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APPENDIX 4.1.A
HYDROLOGIC IMPACT ASSESSMENT

DECEMBER 1985

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

LIST OF TABLES

LIST OF TABLES
(Continued)

LIST OF FIGURES

LIST OF FIGURES
(Continued)

1.0 INTRODUCTION

1.1 OBJECTIVE AND OVERVIEW OF STUDY

The Crandon Project is a proposed zinc, copper, and lead mine and mill in northeastern Wisconsin. Ore will be removed from an underground mine and milled to extract the minerals of interest. Project facilities include an underground mine, mine/mill surface facilities, a mine waste disposal facility (MWDF), and a water discharge structure. The objective of the hydrologic impact assessment discussed in this document is to evaluate the potential effects of these facilities on the site hydrologic regime. Effects evaluated include water quantity and quality during the construction, operation, and post-operation phases. The methodologies and results of this study were prepared by D'Appolonia Waste Management Services, Inc. (D'Appolonia), a Division of IT Corporation.

Analytical techniques and computer simulation methods were used to perform the study. Input data were taken from previous Project study documents provided by Exxon Minerals Company (Exxon) and are cited as references. To accomplish the study objective, the following tasks were performed:

1. A review of previous Crandon Project studies to understand the physical setting of the site and the engineering aspects of the proposed activities in the environmental study area and to obtain data for the hydrologic impact study.

2. The selection of a computer model(s) capable of simulating the potential hydrologic impacts of the Project facilities.

3. Meetings with the Wisconsin Department of Natural Resources (WDNR) staff and their consultants to receive their suggestions for the modeling procedure and selection of the model input data.

4. An evaluation of available data for input to and calibration of the model(s).

5. A simulation of the hydrologic actions (effects) of the proposed facilities and assessment of the potential impacts to the hydrologic regime (water quantity and quality).

The Crandon Project will include three phases: construction, operation, and reclamation (post-operation) of the mine, mine/mill surface facilities, MWDF, and the water discharge system. Construction of the various Project facilities will require approximately four years. Mining and milling operations are planned for approximately 22 years plus 3 years of physical reclamation activities. Descriptions of the facilities, including the construction, operation, and post-operation phase schedules and related hydrogeological and chemical data, are presented in Section 2.0.

The site area boundary (as defined for the model), shown in Figure A-1, was used for the computer simulation studies. The study area boundary encompasses the site area boundary and zones adjacent to the site area (Figure A-1). The site area is hydrologically bounded by several perennial streams and lakes. The streams and lakes are ecological systems, with the lakes either perched above the ground water table or in hydrologic communication with the ground water regime.

The site area is underlain by up to 90 m (300 feet) of glacial deposits overlying bedrock. Ground water exists in most units of the glacial deposits which receive ground water recharge (recharge) from precipitation infiltration. Primary transport of ground water occurs in the saturated coarse- and fine-grained stratified drift, which is referred to as the main aquifer, and is found throughout most of the site area and in localized areas of weathered bedrock over the mine area (TAP Associates, 1984). Typically, the stratified drift is underlain and/or overlain by a less pervious saturated or partially saturated till. Ground water movement is generally toward the streams and lakes on the boundaries of the site area. Ground water discharge occurs into these streams and lakes.

Hydrologic actions of the proposed Project facilities include:

1. Ground water entering the mine through weathered bedrock courses from the glacial deposits.

2. Seepage from the MWDF tailings ponds toward ground water and zero recharge below the water reclaim ponds until their removal during reclamation.

3. Infiltration from the sanitary wastewater absorption field

4. Ground water extraction by the potable water supply well

5. Recharge alterations resulting from the location of the various mine/mill surface facilities.

The location of the water discharge structure at Swamp Creek south of County Road M is outside the hydrological impact assessment study area.

The alterations in seepage, infiltration, ground water extraction, and recharge rates for Project surface facilities will be small compared to the rate of ground water entering the mine. In addition to this potential effect on water quantity, the predicted quality of the MWDF seepage will be different from the quality of the existing ground water, which is generally of moderate alkalinity and neutral pH. A few chemical constituents (iron and manganese) in the ground water have mean concentrations which exceed the U.S. Environmental Protection Agency (U.S. EPA) Drinking Water Standards. The potential changes in water quantity and quality have been evaluated as discussed below.

Descriptions of the existing site hydrologic regime and other current environmental data were reviewed to evaluate the consequences of the proposed facilities on the hydrologic regime. A detailed review of available Project reports was performed. Parameters characterizing the hydrologic regime, such as permeability, ground water flow direction(s), aquifer thickness and type, geochemical characteristics of the glacial deposits, and site recharge rate(s) were reviewed and the ranges of these data were identified. The data most representative of site conditions were selected and used in the hydrologic assessment. Where the evaluation results were sensitive to a selected parameter, sensitivity analyses were performed for ranges of the available data. Discussions of the site hydrologic setting and hydrologic parameters are presented in Section 3.0 of this document.

Various analytical techniques and computer models were used to assess the potential impacts of the proposed Project facilities on the hydrologic regime. Finite element computer models were used to predict and evaluate changes to the potentiometric surface and the ground water flow rates and transport of chemical constituents within the site area. Section 4.0 presents discussions of the models employed and methods of simulation. The models incorporated site-specific conditions, facilities locations, and hydrologic parameters, and were calibrated to measured field data. Section 5.0 discusses calibration of the models.

The hydrologic regime simulations were conducted for activities during the construction, operation, and post-operation phases. The post-operation phase was simulated by computer modeling for 31 years after cessation of the operation phase and reclamation activities. Long-term ground water quality impacts were evaluated using analytical and numerical methods. Section 6.0 presents the results of these evaluations.

Alternatives to the proposed MWDF layout and operations were also evaluated and the associated impacts are discussed in Section 7.0. The alternatives presented are for variations in tailings disposal methods for the MWDF and their potential effects on seepage quantity and quality and the hydrologic regime.

1.2 ASSESSMENT METHODOLOGY

The site area was evaluated using finite element computer models. The hydrologic actions were applied to calibrated site area models. A horizontal planar model covering the entire site area was used to estimate drawdown of the potentiometric surface resulting from mine inflow and lesser hydrologic actions, and provided information for evaluating changes in discharges to and from adjacent lakes and streams. The horizontal model was also used to simulate the steady-state migration of chemical constituents from MWDF seepage. Vertical cross-sectional models were used to evaluate the migration of chemical constituents from the MWDF. Results of a one-dimensional vertical model, used to compute the rate of migration of chemical constituents through partially saturated till beneath the MWDF, were input to a two-dimensional cross-sectional model. The two-dimensional vertical model simulated chemical constituent transport through the saturated till and stratified drift. Vertical and horizontal variations of concentration within the cross section and the predicted arrival time of chemical constituents at the MWDF compliance boundary were determined.

Calibration of the horizontal planar model was conducted by using existing site-specific input parameters (recharge, permeabilities, and aquifer thicknesses) so that the model approximated the existing potentiometric surface and ground water discharge to surface streams. The calibrated model was checked for a water balance between recharge, or inflow by infiltration, and ground water outflow at the site area boundary. Parameters were selected for input to the model by considering the range of data gathered during on-site investigations and/or recommended by others based on experience from previous studies.

Hydrologic actions were simulated as either outflow or inflow zones within the horizontal models. Development and operation of the mine will result in ground water inflow by drainage from the main aquifer. Mine inflow was simulated as outflow nodal points above the mine providing a range of estimated cumulative discharge. The water supply well, sanitary wastewater absorption field, and other facilities were simulated in a similar manner.

Steady-state mine inflows were established by TAP Associates (1984) based on low, middle, and high recharge rates established by the WDNR. These rates are shown in Table A-1 and were used in the present study for modeling of the three recharge cases.

The results of the computer modeling were used to predict the impacts of the hydrologic actions. The values obtained from the models were reviewed in relation to the known characteristics of the site and planned activities, and the importance of the impacts was evaluated.

Exxon provided the data on quantity (Exxon, 1984b) and quality (Exxon, 1982) of seepage from the MWDF. The MWDF seepage discharge was input to the models in accordance with the defined quantity rate and quality.

1.3 RESULTS

The predicted maximum drawdown of the potentiometric surface during the Project life is approximately 17 m (56 feet) and occurs in the glacial deposits directly overlying the mine at the end of mine operations (Year 28). The maximum potentiometric drawdown is approximately the same for all three recharge cases. Potentiometric drawdown resulting from ground water inflow to the mine is less than 1 m (3.3 feet) within most of the Project site area, shown in Figure A-1.

Changes in ground water discharges to site area lakes and streams were calculated from the predicted potentiometric surface changes resulting from Project hydrologic actions. The changes in discharges to lakes on the site periphery (Crane, Ground Hemlock, Pickerel, Rice, Rolling Stone, and Walsh lakes) will be primarily through changes in stream flow rates into these lakes rather than by changes to the potentiometric surfaces at the lakes. These lakes are outside the zone of potentiometric drawdown influence (less than 1 m [3.3 feet]) and thus changes in ground water flow gradients are not predicted.

For the lakes within the zone of influence, lake level reductions are predicted to be on the order of 0.0 to 0.2 m (0.0 to 0.6 feet) for average meteorologic conditions. The relatively impervious lacustrine deposits which underlie these lakes will mitigate increases in lake recharge when the potentiometric surface is lowered.

Ground water discharge reduction to streams could reduce the average annual base and total flow rates in the streams. The predicted reduction in average annual base flow at Year 28 for Swamp Creek and Hemlock Creek combined is approximately 5, 8, and 10 percent for mine inflow corresponding to Low, Middle, and High Recharge cases, respectively.

Considering average annual total flow rates for these streams, the predicted percentage changes in total flow rates at Year 28 are less than one-half of the base flow percentage change, or approximately 2, 3, and 4 percent for mine inflow corresponding to Low, Middle, and High Recharge cases, respectively. Reductions in other stream flow rates are of similar magnitude.

Modeling has predicted that for all three recharge cases, the potentiometric surface will return to approximate preconstruction conditions approximately six years after mine inflow ceases. The discharge to area streams and lakes will also return to preconstruction conditions at this time.

Movement of chemical constituents from MWDF seepage was simulated for a time period of 8,800 years after the start of construction. Results were analyzed for Year 4800, at which time chemical constituent transport corresponds to approximately 80 percent of steady-state conditions. Predicted normalized concentration of 0.1 (the ratio of predicted concentration to the source concentration at the bottom of the tailings pond) for a chemical constituent with a retardation factor of 1.0 will reach the bottom of the aquifer at this time and will have some lateral movement toward Hemlock Creek, but will not reach the compliance boundary. No major horizontal migration of MWDF seepage toward Deep Hole Lake will occur at this time. The maximum normalized concentrations predicted after 4,800 years are approximately 0.7 in the saturated till below the MWDF and less than 0.1 at the compliance boundary.

A retardation factor of 1.0 assumes that a chemical constituent moves with the velocity of the transporting fluid with negligible chemical retardation. The major constituents in the seepage with estimated retardation factors of 1.0 are sulfate and filterable residue (Total Dissolved Solids [TDS]). Other constituents of potential concern have retardation factors of 2 to over 100 times higher than that for sulfate and TDS. For all practical purposes, these constituents can be considered immobile.

After 4,800 years, the only chemical constituents which are estimated to continue migrating are sulfate and TDS. The average steady-state concentration of sulfate along the compliance boundary is predicted to be less than the U.S. EPA Drinking Water Standards. Other chemical constituents of the seepage will decrease approximately 50 years after reclamation of the MWDF.

1.4 CONCLUSIONS

The hydrologic impacts of the proposed Project upon the existing potentiometric surface will be observed primarily during the construction and operation phases. Recovery will occur within six years after mine inflow has ceased. Predicted potentiometric drawdowns as a result of mine inflow and other hydrologic actions do not cause detrimental or irreversible impacts to surface water bodies in the area.

Projected changes in water quality from MWDF operation are small. Of the chemical constituents in the U.S. EPA Primary and Secondary Drinking Water Standards, sulfate and TDS (secondary standards) are the only constituents which are estimated to have measurable concentrations differing from the current levels measured in the ground water. This occurrence is not probable for several hundred years after operations have ceased. Model predictions indicate that none of the chemical constituents resulting from projected MWDF seepage will exceed present U.S. EPA Drinking Water Standards in the long-term at the MWDF compliance boundary.

