous constituents from this soil, thus increasing alkalinity and hardness.

Areas of apparent ground water discharge include Swamp Creek, Hemlock Creek, upper Pickerel Creek, the low-lying area between Little Sand Lake and Rolling Stone Lake in which Creek 12-9 originates, and directly into Rice and Rolling Stone lakes (section 2.3, Ground Water; Figure 2.3-17). As presented in Surface Water, section 2.4, although the Swamp Creek and Pickerel Creek drainage basins are two geographically separate and independent basins, the streams and lakes that receive ground water discharge have a similar water chemistry that is summarized below.

PARAMETER	RANGE OF MEAN VALUES OBTAINED IN 1977 TO 1978
Alkalinity	<81 - 103 mg/l as $CaCO_3$
Hardness	91 - 115 mg/l as $CaCO_3$
pH	7.1 - 7.7
Field Conductivity	117 - 145 µmhos/cm

Oak Lake, situated in the Swamp Creek drainage basin, and Little Sand, Deep Hole, Duck, and Skunk lakes, situated in the Pickerel Creek drainage basin, have surface elevations above the potentiometric surface of the main ground water aquifer (Figure 2.3-3), and therefore, receive no discharge from the aquifer. Water chemistry in these lakes is generally similar and is summarized below.

PARAMETER	RANGE OF MEAN VALUES OBTAINED IN 1977 TO 1978
Alkalinity	<2 - 10 mg/l as $CaCO_3$
Hardness	10 - 16 mg/l as $CaCO_3$
pH	5.0 - 6.0
Field Conductivity	23 - 30 µmhos/cm

As described in section 2.4, Surface Water, the Wolf River was lower in alkalinity and hardness than Swamp Creek and Pickerel Creek. The surface water discharges from these creeks tend to increase alkalinity and hardness concentrations in the Wolf River, as indicated by the lower alkalinity and hardness values above the confluence of Swamp and Pickerel creeks, Station Y (52 and 60 mg/l, respectively), than below the confluence, Station Z (63 and 73 mg/l, respectively).

The surface water drainage pattern in the environmental study area portion of the Swamp Creek drainage basin was essentially linear. Surface water flow was largely confined to Swamp Creek, its tributaries (Hemlock Creek, Metonga Creek, and Hoffman Creek), and Rice Lake through which Swamp Creek flowed to its confluence with the Wolf River. Flow from Oak Lake to

Swamp Creek via Hoffman Creek was intermittent and Oak Lake was considered effectively isolated from the surface water flow of Swamp Creek. In the environmental study area portion of the Pickerel Creek drainage basin, the surface water flow pattern was basically radial. Creeks, which originated in wetlands in the southern part of the environmental study area (Pickerel Creek, Creek 11-4, Creek 12-9) flowed south into Rolling Stone Lake. Pickerel Creek emerged from Rolling Stone Lake and flowed south and west to its confluence with the Wolf River. Surface water flow was intermittent from Duck and Deep Hole lakes to Little Sand Lake via wetlands, then to Creek 12-9. Skunk Lake, located in a topographic depression, was isolated from the surface water flow of Pickerel Creek.

Within the matrix of linear and radial surface water flow patterns and the seepage and drainage (soft and hard water) systems, the distribution and composition of aquatic biota was influenced by factors particular to each stream or lake.

The streams of the environmental study area generally shared similar physical characteristics. They were small, often not well defined, and had low gradients. Generally, the creeks had surface water drainage from and through wetland areas and the creek bottoms were composed of soft muck; however, small areas of firm sand and gravel substrate also existed in portions of most creeks. The Wolf River also drained wetlands, but the bottom composition was generally more firm than the creeks.

The analysis of periphytic algal samples suggests that communities were generally similar in the running waters. Diatoms comprised the major portions of the collections, and _Cocconeis placentula_ or _Achnanthes minutissima_ were the most abundant species. Notable exceptions occurred in

Pickerel Creek where Eunotia curvata and Navicula minima were most abundant, and Creek 11-14 where A. lanceolata was most abundant.