Subsequent to the modeling analysis included in this Appendix, minor Project revisions, including a schedule extension and a downsizing of some Project facilities has occurred. These changes have had no effect on the analysis' conclusions. Attachment A-12 includes a complete description of the revisions and the effect they have on the results presented in this Appendix.

2.0 FACILITIES DESCRIPTION AND HYDROLOGIC ACTIONS

The Crandon Project will include construction, operation, and reclamation of surface and underground facilities. Figure A-2 presents the location of the Project facilities and mine area. Each facility will result in a hydrologic action with the potential for affecting the existing hydrologic regime. The cumulative effect of these actions constitutes the site hydrologic impacts.

The following facilities and the associated hydrologic actions are anticipated:

FACILITY	ACTION
Mine	Drainage of ground water from the main aquifer during mine construction and operation.
Mine/Mill Surface Facilities	Precipitation over the mine/mill area is redirected to surface drainage basins according to the planned site grading, altering ground water recharge rates.
Surface Drainage Basins Nos. 1 and 2	Increase in ground water recharge resulting from redirected surface water runoff from the mine/mill surface facilities area.
Preproduction Ore Storage Pad, Oily Runoff Collection Area, and Waste Rock Storage Area	Reduction of ground water recharge resulting from collection of precipitation over lined facilities.
Potable Water Supply Well	Pumping of water from the main aquifer.
Sanitary Wastewater Absorption Field	Infiltration of treated sanitary wastewater.
Mine Waste Disposal Facility (MWDF)	Seepage from the tailings ponds and zero ground water recharge beneath the reclaim ponds. Precipitation over the reclaimed MWDF is distributed around the MWDF perimeter.

MWDF Construction Water Supply Well	Pumping of water from the main aquifer on a limited and interim basis.

A detailed description of these facilities is presented in Chapter 1.0 of the Crandon Project Environmental Impact Report (EIR) (Exxon, 1984a). A brief discussion of these facilities and their schedules follows with an indication of the magnitude of their associated hydrologic actions.

2.1 HYDROLOGIC ACTION OF FACILITIES

Construction of the various Project facilities will occur primarily during Project Years 1 through 4. The "Year" designation refers to the time elapsed from the start of on-site activities. Mining and milling operations will start at Year 5 and continue through approximately Year 26. Figures A-3a and A-3b present the schedules for construction and operation of each facility and indicate the estimated magnitude of the anticipated hydrologic actions.

2.1.1 Underground Mine

Development and operation of the mine will result in ground water inflow by drainage from the main aquifer. Steady-state mine inflows were established by TAP Associates (1984) for three different ground water recharge rates. These recharge rates and corresponding mine inflows are presented in Table A-1.

The mine inflow was simulated as different withdrawal rates at several points above the mine. These points were chosen to best represent the location and estimated flow rates of ground water into the mine. Table A-2 presents the steady-state mine inflow rate distribution employed, and Figure A-2 shows the location of the 45 inflow points. The mine inflow is assumed to start at 30 percent of the steady-state values during Year 2. Beginning with Year 3, the mine inflow attains 100 percent of its steady-state rate and remains constant through

Year 28 (TAP Associates, 1984). During Year 29, the mine inflow is reduced 50 percent to represent mine inundation following reclamation, and then terminated at Year 30 (TAP Associates, 1984). Figure A-3a shows the projected mine inflow rate schedule.

2.1.2 Mine/Mill Surface Facilities

Figure A-2 shows the general location of the proposed mine/mill surface facilities, the surface drainage basins, the preproduction ore storage pad, potable water supply well, and sanitary wastewater absorption field. Included in the mine/mill surface area are the surface water runoff collection areas, the waste rock storage area, buildings, and paved areas. Figure A-3a presents the projected operations schedule for the surface facilities.

Redirection of precipitation surface drainage caused by the construction of the surface facilities on the mine/mill site will affect approximately 24 ha (58 acres) beginning in Year 3 and continuing through Year 28. Within this surface area, ground water recharge will be reduced to an estimated 25 percent of the current recharge rate, and the remaining 75 percent will be redirected to surface drainage basins where it will infiltrate to the ground water table. During Years 3 through 28, the surface drainage basins, as shown in Figure A-2, will receive the estimated 75 percent of the redirected infiltration from the mine/mill surface facilities areas in addition to precipitation recharge. This water is expected to infiltrate to the ground water table.

Precipitation in the oily runoff collection and waste rock storage areas (approximately 1.6 ha [4 acres]) will be collected and directed into the process water circuit; therefore, ground water recharge over this surface area will be eliminated during the operation phase. After operations are completed, the facilities will be removed and the rate of ground water recharge from precipitation will be restored.

In addition, precipitation on the preproduction ore storage pad (approximately 3.2 ha [8 acres]) will be collected and directed into the process water circuit eliminating ground water recharge in this area. After operations, the storage pad will be reclaimed and ground water recharge from precipitation to this area will be restored.

The potable water supply well will operate from the start of construction at approximately 0.003 m^3/s (50 gallons per minute) and will terminate operation at Year 30.

In addition to the potable water supply well, a second water well will be located in the MWDF area to supply construction water during phases of the MWDF construction. The MWDF well will be sized to supply approximately 0.03 m^3/s (500 gallons per minute) and be used in the summer months in the years when construction occurs. Because of the limited and interim use of this well, it was not included in hydrologic simulations.

The sanitary wastewater absorption field is expected to cover approximately 1.0 ha (2.5 acres) and have a continuous seepage rate during mill construction and operations. The seepage rate will be approximately 0.001 m^3/s (20 gallons per minute) beginning at Year 2 until termination of operation at Year 29. Precipitation recharge also occurs in the sanitary wastewater absorption field area throughout the operation phase.

2.1.3 Mine Waste Disposal Facility (MWDF) and Reclaim Ponds

The proposed MWDF and reclaim water ponds, designated as System 41-114B in Figure A-2, will consist of four tailings ponds (T1 through T4) and two reclaim ponds (R1 and R2). The reclaim ponds will be lined with a synthetic and a bentonite modified soil liner with a collecting drain layer between the two; virtually no seepage is anticipated for the areas covered by the reclaim ponds. Precipitation entering an active reclaim pond will become part of the process water circuit. Ground water recharge from precipitation in the area covered by the reclaim ponds will, therefore, be eliminated during operations. After operations, the reclaim ponds will be removed and ground water recharge from precipitation will be restored.

The tailings ponds will be lined with bentonite modified soil. A small amount of seepage will occur from the ponds, with the quality of the seepage different than ambient ground water quality. Seepage will continue into the post-operation phase. The amount of seepage during operations will be minimized by the pond liners and underdrains placed above the bentonite modified soil liners. The underdrains will be dewatered during operations, thereby minimizing the hydraulic head across the liners. The seepage rate during the operation phase for the four tailings ponds will vary from 1.8×10^{-4} to 2.4×10^{-4} m^3/s (2.9 to 3.8 gallons per minute) per pond (Table A-3).

Figure A-3b presents the estimated seepage rates from the tailings ponds (Exxon, 1984b). The rates reflect seepage during both the operation and post-operation phases. Seepage during the operation phase will result from water accumulated on top of the pond liners. Such accumulation of water is minimized by underdrains which are pumped during the operation phase and for approximately three years after the termination of the operation phase. It is projected that pumping of the underdrains will then no longer be necessary.

After sealing and covering the ponds with a reclamation cap and ceasing underdrain pumping, the drainable pore water in the tailings will move to the bottom of the pond and accumulate in the underdrains. This could increase seepage for a short period from Tailings Pond T4 to an estimated maximum of 4.1×10^{-4} m^3/s (6.5 gallons per minute) as shown in Table A-3.

The drainable pore water will eventually leave the pond as seepage which will continuously decrease to a steady-state rate equal to the surface infiltration which percolates to the tailings. The pond reclamation cover will minimize infiltration of precipitation to the tailings (Exxon, 1984b). Precipitation infiltrating the upper layers of the reclamation cap will be collected and allowed to infiltrate at the MWDF periphery. Eventually, a steady-state seepage rate varying from 1.8×10^{-5} to 2.3×10^{-5} m^3/s (0.29 to 0.37 gallon per minute) per pond will develop beneath the MWDF.

Table A-4 presents the estimated tailings ponds seepage chemistry at pond bottom, as projected by Exxon (1982), for the operation phase and the initial 50 years after operations (Years 5 through 79) and the period beyond 50 years of post-operations (80 Years and beyond). During the operation and early post-operation phases, the tailings will be desaturating. Approximately 50 years after operations, it is estimated that the tailings should be approaching chemical equilibrium with the tailings pore water. As shown in Table A-4, sulfate and filterable residue are projected to remain constant at approximately 2,000 and 3,000 mg/l, respectively. The seepage pH is expected to remain between 7 and 8 (Exxon, 1982). For comparative purposes, Table A-4 also presents the U.S. EPA Primary and Secondary Drinking Water Standards. Except for manganese, iron, and cadmium, most heavy metals in the tailings ponds leachate are projected to be near the U.S. EPA Drinking Water Standards at the top of the liners for the operation phase and initial 50-year post-operation phase. After the 50-year post-operation phase, metal concentrations in the tailings ponds seepage are expected to decrease to below the U.S. EPA Drinking Water Standards (Table A-4).

2.2 ALTERNATIVES

The alternatives provided by Exxon and reviewed during the hydrologic impact assessment study relate only to the MWDF. Mine waste disposal alternatives were evaluated only for comparison to the proposed MWDF plan. Alternatives for the other Project facilities, including the mine/mill surface facilities and the mine, are not expected to cause different hydrological impacts from those of the proposed conditions. For additional information on Project alternatives, refer to the Crandon Project Environmental Impact Report (EIR), Chapter 3.0 (Exxon, 1984a).

2.2.1 MWDF 41-114B Seepage Control

2.2.1.1 Tailings Ponds Liner

The projected pond seepage rates discussed above are based on a pond liner with a permeability of 5.0×10^{-10} m/s (1.4×10^{-4} feet per day). An alternative examined was the seepage from a liner with a permeability of 5.0×10^{-9} m/s (1.4×10^{-3} feet per day). This alternative increases MWDF seepage rates during the operation phase by approximately an order of magnitude over the projected seepage rates for the proposed liner system. The post-operation phase steady-state seepage will be the same for the alternative because the reclamation cap is identical.

2.2.1.2 Reclamation Cap

The projected total steady-state MWDF post-operation phase seepage rate is approximately 8.3×10^{-5} m^3/s (1.3 gallons per minute) or 1.68 mm/y (0.066 inch per year) per unit area (Table A-3). This seepage rate is based on a reclamation cap design consisting of a bentonite modified soil seal overlain by a synthetic membrane and a drainage blanket of coarse sand and gravel, covered with a layer of till. An alternative to this proposed design would include a similar seal and till cover, but without the overdrain and synthetic liner. The steady-state MWDF post-operation phase seepage rate for this alternative reclamation cap design is assumed to be approximately 2.04×10^{-3} m^3/s (32 gallons per minute) for the total MWDF area or 39.6 mm/y (1.56 inches per year) per unit area.

As a sensitivity analysis to the projected seepage rate for the proposed design, the MWDF seepage was analyzed assuming that the synthetic membrane was not present. The estimated total steady-state

MWDF post-operation phase seepage rate without the synthetic membrane is approximately 8.3 x 10^{-4} m^3/s (13.3 gallons per minute) or 16.8 mm/y (0.66 inch per year) per unit area.

2.2.2 Tailings Disposal Layout and Method Alternatives

2.2.2.1 MWDF Area 41 Layout Variations

The effects of variations in the layout of the proposed MWDF (41-114B) have been evaluated. Alternative MWDF tailings ponds layouts designated as 41-103 and 41-121 are shown in Figure A-4. These alternatives have been included to assess the effect of tailings ponds siting within MWDF
Area 41. Alternative layout 41-103 is located west of the proposed MWDF encroaching within the 305 m (1,000 feet) regulatory setback from Duck and Deep Hole lakes. Alternate layout 41-121 is located southwest of the proposed MWDF and also encroaches on the regulatory setback. Vertical cross sections for these MWDF layout variations are presented in Figure A-5. Seepage rates per unit area from the alternate MWDF layouts are projected to be similar to the proposed MWDF 41-114B design (Table A-3).

2.2.2.2 Subaerial Disposal

The subaerial disposal alternative includes a more managed slurry deposition of the tailings than for the conventional proposed wet disposal system. The in-place tailings would be at a higher density. The result would be reduced overall MWDF size. Seepage rates per unit area are dependent on the liner system and ultimately the reclamation cap. For analysis of operating and steady-state conditions, unit area seepage rates were assumed to be the same as for the proposed MWDF. Total seepage, because of the reduced facility area, would be less than for the proposed MWDF conditions. The location of the alternative subaerial MWDF is presented in Figure A-6 while Figure A-7 depicts its vertical cross section.

2.2.2.3 Dry Disposal

Another alternative to the proposed MWDF is dry tailings disposal. In the dry disposal alternative, the tailings would be dewatered mechanically to eliminate or reduce contained process water. Tailings disposal would be accomplished either as a cut-and-cover operation or as a more conventional landfill operation. Seepage may occur during the operation phase as the tailings consolidate under loading. Seepage from the dry disposal alternative will be dependent on the reclamation cap design, and steady-state, long-term seepage may occur as precipitation infiltrates and passes through the placed tailings. For this alternative, a conservative final steady-state seepage rate per unit area similar to the proposed MWDF design has been assumed based on utilization of a reclamation cap which performs similarly to the proposed MWDF reclamation cap. Figure A-6 depicts the location of an alternative dry disposal operation by conventional cut-and-cover landfill. Figure A-7 shows a vertical cross section of this disposal method.

3.0 SITE AREA HYDROLOGIC SETTING

The site area hydrologic conditions pertinent to the Crandon Project hydrologic impact assessment are summarized in this section, which includes a discussion of the components of the hydrologic regime and relevant characteristics necessary to evaluate the impacts of Project activities during construction, operation, and post-operation phases. Detailed descriptions of the hydrologic conditions are discussed in Chapter 2.0 of the EIR, including Sections 2.2, Geology; 2.3, Ground Water; and 2.4, Surface Water (Exxon, 1984a).

3.1 SITE GEOLOGY

The site geology is an integral part of understanding the ground water and surface water regimes. The pertinent aspects of the geology related to ground water and surface water are summarized below.

The Crandon orebody occurs in Precambrian Age bedrock in the Southern Province of the Canadian Shield. The bedrock in the site area is composed of volcanic flows and pyroclastics with interbedded sedimentary rocks and younger granitic intrusions (Exxon, 1984c). These strata were originally deposited horizontally, but through subsequent deformation have been tilted to a nearly vertical attitude. In addition to structural deformation, the combination of heat and pressure has altered the mineralogical composition of the strata. During Pleistocene time, the bedrock surface was scoured by glaciers, which deposited a mantle of unconsolidated materials (Golder Associates, 1982a).

The mine/mill surface facilities in the site area will be constructed on the unconsolidated materials (glacial deposits). A mine access shaft will be advanced through the glacial deposits, providing entry to the orebody.

Five types of glacial deposits were identified in the site area by STS Consultants, Ltd. (1984a): (1) glacial till, (2) basal till, (3) coarse-grained stratified drift, (4) fine-grained stratified drift, and (5) lacustrine. Each is distinguished by characteristic particle size distribution, shape of the soil gradation curve, degree of particle sorting, and depositional features. Borings at the locations shown in Figure A-8 were used to characterize the glacial deposits. Stratigraphic cross sections are illustrated in Figures A-9 through A-12.

A brief description of the glacial deposits follows:

1. Glacial Till - This unit consists of a poorly sorted mixture of silt, sand, gravel, and clay. The glacial till deposits are extensive across the site and form many upland areas. The thickness of this unit varies from 0 m in some low-lying wetland areas to greater than 60 m (197 feet) in certain upland areas.

2. Basal Till - The layer of glacial till found on the bedrock surface under various portions of the site was designated as basal till. It can generally be distinguished from the other till deposits by color and by a higher percentage of fine-grained material. The basal till was often encountered above or below lacustrine deposits. The basal till layers are relatively thin, usually less than 10 m (30 feet) thick.

3. Coarse-Grained Stratified Drift - The stratified nature of this unit suggests that flowing water (glacial melt water) was involved in its deposition. The coarse-grained stratified drift samples were distinguished by the presence of stratification, which was absent in the till samples, and by the relatively low percentage of fine-grained materials. The unit thickness varies from 0 to 70 m (0 to 230 feet) and is exposed primarily in the lowland areas of the site.

4. Fine-Grained Stratified Drift - The fine-grained stratified drift unit is also a glacial melt water deposit, but consists of finer materials than the coarse-grained stratified drift unit. The thickness of this unit varies from 0 to 30 m (0 to 98 feet). The fine-grained stratified

drift, together with the coarse-grained stratified drift, form the major water-bearing zone at the site area.

5. Lacustrine - The lacustrine category includes both very fine-grained sediments deposited at the bottom of present-day lakes (lake lacustrine) and fine-grained sediments deposited in a quiet water setting during glacial times (glacial lacustrine). Samples of the lacustrine sediments from present-day lakes included deposits of fine silt and clay in thicknesses ranging from 1 m (3.3 feet) in Skunk Lake to 15 m (49 feet) in Duck Lake.

3.2 GROUND WATER HYDROLOGY

Ground water flow occurs in the saturated glacial deposits within the site area. The fine- and coarse-grained stratified drift units within these saturated deposits are defined as the "main aquifer" in the site area. The saturated thickness of the main aquifer varies from greater than 70 m (230 feet) to zero, with an average saturated thickness of 20 to 30 m (66 to 98 feet) over the site area. The hydrologic characteristics of the main aquifer are discussed below.

3.2.1 Main Aquifer Characteristics

Recharge and Flow Direction

The main aquifer recharge in the site area occurs from infiltration of precipitation and as a result of recharge from lakes located in upland areas, including Duck, Little Sand, Deep Hole, Oak, and Skunk lakes (Dames and Moore, 1984a). Zones of ground water discharge occur mainly in low-lying wetland areas. In these areas, ground water from the site is discharged to Swamp Creek, Pickerel Creek, Hemlock Creek, Rice Lake, Crane Lake, Pickerel Lake, Rolling Stone Lake, and Hoffman Spring (Dames and Moore, 1984a).

The estimated average recharge rate for the site area was calculated to be 137 to 228 mm/y (5.39 to 8.98 inches per year)

(Attachment A.2). Therefore, it was difficult to determine a single recharge rate for the site area. After meetings with the WDNR, it was agreed that the following three different precipitation recharge rates would be considered for the hydrologic impact assessment:

Low Recharge Rate	152 mm/y (6.0 inches per year)
Middle Recharge Rate	216 mm/y (8.5 inches per year)
High Recharge Rate	279 mm/y (11.0 inches per year)

These rates correspond to the probable range of average recharge for the site area. Consequently, each of these recharge rates has been evaluated to analyze the sensitivity of the hydrologic regime. The hydrologic impacts were then evaluated for each recharge rate.

The observed potentiometric surface of the main aquifer is shown in Figure A-13. Ground water elevations (potentiometric heads) within the site area vary from 485 m MSL (1,591 feet) beneath the MWDF area to 467 m MSL (1,532 feet) along Swamp Creek. General ground water flow in the site area is toward the south-southwest, with some radial flow from the ground water mound beneath the MWDF area (Figure A-13). Hydraulic gradients in the site area, as determined from the potentiometric surface shown in Figure A-13, range from near zero in the MWDF area to approximately 0.033 near Swamp Creek.

Ground water level data (Dames and Moore, 1982) from various observation wells in the site area indicate that the seasonal fluctuation of the potentiometric surface is approximately 1 m (3.3 feet) in the upland recharge areas, with less fluctuation in the lowland discharge areas.

Permeability

The permeabilities of the various types of glacial deposits and the underlying bedrock have been measured by various field and laboratory tests (Exxon Minerals Company, 1984c; STS Consultants, Ltd., 1984a, 1984b; Golder Associates, 1981, 1982b; and Dames and Moore, 1981). These test results indicate that the permeability of these units varies widely (Table A-5). In general, the coarse-grained stratified drift is the most permeable glacial unit in the site area. The till and lacustrine deposits, which contain more silt and clay, are the least permeable. The till acts as an effective confining layer in certain portions of the site area and can affect the behavior of the ground water flow in the stratified drift.

The coarse- and fine-grained stratified drift are identified as the primary ground water transporting portion of the main aquifer. Because of its higher permeability and widespread occurrence in the site area, most of the following discussions of aquifer characteristics primarily refer to the coarse- and fine-grained stratified drift.

A pumping test in the stratified drift at the MWDF area (Golder Associates, 1981) was performed to define the aquifer permeability. Table A-6 presents these pumping test results for the stratified drift. A permeability range of 1.06×10^{-4} to 1.2×10^{-3} m/s (30 to 340 feet per day) is presented. Golder Associates' (1982a) recommended permeability value of 1.3×10^{-4} m/s (37 feet per day) for the horizontal flow in the stratified drift is within this measured range and is considered realistic for impact hydrologic assessments.

The horizontal permeability of the till was evaluated using on-site field tests. STS Consultants, Ltd. (1984a), presents a range of horizontal till permeabilities of 9×10^{-8} to 3×10^{-5} m/s (2.6×10^{-2} to 8.5 feet per day), with a mean value of 6×10^{-6} m/s (1.7 feet per day). This average value is in reasonable agreement with Golder Associates' (1981) recommended value for horizontal till permeability of 2.8×10^{-6} m/s (0.79 foot per day).

The bedrock was considered to be an impermeable boundary for the purpose of the hydrologic impact assessments. Tests performed during subsurface investigations indicate bedrock permeabilities of 10^{-6} to 10^{-10} m/s (2.8 x 10^{-1} to 2.8 x 10^{-5} foot per day) (Exxon Minerals, 1984c). In areas of the orebody where bedrock is extremely weathered, permeability values may be higher than those measured during field testing. However, for the purposes of these evaluations, it is appropriate to assume that the bedrock is an impermeable boundary.

Aquifer Thickness and Ground Water Flow Conditions

The isopach contours of the saturated thickness of the stratified drift are shown in Figure A-14, and contours of the elevation of the base of the stratified drift are presented in Figure A-15. As shown in Figure A-14, the saturated thickness of the stratified drift varies from zero near the mine to greater than 70 m (230 feet) southeast of the MWDF.

Four types of ground water flow conditions within the main aquifer are present in the site area: (a) semiconfined with overlying saturated/ partially saturated till; (b) unconfined with overlying partially saturated till, (c) unconfined with no overlying till; and (d) unconfined saturated/ partially saturated till only. Where a saturated stratified drift unit lies beneath less pervious material such as a saturated till or lacustrine deposit (e.g., beneath a thick till layer at the MWDF area), the stratified drift acts in a semiconfined manner (a). When the confining layer exists, but is not fully saturated, an unconfined condition with a relatively impervious overlying strata exists (b). In other locations, the confining layer does not exist and the stratified drift is hydraulically unconfined (c). In some areas, the stratified drift does not exist (STS Consultants, Ltd., 1984a) and the aquifer is unconfined and primarily composed of low-permeability till (d).

Figure A-16 presents a schematic map depicting the location and extent of the four ground water flow conditions. As indicated in this figure, the stratified drift (primary conduit of the main aquifer) acts as a semiconfined aquifer in the northeastern portion of the site where the MWDF is located. In the mine area, the stratified drift is primarily unconfined (overlain by partially saturated till) or is absent. Where the stratified drift is absent, the aquifer consists of unconfined low-permeability till.

Storage Coefficient

The storage coefficient of the stratified drift varies from 0.05 to 0.07 (Golder Associates, 1982b). The portions of the stratified drift acting hydrogeologically as a semiconfined aquifer commonly exhibit a smaller storage coefficient than for other ground water regime conditions. Because the majority of the planned hydrologic actions are in the area of the semiconfined aquifer, the value of 0.05 was selected as the storage coefficient for use in the hydrologic analysis. The storage coefficient of till varies from 0.0015 to 0.054; the higher value was recommended for units in the site area (Golder Associates, 1982b).

3.2.2 Ground Water Quality

The ground water quality of the main aquifer at the Project site was investigated by Dames and Moore (1982) and is summarized in Table A-7.