Benthic macroinvertebrate data indicate that benthos composition and abundance was primarily dependent on the habitats present; that is, substrate type, current velocity, and dissolved oxygen content. In the creeks, numbers of organisms were highest (consistently $>14,000/m^2$) in samples from areas of soft silty substrate such as Creek 11-4 and Hemlock Creek. Densities were lowest ($<4,000/m^2$) in samples from areas of highest current velocity with sand and gravel substrates, such as Station D at Swamp Creek. Midges, which occur over a wide range of substrates (Curry, 1965), were the most abundant benthic taxa at all stations except Creek 11-4 and the Wolf River. In Creek 11-4, worms from the family Tubificidae were abundant in the organic sediment. Brinkhurst (1966) and Brinkhurst and Jamieson (1971) have indicated that most tubificids are generally dominant in soft sediments. The largest densities of clams were typically found in substrates composed of silt with some sand such as occurred at Station E on Swamp Creek, Creek 12-9, and both stations on the Wolf River. DeMarch (1976) reported that the clam Sphaerium sp. was very common in substrates composed of sand overlain with silt. Caddisflies, specifically Leucotrichia pictipes and Glossosoma sp., which were subdominant at Station D in Swamp Creek, are typical of such fast-flowing areas of streams (Wiggins, 1978).

Information on the spatial and temporal relationships of benthic macroinvertebrates in Swamp Creek downstream from County Trunk Highway M is presented in reports by Ecological Analysts, Inc. (1983, 1984a). These reports contain biotic index values for macroinvertebrates and identification of dominant taxa in the vicinity of the proposed water discharge site.

Based on electrofishing data, three general fish associations were apparent in streams of the environmental study area. In the smaller, headwater streams such as Hoffman and Pickerel creeks and Creek 12-9, numbers of species were low (5 to 9) and brook trout and mottled sculpin were dominant. Station D in Swamp Creek had intermediate characteristics. It is a large stream providing more habitats for varied fish species (15), but because of the steep gradient, it has characteristics of a headwater stream, such as an abundance of brook trout, mottled sculpin, and other trout indicator species, specifically blacknose and longnose dace (Becker, 1976). In the larger sluggish streams (>4.0 m [>13 feet] mean width), including portions of Hemlock Creek, Swamp Creek, and Creek 11-4 (because of its pond-like characteristics), numbers of species were relatively high (15 to 21) and generally dominated by minnows.

Information on fish communities in Swamp Creek downstream from County Trunk Highway M is presented in reports by Ecological Analysts, Inc. (1983, 1984a). These reports contain documentation on the spatial and temporal characteristics of fish species in the vicinity of the proposed water discharge site and a comparison of the species found in Swamp Creek in relation to those reported in the Wolf River and Rice Lake and in Swamp Creek upstream from Rice Lake.

Lakes in the environmental study area differ according to their relationship to the main ground water aquifer. The drainage lakes, Rice and Rolling Stone, receive discharge from the main ground water aquifer largely through perennial inlet streams. These lakes are shallow, generally have a soft bottom in the littoral zone and support extensive growths of aquatic macrophytes. Aquatic plant communities in Rice and Rolling Stone lakes were characteristic of lakes containing hard water according to generalizations presented in Moyle (1945). Rice Lake is shallower than Rolling Stone Lake and supports extensive areas of emergent wild rice throughout the central portion of the lake. The central portion of Rolling Stone Lake was also heavily vegetated but was composed primarily of the submergent species water milfoil, flatstem pondweed, and whitestem pondweed.