Ground water pH is usually near neutral (mean pH of 7.6 to 7.7) but has ranged from slightly acidic to very strongly alkaline (pH 5.5 to 12.2); the upper limit pH is considered anomalous. The range of pH is more typically 6.7 to 8.7. The TDS concentrations range from 14 to 836 mg/l and average 166 mg/l. Alkalinity and hardness account for most of the dissolved solids content; i.e., the ground water has a prevalent calcium bicarbonate chemical character. Both the chloride and sulfate maximum concentrations are below 90 mg/l with mean concentrations of less than 4 and less than 9 mg/l, respectively. Most heavy metal concentrations are low, with a mean concentration of less than 1 mg/l.

For comparative purposes, Table A-7 also depicts the U.S. EPA Primary and Secondary Drinking Water Standards. Occasional reported values for pH, TDS, nitrate, cadmium, and lead have exceeded U.S. EPA Drinking Water Standards. The mean concentrations of iron (less than 1.74 mg/l) and manganese (less than 0.423 mg/l) exceed the U.S. EPA Drinking Water Standards. The maximum or mean concentration of the other tested parameters do not exceed U.S. EPA Drinking Water Standards.

3.2.3 Ground Water Usage

Data from a water well inventory performed by Dames and Moore (1982) indicate that current regional ground water use is primarily for municipal and domestic consumption. Most producing wells are completed in unconsolidated glacial sands and gravels. Within the site area, ground water use is currently limited to the domestic needs of a limited number of residents.

3.3 SURFACE WATER HYDROLOGY

The existing characteristics of the surface water hydrology are discussed in detail in Chapter 2.0 of the EIR (Exxon, 1984a). These characteristics, as related to the hydrologic impact assessments, are summarized below.

In assessing the impacts of the proposed activities on surface waters, the relationship of the surface water regime to the ground water hydrogeologic system is of prime importance. Hydrologic actions will occur within the ground water regime which can, in turn, influence the surface water if interconnection exists. For example, alteration of surface water infiltration can result from construction of proposed facilities. The relationship between surface water recharge potential and ground water flow is therefore a factor related to overall hydrologic impacts.

The components of the surface water hydrology reviewed to assess the interrelationships with the ground water regime and resultant impacts of the proposed facilities included (1) climatology (as related to available precipitation for infiltration and runoff), (2) stream and lake characteristics, (3) spring locations, (4) surface water quality. The data reviewed were primarily obtained from a detailed field monitoring program conducted during the period April 1977 through November 1980 (Dames and Moore, 1984a). The data collected during this program included stream flow hydrographs, stream and lake water levels, stream and lake water quality samples, and stream and lake bottom sediment characteristics. Data on lake sediment characteristics were supplemented with documentation by STS Consultants, Ltd. (1984b). The field data were also supplemented with U.S. Geological Survey (USGS) records to provide a comprehensive summary of the surface water hydrology in the study area. Complete documentation of the results of the hydrologic study is presented in Dames and Moore (1984a) and most of the hydrologic parameter values cited herein are based on this reference.

3.3.1 Climatology

The precipitation and evapotranspiration components of the climatology are related to the water available for infiltration (recharge to the ground water regime) and surface water runoff. The average annual precipitation in the study area is 781.6 mm (30.77 inches). On a seasonal basis, the precipitation rate is greatest in the late spring and early summer and decreases to its minimum value during winter. The total mean annual snowfall is 1,270 mm (50 inches). The average monthly precipitation varies from a high of 115.6 mm (4.55 inches) in June to a low of 25.4 mm (1.0 inch) in February (Dames and Moore, 1984a).

3.3.2 Stream and Lake Characteristics

The site area lies entirely within the Wolf River drainage basin. Two major Wolf River tributaries, which pass through the site area, are Swamp Creek and Pickerel Creek (Figure A-17). The orebody and the proposed mine and mill facilities lie approximately on the boundary between these two drainage basins. The Swamp Creek and Pickerel Creek drainage basins contain forested land, lakes, wetlands areas, and several perennial streams. Hemlock Creek bounds the site area to the east; the characteristics of its drainage basin (subwatershed of the Swamp Creek drainage basin) are similar to those described above.

Drainage Basins

The Swamp Creek drainage basin is located in the north-central portion of the Wolf River basin. Swamp Creek is a perennial stream that originates approximately 7.2 km (4.5 miles) northeast of the orebody at Lake Lucerne and flows 24.9 km (15.5 miles) to its confluence with the Wolf River approximately 12.6 km (7.8 miles) southwest of the orebody. A summary of the characteristics of streams and lakes in the Swamp Creek drainage basin is presented in Table A-8.

The Pickerel Creek drainage basin is located in the center of the Wolf River drainage basin. Pickerel Creek is a perennial stream that originates north-northwest of Rolling Stone Lake, approximately 4.7 km (2.9 miles) west of the orebody, flows southeast to Rolling Stone Lake and Pickerel Lake and then flows west to its confluence with the Wolf River. A summary of the characteristics of streams and lakes in the Pickerel Creek drainage basin is presented in Table A-9.

Stream Flows and Floods

The total annual stream discharge, in terms of surface water runoff resulting from precipitation over the watersheds in the vicinity of the study area, ranges from 279 to 330 mm (11 to 13 inches). The mean annual discharge from the Wolf River drainage basin (1966 to 1978) as measured at the Langlade Station is 13.2 m^3/s (466 cubic feet per second), corresponding to an average surface water runoff depth of 352 mm (13.87 inches) over the watershed. The average monthly stream flow, in terms of surface water runoff over the watersheds, ranges from a high of 56.4 mm (2.22 inches) during April when snowmelt runoff is greatest to a low of 17.5 mm (0.69 inch) during February when precipitation is retained on the ground surface as snow and ice (Dames and Moore, 1984a).

Flooding is a factor in impact evaluations because the proposed activities will deposit materials at the surface which could be transported to surrounding areas if inundated by flood waters. Flood potential is low and the area affected in the site area is small. The extensive areas of lakes and wetlands within the drainage basins provide storage for relatively large volumes of water, thereby keeping flood peaks low. In addition, the high permeability of the soils results in a low percentage of surface runoff.

Lakes

Lakes considered in the impact assessment in the Swamp Creek and Pickerel Creek drainage basins can be characterized as one of the following three types (Dames and Moore, 1984a):

> Drainage Lake - Drainage lakes have at least one inlet and one outlet and receive water mainly from stream drainage (Rice, Rolling Stone, and Pickerel lakes).
>
> Seepage Lake - The water level in seepage lakes, which usually have no stream inlet or outlet, is maintained by surface runoff and seepage through a low permeability lake bottom (Little Sand, Deep Hole, Duck, Skunk and Oak lakes).
>
> Spring Lake - The source of water for spring lakes is ground water inflow and direct precipitation rather than surface water runoff. These lakes always have an outlet but seldom have an inlet (Ground Hemlock Lake).

The lakes along the site boundary (Ground Hemlock, Rice, Rolling Stone, and Pickerel lakes) are in direct communication with the ground water and receive ground water discharge from the site area. The lake bottoms in Little Sand, Duck, Deep Hole, and Skunk Lakes are below the potentiometric surface in this area and, thus, their rate of seepage is dependent on the lake bottom permeability and thickness and the head difference between the potentiometric lake surface elevation and the ground water potentiometric level. Oak Lake, however, is not hydraulically connected to the ground water and its seepage is independent of the potentiometric surface (STS Consultants, Ltd., 1984b).

3.3.3 Surface Water Quality

Water quality in the surface water bodies is the basis for evaluating the impacts of proposed activities. The water chemistries of the lakes and streams in the Swamp Creek and Pickerel Creek drainage basins are presented in Dames and Moore (1984a). The water chemistry data suggest that many of the surface water bodies exhibit water quality similar to the main ground water aquifer, having relatively high alkalinity and hardness, and a neutral pH. These surface water bodies include Rice and Ground Hemlock lakes; and Hemlock, Swamp, and Outlet creeks 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. Seepage lakes typically have lower hardness, alkalinity, conductivity, TDS, and pH values than the other lakes and streams of the drainage basins.

Neither lake nor stream bottom sediment samples exhibited unusual chemical characteristics (Dames and Moore, 1984a). The overall sediment transport by streams in the study area is small. This appears to be a result of the following factors: forested land, granular soils, moderate slopes, low stream velocities, and the numerous lakes and wetlands which serve as sediment traps.

3.3.4 Springs

Hoffman Spring is located approximately 2.9 km (1.8 miles) west of the orebody (Dames and Moore, 1984b). The elevation of the spring is the same as the potentiometric surface in this area, indicating a hydraulic connection between the spring and the ground water.

4.0 METHOD OF SIMULATION AND MODEL INPUT DATA

To assess the hydrologic impacts of the proposed activities, the site area hydrologic conditions were simulated using numerical computer models. The simulation resulted in numerical predictions of the hydrologic conditions and water quality at the site area during and subsequent to mine and mill operations.

The site area hydrologic regime was numerically modeled using a finite element program developed by D'Appolonia (1983) known as GEOFLOW. The site area, including adjacent streams and lakes, the mine, and other related facilities, was modeled in two-dimensional plan (horizontal planar model) and cross section (vertical models). Section 6.0 presents the results of these models.

The two primary effects of the proposed facilities are (a) drawdown of the potentiometric surface resulting from ground water drainage into the mine, and (b) changes in the ground water quality because of seepage from the MWDF. These two effects could be studied separately without affecting the accuracy of the results because the time predicted for the MWDF seepage to reach the water table is longer than the predicted period of potentiometric surface drawdown and recovery.

To satisfy WDNR concerns, model calibrations and hydrologic impact assessments were conducted using the recharge rates presented in Table A-1.

4.1 METHOD OF SIMULATION

A horizontal planar model and several vertical models were used in the hydrologic impact assessment. The horizontal model is a two-dimensional model designed to simulate ground water flow and chemical constituent transport in the stratified drift and was used to evaluate the hydrologic actions of the proposed facilities. The stratified drift was modeled as the principal ground water flow unit because it is the most permeable unit of the glacial deposits. The model was calibrated based on available hydrogeologic and hydrologic data for the site area ground and surface water regimes. The hydrologic actions associated with the proposed mine and facilities were then incorporated into the model. The interaction of the site area hydrologic components, such as potentiometric levels and ground water discharge rates, with the hydrologic actions resulting from the proposed activities was evaluated using the horizontal planar model.

The horizontal model was also used to simulate the lateral steady-state transport of chemical constituents from the MWDF. The horizontal and vertical models were correlated where appropriate to provide consistency of results between the modeling efforts. One- and two-dimensional vertical models were designed to evaluate the vertical distribution of chemical constituents migrating from the MWDF.

The one-dimensional vertical model was used to compute the rate of migration of chemical constituents through partially saturated till beneath the MWDF. In addition, this model predicted the concentration distribution of chemical constituents at the top of the water table. Results of the modeling through the partially saturated till were used as input for the transient two-dimensional vertical model.

A calibrated two-dimensional vertical model was used to simulate transport of chemical constituents through the saturated till and stratified drift. Vertical and horizontal variations of concentration within the till and drift, and the predicted arrival time of chemical constituents at the MWDF compliance boundary, were also determined using the two-dimensional vertical model.

4.2 COMPUTER PROGRAM DESCRIPTION

The computer program GEOFLOW (D'Appolonia, 1983) utilizes the finite element method to apply the governing partial differential equations required to model ground water flow and mass transport of chemical constituents in the ground water regime. The program consists of two independent subprograms. By providing hydrodynamic parameters (such as transmissivity, storage coefficient, pumping rate), the hydrodynamic subprogram computes potentiometric heads and, consequently, the velocity vectors of ground water flow. The resulting velocity vectors are incorporated into the mass transport subprogram to yield the concentration distribution of chemical constituents in the ground water flow domain. Transient and steady-state solutions for ground water flow and mass transport equations can be computed by the program.

4.3 DEFINITION OF SIMULATION PERIOD

The impacts associated with proposed hydrologic actions were simulated for the three Project phases, (a) construction, (b) operation, and (c) post-operation. As shown in Figures A-3a and A-3b, the hydrologic actions associated with the construction phase were simulated for four Project years. The hydrologic actions associated with the operation phase were simulated for an additional 25 Project years, including 22 Project years of mine/mill operations and 3 Project years of the post-operation phase reclamation activities. Post-operation phase activities were simulated for an additional 31 Project years following completion of the reclamation activities. The potentiometric surface was predicted to return to within 1 m (3.3 feet) of the premining conditions within the 31-year simulation period of the post-operation phase. Longer term hydrologic impacts were analyzed by simulating transient conditions until steady-state conditions were reached.

4.4 MODEL INPUT DATA

The input data for the model, (a) hydrologic parameters and (b) geochemical mass transport parameters, were based on previous study reports presenting site-specific information. These data were obtained from field measurements, data analysis, laboratory testing, and literature review. Where large variations occurred in values of certain field parameters, the range for each parameter was reduced by model calibration. For parameters and site area conditions where site-specific measurements were not available, data from the literature were selected for sites with similar hydrologic properties. In addition, a sensitivity analysis was performed to examine the effect of parameter variation on the results of the modeling.

4.4.1 Hydrologic Parameters

The following hydrologic parameters were used in the ground water flow simulation:

Permeability;

Water elevation:
- Potentiometric surface;
- Surface water elevation of streams and lakes;

Aquifer type, thickness, and datum elevation;

Recharge mechanism:
- Precipitation infiltration;
- Lake seepage; and

Storage coefficient.

Values used for the hydrologic parameters, except the recharge rate, were determined from measured data as discussed in Section 3.0, and are further clarified in this section. Three different precipitation recharge rates were used in the impact assessments. Lake seepage (recharge) rates were calculated based on lake configurations, head differences, and the permeabilities of material under the lakes.

An adjustment to the base of the stratified drift elevation (Figure A-15) was made to properly represent the aquifer for model simulation. The base of stratified drift elevation for model input is presented in Figure A-18 and is based on data presented in Figures A-9 through A-12. The permeabilities, storage coefficients, and porosities for the various geologic units selected for use in model simulation are presented in Table A-5.

Attachment A.7 contains a detailed listing and discussion of all input parameters and the assumptions and modeling conditions which were used in these evaluations. Table A.7-1 of Attachment A.7 has been prepared to cross reference the location of these data in the text.

The following two sections present further discussions of the permeabilities of the saturated and partially saturated zones and the ground water recharge rates used in the simulations.

4.4.1.1 Permeability of the Saturated and Partially Saturated Zones

The saturated permeability of the stratified drift was used in the horizontal model for the hydrologic impact assessment. The permeabilities of the saturated and partially saturated zones of the till, along with the saturated permeabilities of the stratified drift units, were used in the vertical models for assessment of ground water flow and mass transport of chemical constituents from the MWDF.

The horizontal saturated permeabilities of the main aquifer components are presented in Table A-5. The range of permeability values from pumping test data was examined during model calibration, utilizing observed site area potentiometric surfaces as discussed in Section 5.0.

The evaluation of chemical constituent mass transport required an understanding of hydrologic parameters for the partially saturated till beneath the MWDF. In a partially saturated soil, the permeability of the soil and negative pressure in the soil pores (suction pressure) are a function of the percent saturation. Permeability increases as the percent saturation increases and reaches its maximum value when the soil reaches a fully saturated condition. Suction head decreases as the percent saturation increases; the suction head value is equal to atmospheric pressure (zero gage pressure) for fully saturated soil.

The relationships between (a) suction head and percent saturation and (b) permeability and percent saturation are presented in Figures A-19 and A-20, respectively, for the partially saturated till. Data for suction head and percent saturation were obtained from laboratory tests of site soil samples (D'Appolonia, 1982). The method for empirical determination of partially saturated permeabilities from these figures is presented in Attachment A.1.

4.4.1.2 Ground Water Recharge

The net ground water recharge rate from precipitation in the study area is a required input parameter for the computer model. A range of recharge rates was determined by computing the total base flow rate in streams along the study area boundary, as presented in Attachment A.2, and then comparing the base flow rate to precipitation and evapotranspiration rates. The analysis was based on a mass balance between water entering the aquifer system (net ground water recharge) and that leaving the system (ground water discharge into bordering streams, i.e., base flow). Base flow rate measurements for streams along the study area boundary were the primary source of data for the analysis.

The results indicated that the total net ground water recharge rate over the study area could vary from 0.249 to 0.415 m^3/s (8.7 to 14.6 cubic feet per second) during dry and wet periods of the year. Expressed in terms of depth of water over the site area, the net recharge rate could vary from 137 to 228 mm/y (5.39 to 8.98 inches per year).

The calculated recharge values are similar to the independent analysis performed by Golder Associates (1982a). According to their calculations, the recharge values vary from 218 to 269 mm/y (8.58 to 10.59 inches per year) (Golder Associates, 1982b).

Because of the variation in the estimated recharge values, and based on WDNR requests, three different recharge rates were used in the hydrologic impact assessment. The recharge rates (Table A-1) represent the estimated range of calculated average recharge rates in the site area. Each recharge rate was uniformly applied throughout the site area, with the exception of areas such as the lakes and the mill/mine facilities, where different recharge values were used during the model simulations. Since the purpose of hydrologic simulation was to predict the yearly average impact of the facilities, uniform precipitation recharge was used in the modeling. Additionally, since the stratified drift has a relatively high permeability, the effect of localized areas of different precipitation recharge is not noticeable when averaged over a year. The location and values for different recharge zones are discussed in Section 5.0.

Lake recharge rates (seepage from site area lakes to the aquifer system) were simulated using available site-specific hydrologic data. Subsequent to the GEOFLOW simulations, more detailed water balance information about the lakes became available (Dames and Moore, 1985). This water balance information presented estimates of lake recharge rates which differ from those computed in the GEOFLOW simulations; however, the two sets of lake recharge rates produce very similar computed potentiometric surfaces when used as input for the horizontal model (Attachment A.10). Therefore, the existing GEOFLOW model parameters for lake recharge continue to provide a valid representation of the area hydrogeologic system.

For the GEOFLOW simulations, the recharge rates from the lakes were calculated using Darcy's Law. Flow rates were calculated for seepage through the lake bottom lacustrine deposits. Appropriate permeabilities and thicknesses for the lacustrine deposits were selected from the data presented in Tables A-5 and A-10 (STS Consultants, Ltd., 1984a and 1984b). The driving head was equal to the difference between the water elevation in the lake and the potentiometric surface of the main aquifer underlying the lake. Lake level and lacustrine deposit thickness was incorporated in the model for each lake, and preconstruction and operation phase seepage recharge rates were calculated for each lake based on an average lake bottom thickness. The operation phase recharge rates computed by GEOFLOW vary from 213 to 406 mm/y (8.4 to 16.0 inches per year) per unit area (Table A-10). As the water level in the aquifer declined during mine inflow, variable lake recharge values were calculated by the model.

Subsequent to the GEOFLOW simulations, a separate analysis of lake seepage recharge rates for the preconstruction phase was performed (Dames and Moore, 1985). The Dames and Moore analysis used a water balance approach to compute seepage as a residual component of each lake's water budget; these computed lake recharge rates are also presented in Table A-10. New information contained in the water balance report (Dames and Moore, 1985) and additional field data (Exxon, 1985a; 1985b) were used to assess operation phase impacts on lake recharge rates and levels. Changes in lake seepage and levels were computed using Darcy's Law, detailed information about site area lake and wetland hydrology, and the water balances developed by Dames and Moore (1985). These computations are detailed in Attachment A.10, and the resulting operation phase lake recharge rates are indicated in Table A.10.

Table A-10 presents the lake recharge rates computed by two methods, simulation using the horizontal GEOFLOW model, and water balances using water budget and Darcy's Law calculations. The differences between the two sets of lake recharge rates did not affect the GEOFLOW horizontal model calibration to a large degree, as discussed in Attachment A.10. An evaluation of the effects of the lake recharge rates computed by the water balance method on mine inflow rates was performed using the GEOFLOW horizontal model; results of this evaluation are discussed in Section 6.6.2.

4.4.2 Geochemical and Mass Transport Parameters

Geochemical and other mass transport parameters were used, in addition to the hydrologic parameters, to predict the migration of chemical constituents from the MWDF. As an aqueous fluid migrates through a porous media, certain reactions occur that are dependent upon the chemistry of the fluid itself and upon the chemistry and geochemistry of other fluids and solid phases with which it comes in contact. These geochemical interactions determine the relative rates at which chemical constituents in the migrating fluid may travel with respect to the advancing front of water.

The major geochemical/physical parameters used in the mass transport simulation include:

Geochemical Characteristics of the Soil:

Distribution Coefficient (K_d);
Retardation Factor (R_d);

Physical and Mineralogical Characteristics of the Soil:

Grain Size;
Mineralogical Composition;
Effective Porosity; and
Dispersion Coefficients.

The description of these major parameters and their sources is presented below.

4.4.2.1 Geochemical Characteristics

Geochemical processes of potential importance in retarding the flow of chemical constituents in the migrating fluid include ion exchange, adsorption, precipitation or coprecipitation, oxidation-reduction reactions, and precipitate filtration. The variable exchange capacities of different minerals, the variable concentrations of ions in water, and the generally low concentration of ions-of-interest relative to the chemical character of the solution make it difficult to derive generalized equations to depict ion exchange-adsorption reactions. Instead, the chemical attenuation capacities of soils are usually expressed in terms of distribution coefficients (K_d) and/or retardation factors (R_d). Distribution coefficients are used to assess the degree to which chemical constituents will be removed from solution as the fluid migrates through the porous media. The retardation factor (also called sorption equilibrium constant) is used to express the rate of chemical constituent movement relative to the ground water front advancement.

The distribution coefficient (K_d) for a specific chemical constituent may be defined as the ratio of (a) the mass sorbed onto a solid phase to (b) the mass remaining in solution. As expressed by Freeze and Cherry (1979):

$$K_d = \frac{\text{mass of solute on the solid phase per unit mass of solid phase}}{\text{concentration of solute in solution}}$$

The dimensions of this coefficient are cubic length per mass (L^3/M). It is conventional to express K_d in units of milliliters (or cubic centimeters) of solution per gram of soil sample.

The distribution ratio (K_r) is defined as the degree of partitioning between liquid and solid, under a defined set of testing conditions; i.e., one point on an adsorption isotherm. The retardation factor (R_d), when calculated from K_r values, assumes that, at a specific pH and Eh, the adsorption isotherm is linear ($K_r = K_d$) and does not involve attenuation solely by chemical precipitation. For the purpose of this study, the values of K_r and K_d were assumed to be equivalent, and the term K_d (distribution coefficient) is used throughout the report.

The retardation factor (R_d) for a particular solute or chemical constituent is defined as the dimensionless ratio of the average ground water velocity to the solute migration velocity.

$$R_d = \frac{\text{average velocity of ground water}}{\text{average velocity of solute}}$$

The retardation factor is equal to or greater than 1.0. When the R_d is greater than 1.0, the chemical constituents will move slower than water in the porous media and will, therefore, take a longer time to reach a given point in that media.

For a saturated or partially saturated porous media, the retardation factor is defined as (Van Genuchten, et al., 1974):

$$R_d = 1 + \frac{K_d \rho}{S \eta}$$

where

K_d = distribution coefficient (ml/g),
ρ = bulk density (g/cm^3) of the geomedia,
η = porosity, and
S = percent saturation.

For saturated media, a chemical constituent in the transported solution will migrate at the same velocity as the ground water if R_d is equal to 1.0 (i.e., $K_d = 0$). The K_d value increases as the chemical constituent migration is more strongly influenced by sorption phenomena and, hence, causes R_d to exceed 1.0, resulting in retardation of chemical constituent transport.

The K_d and R_d parameters are determined by either field or, more commonly, laboratory tests. The K_d and R_d parameters used in the model simulation for this study were determined primarily by laboratory testing (D'Appolonia, 1982).

The retardation factors for the glacial drift units used in this study are presented in Table A-11. The chemical constituents studied for attenuation were those estimated for liquids and solids present in the MWDF, all of which are not necessarily anticipated in the seepage from this facility. Table A-4 presents the chemical species projected to occur in the tailings leachate. The retardation factors for the major chemical constituents evaluated are presented in Table A-11 and vary from 1.0 to 113.0.

Retardation factors were primarily obtained from laboratory methods including both batch and column testing (D'Appolonia, 1982). Batch tests were used to define the distribution ratios (K_r) and consequently assess the distribution coefficients and the retardation factors (assuming $K_d = K_r$) for those chemical constituents which exhibited adsorption potential for soil sediments. Column tests were used to determine the retardation factors for more mobile species.