The seepage lakes, Oak, Duck, Deep Hole, Little Sand and Skunk, do not receive discharge from the main ground water aquifer and as a group have similar water chemistry. However, minor differences in seepage lakes were observed, most notably in water color and the type of vegetation surrounding the lakes. Oak Lake in the Swamp Creek drainage basin and Little Sand Lake in the Pickerel Creek drainage basin are situated in upland areas and have clear, uncolored water (mean color <4 and <5, respectively). Duck and Deep Hole lakes, both in the Pickerel Creek drainage basin, have brown stained water (mean color 59 and <23, respectively) and share similar characteristics, particularly sphagnum moss growths, which are characteristic of bogs (Boelter and Verry, 1978). Skunk Lake in the Pickerel Creek drainage basin is located within its own drainage basin and, unlike the other seepage lakes, had little or no intermittent outflow. Although it has bog-like properties, such as low pH (5.8) and brown stained water (mean color 119), sphagnum growths were not observed.

With few exceptions, phytoplankton densities in the lakes were lowest in samples collected during winter and with improving light conditions and increasing temperature during spring, phytoplankton densities increased and peaked in July, August or September then decreased in fall. Nitrate, an important nutrient for phytoplankton, was generally highest during winter when phytoplankton levels were lowest, and decreased throughout the year to levels below detection limits in the autumn (section 2.4, Surface Water). Exceptions to the general pattern of summer phytoplankton maxima were observed in samples from Deep Hole and Rolling Stone lakes where phytoplankton exhibited two peaks in abundance: May and September 1978 in Deep Hole, and March and August 1978 in Rolling Stone Lake.

Golden-brown algae were abundant in samples from all lakes, and green algae and blue-green algae were also common. Diatoms, in contrast to their abundance in periphyton, were common only in phytoplankton samples from Rice Lake.

Zooplankton densities were typically lowest in samples collected in March, and spring or autumn pulses were observed. Both spring and autumn pulses were recorded in samples from all lakes except Duck, Deep Hole, and Skunk. Autumn maxima only were observed at Duck and Deep Hole lakes. Skunk Lake, sampled from June through October, exhibited highest density in July and low densities during subsequent months. Densities were typically <400/1 in all lakes except when high numbers of rotifers were collected. Rotifers were most abundant in Skunk, up to 1,200/1, Duck and Deep Hole lakes. Copepods dominated in Little Sand and Oak lakes, lakes with the clearest water. Copepods and rotifers were generally codominant in Rice and Rolling Stone lakes, the hard water lakes.

Diatoms comprised the major portion of the periphytic algae samples from the lakes which also was observed in the creeks. Most diatoms are sessile and are associated with littoral substrates (Hutchinson, 1967). Diatom dominance generally was greatest in samples collected during spring and autumn and least during summer. Diatoms were less dominant in the samples from seepage than drainage lakes possibly because the levels of silica were lower in the mineral-poor waters of the seepage lakes. Cocconeis placentula, a dominant or subdominant in most creeks, was the dominant species in the drainage lakes. Tabellaria fenestrata or T. flocculosa were the dominant diatoms in the seepage lakes, except Skunk Lake. In Skunk Lake, Nitzschia palea was most abundant. Water chemistry data (Surface Water, section 2.4) indicate that nutrient levels were highest in Skunk Lake, which is consistent with the abundance of N. palea, an indicator of organic enrichment (Palmer, 1969).

Density of benthic organisms was lowest in samples collected from the uniform muck substrate in Oak Lake ($<8,000/m^2$) and tended to be highest in the dense vegetation at Rice and Rolling Stone lakes (up to $58,000/m^2$). Midges predominated in samples from all seepages lakes except Duck Lake. Snails, midges and worms were prominent in the drainage lakes. Tanytarsus sp. was the most common midge at all lakes except Skunk and Rolling Stone, where Chironomus sp. was most common. Chironomus sp. is typically predominant in the benthos of eutrophic lakes or areas subject to oxygen depletion (Brundin, 1956). Tanytarsus sp. is more sensitive to oxygen depletion and is typically found in less enriched areas (Brundin, 1956).