The projected initial MWDF seepage concentration for sulfate (2,000 mg/l) is 8 times U.S. EPA Drinking Water Standards as shown in Table A-4. Sulfate also had a laboratory-estimated retardation factor of 1.0. The projected seepage concentrations of the other parameters presented in Table A-4, except for filterable residue (TDS), will decrease to below drinking water standards with time and/or have very high retardation factors. The time rate of movement of these elements will be less than for sulfate. Sulfate was therefore selected as an indicator constituent for predicted long-term hydrologic impacts of seepage from the MWDF.

Because the first 13 m (43 feet) of soil beneath the MWDF will be partially saturated, the saturated retardation factors may not be appropriate to assess movements of chemical constituents through this zone. The retardation factor in partially saturated media, as discussed above, is a function of percent saturation. As the percent saturation increases, the retardation factor decreases. The retardation factor achieves its minimal value at full saturation. Use of saturated retardation factors for partially saturated zones will provide conservative results (unless $K_d = 0$).

Sufficient information is not available in the scientific literature to test and/or evaluate partially saturated retardation factors, so saturated values were used in the simulations. The results of this assumption are that predicted movements of chemical constituents beneath the MWDF will be greater than would be anticipated in actual field conditions.

4.4.2.2 Physical and Mineralogical Characteristics

Site soil attenuation characteristics were assessed for model input parameters by review of the physical and mineralogical parameters for the till and stratified drift units below the MWDF. A brief discussion of these parameters, and their importance in chemical constituent migration, is provided below.

Grain Size

The grain size distribution of the soil samples reflects the geologic history of the materials, the probable permeability of the material, and general attenuation characteristics. Finer grained soils generally have greater attenuation capability than coarse-grained soils, if the geochemical parameters are similar.

The till in the MWDF area exhibited a relatively well-graded distribution of particle sizes with a relatively high percentage of fine-grained materials. In contrast, the grain-size distribution for stratified drift reflects its glaciofluvial history and the coarse nature of the material. Typically, over 70 percent of the drift is medium to coarse sand with a small percentage of fine-grained material. The till generally had higher attenuation characteristics than the drift (D'Appolonia, 1982).

Mineralogy and Reactive pH

Attenuation characteristics are often associated with the reactivity of soil minerals with chemical constituents. The reactivity of the soil minerals and the amount of clay, organic mineral, and/or carbonate in the soil is often measured as the Cation Exchange Capacity (CEC) or Anion Exchange Capacity (AEC).

The till and stratified drift units contained predominantly quartz and feldspar, with approximately 15 percent or less clay minerals. The dominant carbonate mineral present is dolomite. The dominant clay minerals include kaolinite, mica/illite, chlorite, mixed layer clays, and smectites. The mixed layer clay minerals are an irregular, interstratified two-component mixture of chlorite and vermiculite. Quartz and feldspar also constitute more than 50 percent of the clay-size fraction. Measured organic matter in these stratigraphic units was low, ranging from 0.22 percent in the stratified drift to 0.31 percent in the till (D'Appolonia, 1982).

Other mineralogical studies (Dames and Moore, 1981) confirm the above results, except that smectite was often found to be the dominant clay mineral present and kaolinite was often present in only minor amounts. The Dames and Moore (1981) investigation was of 18 individual samples, while the D'Appolonia (1982) results were of two composite samples of 46 individual samples collected at MWDF Area 41.

The reaction pH for both the till and drift is strongly alkaline and typically above pH 9. The neutralization capacity/carbonate minerals distribution at the MWDF site is variable, both vertically and laterally. Neutralization capacities have been measured ranging from 0.2 to 36 percent calcium carbonate equivalent; however, neutralizing capacities are typically appreciable and in the range of 0.5 to 8 percent calcium carbonate equivalent in both stratigraphic units.

Measured CEC's varied from 4.2 to 7.4 milligram equivalents per 100 grams of soil for the stratified drift and till units, respectively. These CEC values are not particularly high in terms of reactive soils and reflect, in part, the low clay content of the strata. CEC resides principally in clay minerals and colloidal materials. Calcium is the most prevalent exchangeable cation, followed by magnesium and sodium.

Measured AEC values varied from 1.6 to 1.7 milligram equivalents per 100 grams of soil in the stratified drift and till stratigraphic units, respectively (D'Appolonia, 1982).

Effective Porosity

The effective porosity values relate to the amount of contact between the soils and pore water, and are a required input for computer simulation. Effective porosity values for this study were selected from available literature based on site soil conditions and measured porosity. The effective porosity of soil is always smaller than measured porosity. For clayey soil, the effective porosity is very small. As soil grain size increases, the effective porosity value increases and approaches total porosity (Bear, 1972). The measured porosity of the stratified drift was 0.307 (Table A-5). An effective porosity of 0.25 was used in the two-dimensional vertical mass transport calculations.

Dispersion

Dispersion characteristics of a soil involve the properties affecting chemical constituent advancement. Dispersion is comprised of two components: (a) mechanical dispersion, influenced by longitudinal and transverse dispersivity, and (b) molecular diffusion. These values were required for input to the horizontal and vertical models.

A review of the literature indicated that previous studies had used longitudinal dispersivity values for sandy materials ranging from 0.001 to 100 m (0.003 to 328 feet) (Freeze and Cherry, 1979). Dispersivity is scale dependent and increases with distance from the source; this is the primary reason for a wide range of values.

Values for longitudinal dispersivities as determined by model calibration to field conditions exhibit somewhat less variation. Robson (1978) used a value of 61 m (200 feet) to simulate solute transport in a California aquifer. Gray and Hoffman (1983) found that a value of 27.4 m (90 feet) provided the best simulation for their field situation, while Konikow (1977) used a dispersivity of 30.5 m (100 feet) to simulate chloride transport in an alluvial aquifer. Other studies (Schwartz, 1977; Naymik and Barcelona, 1981) have utilized longitudinal dispersivities on the order of 2 to 6 m (7 to 20 feet).

Site-specific values for dispersivities in the Crandon area aquifer are not available. However, in a finite element study of solute transport in glacial deposits, Pinder (1973) found a longitudinal dispersivity value of 21.3 m (70 feet) to be most representative. A plot of longitudinal dispersivity versus distance (Anderson, 1984) indicates a range of longitudinal dispersivities of 20 to 60 m (66 to 197 feet) for sandy materials at distances comparable to the distance between the MWDF and the compliance boundary. Therefore, based on site characteristics and the above published values, the longitudinal dispersivity was conservatively selected to be 60 m (197 feet). Various sensitivity analyses for the horizontal and vertical models, as described in Attachments A.4 and A.6, tested values from 5 to 100 m (16 to 328 feet).

In general, transverse dispersivity values are smaller than longitudinal dispersivities by a factor of 5 to 20 (Freeze and Cherry, 1979). A review of horizontal modeling studies in the literature indicated that ratios as low as 1 (Konikow, 1977) and as high as 30 (Gray and Hoffman, 1983) have been used. However, ratio values of longitudinal to transverse dispersivities between 3 and 10 were most often reported (Pinder, 1973; Naymik and Barcelona, 1981; Valocchi, et al., 1981; Sudicky, et al., 1983). This ratio was defined to be 4 or 5 for the various horizontal dispersion simulations of the Crandon site.

Reported ratios of longitudinal to transverse dispersivities for vertical modeling are somewhat higher than those for horizontal models. Pickens and Lennox (1976) tested ratios of 1, 2, 5, 10, and 20 in a cross-sectional model of a hypothetical ground water flow system. Schwartz (1977) used a ratio of 5 for profile modeling of mass transport in glacial deposits, and Duguid and Reeves (1977) also used a longitudinal dispersivity 5 times greater than the vertical transverse dispersivity. In a finite-element profile model of observed chloride concentration distributions, Segol and Pinder (1976) found that a ratio of 10 provided the best results. Recent studies at the Borden Landfill, Ontario, Canada (Cherry, 1984), have used ratios on the order of 100 to 1,000, while Robson (1978) used a value of 330 for modeling a California aquifer. A range of ratios of longitudinal to vertical transverse dispersivities from 5 to 1,000 was tested for the Crandon vertical model, and a value of 50, which represents the most likely value for the Project Area, was selected for use in the transient dispersion simulation.

A diffusion coefficient of 2.0×10^{-9} m^2/s (1.86×10^{-3} square feet per day) was used in the saturated dispersion analyses. This is a maximum value for saturated pervious material (Freeze and Cherry, 1979) and will produce conservative results in the simulations; that is, predicted movements will be greater than should actually occur.

Dispersion in the partially saturated zone beneath the MWDF will be dominated by diffusion because of the low seepage velocities from the tailings ponds. The dispersion coefficients for one-dimensional partially saturated analyses were therefore selected based on the predicted pore velocities (Biggar and Nielsen, 1976) as described in Section 6.4.1.1. The values used ranged from 7.0×10^{-10} m^2/s (6.5×10^{-4} square feet per day) to 8.6×10^{-10} m^2/s (8.0×10^{-4} square feet per day).

5.0 MODEL CALIBRATION

5.1 PURPOSE AND METHOD OF CALIBRATION

The horizontal planar site model (horizontal model) discussed in Section 4.0 was calibrated using site-specific data. The calibrated model provides a realistic analytical base on which to apply the hydrologic actions of the proposed activities and evaluate the resultant impacts. The procedures used to develop a realistic analytical site model are discussed in this section.

The model was calibrated by selecting parameters and conditions (consistent with information set forth in Sections 3.0 and 4.0) such that (a) the recharge rate (from precipitation infiltration, lake recharge) matched the ground water discharge rate at the site area boundaries, (b) the predicted ground water discharge to Swamp Creek was consistent with measured values, and (c) the existing potentiometric surfaces matched those predicted by the computer within a reasonable degree of accuracy.

The horizontal model was calibrated for the low, middle, and high recharge rates by varying aquifer permeabilities, resulting in three predicted ground water discharge rates to Swamp Creek and indicating the sensitivity of this discharge rate to the recharge rate.

The vertical model was also calibrated by selecting permeabilities and permeability ratios (vertical to horizontal) and comparing the simulated potentiometric heads with observed data. The calibrated models were subsequently used in the hydrologic impact assessment and the sensitivity analyses.

5.2 HORIZONTAL MODEL CALIBRATION

5.2.1 Model Setup and Grid System Development

A review of site hydrologic conditions indicated that predominant ground water movement is horizontal through the stratified drift toward the south-southwest, with some ground water flowing radially in other directions from a ground water mound beneath the proposed MWDF area. Site area ground water generally discharges into surrounding lakes and streams. These lakes and streams constitute the hydrologic limits of the site area and were used to establish model hydrologic boundaries as follows:

1. Swamp Creek on the north.
2. Hemlock Creek and Ground Hemlock Lake on the east.
3. Crane Lake and Pickerel Lake on the south.
4. Rolling Stone Lake, Pickerel Creek, and a portion of Rice Lake on the west.

The ground water was assumed to be interconnected with these surface water bodies; that is, the potentiometric level was assumed to be equal to the level of the boundary surface water. A constant potentiometric head at the site boundary was therefore assumed, and different boundary conditions were tested to determine the validity of the constant head boundary condition (Attachment A.6).

The site area was modeled by a grid system consisting of 1,153 quadrilateral elements with 1,227 nodes. Elements and nodes are graphically defined in Figure A-21. The governing differential equations for the site ground water regime, modeled by the element and node assemblage with associated boundary and initial conditions, were solved for this network by the GEOFLOW computer program. The grid system was prepared considering the following:

1. The configurations of the Project facilities and hydrologic components, such as the mine, MWDF, mine/mill surface facilities, and lakes, were represented as closely as possible.
2. The mine area was modeled such that data can be transferred directly into GEOFLOW from the model used to calculate mine inflow; the locations of the 45 mine inflow nodes are consistent with the Prickett Associates mine configuration (TAP Associates, 1984).

3. Finer grid patterns were used in the areas where detailed analysis was required, or where the aquifer characteristics change abruptly, in order to enhance numerical accuracy (such as in the MWDF and mine areas).

4. The boundary of the grid system follows natural boundary conditions specifically defined by streams or lakes.

5.2.2 Constraints and Boundary Conditions

5.2.2.1 Constraints

The model included, as given information, pertinent site area features such as recharge lakes, discharge wetland areas, and lakes and streams on the boundary of the model. Ranges of values for stratified drift permeability, site and lake recharge rates, and aquifer storage coefficients obtained in previous site investigations were included in the model.