The seepage lakes of the environmental study area have only very low intermittent inflow or outflow, which severely restricts opportunity for interlake fish movements. In general, the fish fauna was characterized as consisting of a few species with yellow perch as the dominant. No fish were found in Skunk Lake; the periodically low dissolved oxygen concentrations apparently made the lake uninhabitable for fish. Based on total species counts from all sampling gear, species richness was highest in lakes that contained varied habitat such as Oak Lake (8 species), and Little Sand Lake (10 species), where sand, gravel, muck, and vegetation were present. In Duck Lake, where the bottom substrate primarily consisted of soft muck, only three species were collected. Sunfish, which prefer a firm sand or gravel substrate for spawning, occurred only in Oak and Little Sand lakes.

The data indicate that the fish communities were generally similar in the two drainage lakes. Fifteen species were collected in Rice Lake and 12 in Rolling Stone Lake. Black bullhead, white sucker, and sunfish species were common in samples from both lakes. However, walleye and black crappie were found in Rolling Stone Lake but not Rice Lake. Both species prefer water bodies with firm bottoms (Becker, 1976). Although extensive areas of Rolling Stone Lake contain soft sediments, sand and gravel areas exist along the near-shore areas, particularly along the eastern and western shore, whereas no firm substrate was found in Rice Lake. In the Wolf River 21 species of fish were collected and the collections were generally dominated by suckers, minnow species and black bullhead.

Threatened and Endangered Species

Potamogeton confervoides, a rooted aquatic macrophyte that is listed as threatened in Wisconsin (Jurewicz, 1983), was observed at Duck Lake in 1980; however, no rooted specimens were located. A search specifically for *P. confervoides*, which occurs in low pH and low alkalinity bog situations (Hellquist, 1980), was conducted in other bog-like lakes in the environmental study area, but no specimens were found.

No aquatic species listed as threatened or endangered by the U.S. Department of the Interior, Fish and Wildlife Service (1982) were found or are known to occur in the environmental study area. No Wisconsin-listed threatened, endangered, or "watch" fish or invertebrate species (Jurewicz, 1983) were observed or are known to occur in the environmental study area.

2.5.6 Summary and Conclusions

1. Selected components of the aquatic biota that included phytoplankton, zooplankton, periphytic algae, aquatic macrophytes, benthic macroinvertebrates, and fish were investigated from water bodies in the Swamp Creek and Pickerel Creek drainage basins and the Wolf River.

2. Golden-brown algae dominated the phytoplankton samples from all lakes.

3. Observed differences in the distribution of zooplankton, periphytic algae and aquatic macrophyte taxa were related to factors pertinent to water body type; that is, drainage versus seepage (hard water versus soft water systems).

4. Rotifers and copepods dominated the zooplankton samples from the hard water lakes but no species was predominant. Copepods, especially *Diaptomus minutus*, dominated samples from the clear water seepage lakes, and rotifers, especially species of *Keratella*, dominated in samples from the brown-stained seepage lakes.

5. Diatoms dominated periphytic algae samples from all water bodies and the diatoms *Cocconeis placentula* and *Achnanthes minutissima* dominated in the hard water drainage system and *Tabellaria fenestrata* and *T. flocculosa* in the soft water seepage lakes.

6. Hard water and soft water lakes had distinctive aquatic macrophytic flora whose distribution in a particular lake is influenced by water depth and basin morphometry. Wild rice, which was found only at Rice Lake, covered extensive areas of the lake.

7. Benthic macroinvertebrate composition and abundance appeared to be primarily dependent upon habitat characteristics; that is, substrate type, current velocity, and dissolved oxygen content.

8. Fish sampling indicates minnows generally dominated in the larger creeks, and brook trout and mottled sculpin dominated in the small headwater creeks. Black bullhead, white sucker, yellow perch and/or centrarchid species dominated the fish fauna in the drainage lakes and Wolf River.

9. Based on total species counts from all gear utilized, fewer fish species were found in the seepage lakes than in the drainage lakes and yellow perch were dominant in each seepage lake investigated.

10. Potamogeton confervoides, an aquatic plant listed by the DNR as threatened, was identified from samples collected at Duck Lake. No other threatened or endangered aquatic plants or animals, at the state or federal level, were observed or are known to occur in the environmental study area.

2.5.7 References

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