5.2.2.2 Boundary and Other Fixed Conditions

Constant head conditions were assigned to nodes located on the boundaries of the grid system (model) as shown in Figure A-22. The data used for the constant head conditions are taken from aquifer potentiometric surface maps (Figure A-13). Linear interpolation was performed to determine constant head values for points between the known head values.

Because of the proximity of the mine to Swamp Creek, different boundary conditions were tested to determine the validity of the constant head boundary condition. The resulting sensitivity analyses are presented in Attachment A.6 and summarized in Section 5.2.6. An aquifer saturated thickness and an aquifer bottom elevation were assigned to each element based on the saturated thickness map (Figure A-14) and modified elevation contours of the base of the aquifer (Figure A-18). In areas where the stratified drift is absent, a minimum thickness of

0.1 m (0.33 foot) was assigned to represent the transmissivity of the saturated till.

5.2.3 Variable Conditions

The model was calibrated using the three prescribed annual recharge rates by varying the permeability of the stratified drift and the configuration of constant head nodes in the southern wetlands area. Detailed information on the input parameters for the three calibration runs is included in Attachment A.7.

5.2.4 Calibration Procedure

An iterative procedure was used to calibrate the model by matching computed potentiometric surfaces with observed data according to the following steps:

1. Development of the grid system.
2. Preparation of the input parameters and selection of calibration parameters.
3. Comparison of computed potentiometric heads with the observed data.
4. Variation of the calibration parameters until the calibration requirements were satisfied.

Time variable saturated aquifer thicknesses were used in model calibration runs (i.e., the saturated aquifer thickness was updated with time corresponding to the configuration of the potentiometric surface). Transient solutions of the problem with time steps of one year were solved until the steady-state condition was reached (15 years).

The following criteria for assessing the status of the calibrated model were used:

1. The calculated potentiometric contours matched measured values.

2. Values for input parameters were within known ranges.

3. The principle of mass balance was satisfied.

4. Ground water discharge to Swamp Creek was consistent with the estimates based on measured values.

Several iterative analyses were made for each of the three recharge rates to calibrate the model. The calibration analyses for the Middle Recharge case are summarized in Table A-12. This table shows the effect of the calibration parameters on the potentiometric surface, ground water discharge to Swamp Creek, and the model calibration results. The calibrated computer model potentiometric surfaces and ground water flow vectors for the Middle Recharge case are shown in Figure A-23. The calibration analyses for the Low and High Recharge cases are summarized in Attachment A.6.

5.2.5 Results of Model Calibration

5.2.5.1 Comparison of Potentiometric Surfaces

Comparison of the computed potentiometric surfaces and observed potentiometric contours for the middle recharge rate is shown in Figure A-24. As this figure indicates, the calculated potentiometric surface nearly matches the observed potentiometric surface. The differences are generally less than 1 m (3.3 feet) with the exception of the southeastern portion of the site area, where the difference exceeds 3 m (9.8 feet). Because the southeastern area is not influenced by the Project facilities or the mining activities, this difference in potentiometric surfaces will not have an effect on the result of the hydrologic impact assessment and was, therefore, discounted.

To evaluate the calibrated model results, the computed potentiometric surface values were compared with observed values at site piezometers. The mean and standard deviation of the absolute differences were calculated and are shown in Table A-13. The average potentiometric head difference is 0.69 m (2.3 feet), with a standard deviation of 0.63

m (2.1 feet). This is considered good calibration for the areal extent (5,700 ha [22 square miles]) of this model. Similar differences in potentiometric heads were observed for the calibrated models for the high and low recharge rates.

5.2.5.2 Swamp Creek Base Flow Comparison

A portion of the site area ground water discharges to Swamp Creek and constitutes the stream base flow rate. The computed ground water discharges were compared with estimated stream base flow rates. The average annual base flow rate of Swamp Creek at USGS Station HW-55 is 0.54 m^3/s (19 cubic feet per second) (Table A-8). The total drainage area contributing to this rate is 11,970 ha (29,570 acres) (Attachment A.2); 1,756 ha (4,340 acres) of this drainage basin are located in the site area. Based on the ratio of the two areas, the portion of the base flow rate generated in the site area is 0.079 m^3/s (2.8 cubic feet per second). The ground water discharge into Swamp Creek computed by the calibrated model for the three different recharge rates ranges from 0.090 m^3/s (3.18 cubic feet per second) for the low recharge rate to 0.16 m^3/s (5.68 cubic feet per second) for the high recharge rate. Comparison of these results indicates that the estimated base flow compares favorably with the computed base flow for the smaller recharge rate. The calibrated models for the medium and high recharge rates show the sensitivity of ground water discharges to the creek with variation of average recharge.

5.2.5.3 Comparison With Field Pumping Test

To further evaluate the validity of the input parameters, the calibrated horizontal ground water flow models for the middle and low recharge rates were used to simulate the pumping test using Well TW-41 (Golder Associates, 1981). The simulation procedures and results are shown in Attachment A.9. The results of these analyses show a close agreement between model-calculated and measured drawdowns for the Well TW-41 pumping test, reinforcing confidence in the input data base, model calibration, and predicted hydrologic impacts.

5.2.5.4 Other Mass Balance Evaluations

In addition to the evaluation of the ground water discharge to Swamp Creek, the total discharge around the model boundary was compared to the recharge into the simulated area. The hydrologic mass balance is discussed in Attachment A.8. The hydrologic mass balance was calculated for several analyses, including both transient and steady-state simulations. The percent error in the flow and mass transport simulations is less than 2 percent. The mass balance was determined to be acceptable within the accuracy of the program (i.e., inflow was approximately equal to outflow). For calibration purposes, no storage change was assumed because none should occur.

5.2.6 Calibrated Model Evaluation

The purpose of the horizontal model calibration is to develop a model which closely represents the site hydrologic setting, not only during the preconstruction phase, but most importantly during the construction phase in which hydrologic conditions will be altered, particularly by mine inflow. A calibrated model was developed by following the calibration procedure and meeting the calibration criteria discussed in Section 5.2.4. However, during model calibration, WDNR expressed concerns regarding the appropriateness of a constant head boundary along Swamp Creek and the introduction of a low permeability zone (Zone 2 in Figure A-22). Several model sensitivity analyses were completed to resolve these concerns. The procedure for these sensitivity analyses was as follows:

1. Incorporate the new conditions into the model by changing the calibrated model conditions.

2. Compare the computed potentiometric surfaces with measured values.

3. Compute preconstruction Swamp Creek discharge values.

4. Compute maximum mine inflow and maximum potentiometric surface drawdown by reducing the potentiometric head in the mine area (24-node configuration) to the bottom of the aquifer.

5. Compute maximum reduction of the ground water discharge rate to Swamp Creek from maximum mine inflow.

6. Compare the results of the sensitivity analyses with the selected calibrated model.

These sensitivity analyses were completed for the Middle Recharge case. The following variations to the calibrated model were examined:

1. Combined No-Flow and Constant Head Boundary Conditions (Golder Associates, 1982c): A no-flow boundary condition was assigned to the boundary segment between Rice Lake and the southern end of Mole Lake and to the grid segment from approximately 450 meters north of Walsh Lake to the southwestern end of St. John's Lake.

2. Swamp Creek No-Flow Boundary Condition: A no-flow boundary condition was assigned to the northern boundary along Swamp Creek.

3. Increased Lake Bottom Permeability: The lake bottom permeability was increased from 5×10^{-9} to 1×10^{-8} m/s (1.3×10^{-4} to 2.6×10^{-4} feet per day).

4. Uniform Permeability: A uniform permeability was assigned to the entire aquifer, i.e., Zones 1 and 2 (Figure A-22) had the same permeability, equal to the permeability of Zone 1 (Table A-15).

The computed maximum mine inflow rates and changes in the ground water discharge rate to Swamp Creek for these analyses are presented in Table A-14.

A detailed discussion of each sensitivity analysis is presented in Attachment A.6, and input data for these computer analyses are provided in Attachment A.7. Conclusions based on the results of the sensitivity analyses are summarized below:

1. Potentiometric Head Comparison: Two permeability zones with a constant head boundary provide the best calibration match, followed by the combined no-flow and the uniform permeability zone analyses. The Swamp

Creek no-flow boundary analysis results in elevated potentiometric surface levels around Swamp Creek and hence prevents recharge from reaching this creek. The increased lake bottom permeability analysis produces higher potentiometric surface elevations and also shifts the potentiometric contours farther to the west.

2. Maximum Mine Inflow Comparison: The maximum mine inflows for different calibration conditions are shown in Table A-14. The maximum mine inflow varies from 9.44×10^{-2} to 1.121×10^{-1} m^3/s (1,496 to 1,777 gpm). Constant head, no-flow, and uniform permeability analyses indicate almost equal maximum mine inflow. The maximum mine inflow rate for the Swamp Creek no-flow boundary analysis is the highest. This is a result of the higher potentiometric surface levels around Swamp Creek and the availability of more precipitation recharge to flow into the mine rather than to Swamp Creek.

3. Ground Water Discharge Changes to Swamp Creek: The ground water discharge rate to Swamp Creek for the preconstruction period and the maximum mine inflow case are presented in Table A-14. According to the tables, all analyses except the Swamp Creek no-flow condition (zero discharge) have similar discharges and reductions. For all conditions, the discharge to the creek decreases from 1.18×10^{-1} to 8.24×10^{-2} m^3/s (4.15 to 2.91 cfs). This table indicates that regardless of the calibration condition for the maximum mine inflow case, approximately 70 percent of the ground water during preconstruction will remain available for discharge into Swamp Creek from the site area.

4. Flow Vectors: A review of the ground water flow vectors also indicates that for the maximum mine inflow case, the ground water from the site area is still flowing toward Swamp Creek. This observation indicates that use of the constant head boundary is valid.

5. Conclusions: Sensitivity analyses with different conditions indicate that the selected calibrated model best represents site conditions. The assumption of a constant head boundary along Swamp Creek is valid because, (1) for the maximum mine inflow case, approximately 70 percent of present ground water flow would continue to discharge to Swamp Creek, (2) no reversal of ground water flow vectors along Swamp Creek is predicted from the different calibration analyses, and

(3) the best match of potentiometric surfaces between calculated and field data is seen with two permeability zones; however, the predicted impact is not affected by the presence or absence of this second zone.

The overall applicability of constant head boundary conditions on the Swamp Creek boundary has been confirmed by the first two sensitivity analyses described above. In addition, field observations during the winter/spring of 1984 indicate localized vertical upward gradients at Swamp Creek. This confirms ground water discharge to Swamp Creek. The head losses at the Swamp Creek boundary are relatively insignificant and localized and hence a constant head boundary condition adequately represents the hydrological site conditions. Whereas the two-dimensional horizontal model does not provide a three-dimensional flow system definition at the stream boundaries, the model results are sufficiently accurate for properly predicting the ground water flow directions and changes in the flow. For the minor flow changes being predicted at the boundary, analysis for the full three-dimensional flow system definition is purely academic.

Based on the above analyses and conclusions, it was determined that the model was adequately calibrated and that the most representative site data had been selected. The final hydrologic horizontal model calibration parameters are summarized in Table A-15. The values of these parameters are within the range of measured data. This calibrated model was used for the hydrologic impact assessment.

5.3 TWO-DIMENSIONAL VERTICAL MODEL CALIBRATION

The two-dimensional vertical model discussed in Section 4.0 was calibrated using measured site area data. The calibrated vertical model provides a realistic base for the evaluation of the migration of chemical constituents from the MWDF seepage. The procedures used to develop a realistic vertical flow model are described in this section. In general, the model was calibrated by using fixed parameters and conditions consistent with available site-specific information; variable parameters were adjusted until the computed potentiometric surface distribution matched the observed conditions within a reasonable degree of accuracy.

5.3.1 Model Setup and Grid System Development

The vertical cross section for ground water flow calibration was selected to provide a representative base for later dispersion simulations. Section N-N' (Figure A-8) was chosen because its orientation approximates the principal directions of ground water flow in the MWDF area. Section N-N' includes four nested piezometers (EX-13, EX-12, EX-8, and EX-6) which provide information about vertical gradients, aiding calibration.

The idealized hydrogeologic Section N-N' used for two-dimensional vertical modeling is presented in Figure A-25. The geologic units were incorporated into the model grid according to their observed distribution, and nodes were located to coincide with relevant surface water bodies. Figure A-26 presents the representative vertical model for Section N-N'. It represents the selected cross-sectional area, including MWDF Tailings Ponds T1 and T4. The boundaries of the various glacial deposits have been simplified for ease in modeling.

5.3.2 Constraints and Boundary Conditions

Figure A-26 presents the grid used to model ground water flow for Section N-N'. The model has 957 grid elements and 1,089 nodes. Boundary conditions and input values were selected to represent steady-state conditions and are as follows:

1. The top horizontal grid boundary AF represents the ground water table and the inflow line for ground water recharge, defined as 216 mm/y (8.5 inches per year); Deep Hole Lake seepage was defined as 144 mm/y (5.65 inches per year), a rate based on lake seepage calculations (Table A-10). The boundary condition applied to boundary AF consists of specified recharge. Potentiometric heads are treated as

unknowns and are allowed to vary in the model. The location of boundary AF is fixed in the model at the known water table. For calibrated conditions, the calculated heads on boundary AF are in agreement with observed heads.

2. Constant head boundary line AH represents the interpolated head value (476.00 m) for Well DMA-17.

3. Constant head boundary line FG represents the observed and interpolated head values (482.93 m to 483.52 m) at Well EX-6.

4. Bottom horizontal grid line HG is a no-flow boundary approximating the contact with bedrock or other relatively low-permeability units.

5. Constant head boundary Point E represents the interpolated head value (481.33 m) for Hemlock Creek.

5.3.3 Calibration Procedures

The vertical flow model for Section N-N' was calibrated to simulate measured potentiometric heads by varying values for permeabilities, ratios of vertical to horizontal permeabilities, and boundary conditions. A summary of all calibration runs is given in Table A-17A. The model was calibrated for the middle recharge rate of 216 mm/y (8.5 inches per year); permeabilities were then scaled to provide calibrated heads at the low and high recharge rates of 153 mm/y (6.0 inches per year) and 297 mm/y (11.0 inches per year). The resulting input parameters are summarized in Table A-17B.

5.3.4 Results of Model Calibration

5.3.4.1 Comparison of Potentiometric Heads

The two-dimensional vertical flow model was used to calculate steady-state piezometric heads; results for the intermediate recharge rate of 216 mm/y (8.5 inches per year) are presented in Figure A-27. These simulated heads were compared to measured heads at the 18 well points located along Section N-N'. Measured heads from July 31, 1984 were selected to most accurately represent steady-state conditions because earlier readings may have been affected by well installation procedures which took place during early 1984.

The comparison between measured and computed heads for the vertical flow model is presented in Table A-16A for calibrated conditions. Table A-16B summarizes measured versus computed heads for all calibration runs. The average potentiometric head difference is 0.44 m (1.4 feet). The majority of the differences is less than 0.5 m (1.6 feet), while three locations show differences of slightly over 1 m (3.3 feet). The larger differences occur in localized areas of high hydraulic gradients where piezometric heads vary over short distances (EX-8BL and WP-7U), and at one isolated well point screened in the basal till (G41-K13). Therefore, the steady-state model provides good agreement with observed conditions. An average head difference of less than 0.5 m (1.6 feet) for the steady-state model is within a reasonable degree of accuracy for an area that exhibits annual head fluctuations on the order of 1 m (3.3 feet).

5.3.4.2 Conclusions

Following the above calibration procedures, it was determined that the calibrated model adequately represented vertical ground water flow patterns for Section N-N' and that the most representative site area data had been selected. This calibrated model was subsequently used for the prediction of chemical constituent migration from the MWDF.

6.0 SIMULATION AND RESULTS OF HYDROLOGIC IMPACTS OF THE PROPOSED FACILITIES

The potential impacts of the proposed facilities on the site hydrologic regime were simulated by imposing their respective hydrologic actions on the calibrated horizontal and vertical models. These simulations resulted in time variant predictions for (a) potentiometric surfaces across the site, (b) ground water discharge rates to adjacent streams and lakes, and (c) changes in water quality beneath and adjacent to the MWDF. The horizontal model was used to determine the hydrologic conditions (a and b) and both the horizontal and vertical models were used to determine changes in water quality (c).

6.1 OBJECTIVE AND PERIOD OF SIMULATION FOR THE HORIZONTAL AND VERTICAL MODELS

With the site area models properly calibrated, as discussed in Section 5.0, the hydrologic impacts of the proposed mine and facilities were evaluated. The primary objective of the horizontal simulation was to determine the variation in potentiometric surfaces and ground water discharge rates to surface water streams and lakes resulting from the ground water inflow to the mine. Other hydrologic actions such as the potable water supply well, sanitary wastewater absorption field, and the MWDF were included in the model, but their hydrologic effects were determined to be small in comparison with the mine inflow effects. The horizontal model was also used to simulate the concentration of chemical constituents beneath and adjacent to the MWDF. The primary objective of the vertical models was to determine the change in ground water quality beneath the MWDF.

The impacts associated with proposed hydrologic actions were simulated for the three Project phases, including (a) construction, (b) operation, and (c) post-operation (Figures A-3a and A-3b). For the horizontal simulation, the hydrologic actions associated with the construction phase were simulated for four Project years. The hydrologic actions associated with the operation phase were simulated for an additional 25 Project years, including 22 Project years of mine/mill operations and 3 Project years of the post-operation phase reclamation activities. Post-operation phase activities were simulated for an additional 31 Project years following completion of the reclamation activities to allow time for incorporating all of the hydrologic actions into the model and to predict the potentiometric surface rebound history. Therefore, the period of simulation designated for the horizontal planar model was 60 Project years. The simulation period for the one-dimensional vertical modeling was 600 years, when the full normalized chemical constituent concentration is predicted to reach the top of the water table beneath the MWDF. The period of simulation for the two-dimensional vertical modeling was 8,800 years, when the model predicted steady-state normalized concentration would be achieved.

6.2 HORIZONTAL MODELING

6.2.1 Grid System Setup, Assumptions, and Boundary Conditions

The grid system for horizontal modeling was the same as that used in the model calibration. Figure A-28 shows the grid system with the proposed facilities and hydrogeologic conditions for the horizontal model simulation. The hydrologic action of the facilities was simulated as follows:

1. Ground water inflow to the mine was simulated by a series of point withdrawals at 45 nodes in the main aquifer above the mine. Table A-2 presents the mine inflow rates corresponding to the middle recharge rate for the 45 nodes. These 45 nodal points were selected to correspond with the nodal arrangement used to calculate the mine inflow rates (TAP Associates, 1984).

2. Redirection of surface water drainage from the surface facilities in the mine/mill site area was simulated by reducing the ground water recharge to 25 percent of the precipitation recharge rate. The surface drainage basins received the remaining 75 percent in addition to the precipitation recharge rate.

3. The oily runoff collection and waste rock storage areas were simulated by applying zero ground water recharge over these areas during the operation phase. After operations, the facilities will be removed, so ground water recharge from precipitation was restored as shown in Figure A-3a.

4. The preproduction ore storage pad was simulated by applying zero ground water recharge in this area. After the operation phase, this facility will be reclaimed; therefore, the ground water recharge from precipitation to this area was restored as shown in Figure A-3a.

5. The potable water supply well was simulated as a pumping well with a constant flow rate of 3.15×10^{-3} m^3/s (50 gallons per minute). The well was located to allow pumping of up to 0.038 m^3/s (600 gallons per minute).

6. The sanitary wastewater absorption field was simulated as a recharge area with a constant flow rate of 1.26×10^{-3} m^3/s (20 gallons per minute) in addition to the ground water recharge from precipitation.

7. The water reclaim ponds (R1 and R2) were simulated by applying zero recharge according to the schedule shown in Figure A-3b.

8. A tailings pond seepage rate for each pond (T1, T2, T3, and T4) was specified as operation phase, maximum, or steady state in accordance with the schedule in Figure A-3b; the seepage rates per unit area for these cases are presented in Table A-3.

9. Precipitation infiltrating the MWDF reclamation cap (119 mm/yr [4.67 inches per year]) was distributed at the periphery of the MWDF as tailings pond reclamation was completed (Figure A-3b).

A uniform precipitation recharge rate was prescribed for all elements, except those comprising the facilities described above, the recharge lakes, and the areas of zero stratified drift thickness. Attachment A.7 lists the values for input parameters used in the horizontal simulations.

Other hydrologic data, such as permeability and location of permeability zones, storage coefficient, porosity, potentiometric heads at the site boundaries, and recharge rates for the seepage lakes, remained the same as those for model calibration and are presented in Attachment A.7.

The aquifer saturated thicknesses varied during impact simulation because of the hydrologic actions imposed on the model. The program calculated new saturated thicknesses by subtracting the elevation of the base of the aquifer from the elevation of the changing potentiometric surfaces. The calculated difference was then assigned as a new saturated thickness and a new potentiometric surface was computed. This procedure was applied at each time step during the horizontal simulation to improve the accuracy of model predictions.

6.2.2 Results of Hydrologic Actions on the Hydrologic Regime

The horizontal planar model simulated site hydrologic conditions for 60 Project years. The potentiometric surfaces and ground water flow vectors for Year 3 (end of the construction phase), Year 28 (one year before the end of the reclamation phase), and Year 60 are presented in Figures A-29, A-31, and A-33, respectively.

The potentiometric surface decline (drawdown) was determined by subtracting computed potentiometric heads for a specified year from the potentiometric head in the calibrated model. The influence of ground water inflow to the mine on the potentiometric surface is concentrated in the mine area and extends toward the MWDF to a lesser degree, as shown in Figures A-30 and A-32 for Year 3 and Year 28, respectively.

After ground water inflow to the mine ceases at Year 29, the simulation results predict that the potentiometric surface in the mine area will recover to nearly preconstruction conditions by Year 60 as shown in Figure A-33. In addition, the potentiometric surface decline and rebound history for three site area locations are shown in Figure A-34. As this figure indicates, the potentiometric surface will return to nearly preconstruction conditions after six years.

The variation in ground water discharge rates to surrounding streams associated with the variation in potentiometric surface was computed. Figure A.2-1 (Attachment A.2) shows the stream segments evaluated in this assessment. Tables A-18 through A-20 present the variation in the ground water discharge rates to these segments for the three different recharge cases. The effects of these changes in ground water discharge rates to the total stream flow are discussed in Section 6.6. The predicted changes in discharge rates were evaluated by reviewing changes in the potentiometric surfaces, gradients, and flow vectors generated by the horizontal model.

6.2.3 Horizontal Dispersion Modeling

The calibrated two-dimensional horizontal model was used to predict the normalized concentration profile of chemical constituents adjacent to the MWDF. Hydrologic parameters, identical to those used for the calibrated model, were used in this simulation with the exception that the recharge value in the MWDF area was changed to the MWDF steady-state seepage rate of 1.68 mm/y (0.066 inch/y) and the precipitation infiltrating the MWDF reclamation cap was distributed at the perimeter of the MWDF.

Steady-state dispersion simulations were made for the three different recharge rates. Longitudinal and horizontal transverse dispersion values of 60 and 15 meters, respectively, were used. The results of the simulation for annual Low, Middle, and High Recharge cases are shown in Figures A-35 through A-37.

These simulations indicate that the chemical constituents at the steady-state condition (approximately 8,800 years) will spread along the dominant ground water flow directions (northeast and southwest) with a preferential movement in the northeast direction. The horizontal dispersion simulation indicates that at steady-state approximately 88 percent of the mass input to the model discharges to Hemlock Creek while the remaining 12 percent is discharged to the wetlands to the southwest of the site. The normalized concentrations at the compliance boundary will be from less than 0.005 to a maximum of 0.02. For sulfate (maximum concentration of 2,000 ppm), the normalized concentrations correspond to less than 10 to a maximum of 40 ppm. The maximum normalized concentration at the compliance boundary varies from less than 0.01 (High Recharge case) to 0.02 (Low Recharge case) as shown in Figures A-35 through A-37.

The horizontal dispersion model assumes complete mixing within the aquifer thickness. However, because of vertical variations in aquifer hydrologic and dispersion properties, the concentration profile can vary with depth. These potential variations are evaluated using one- and two-dimensional vertical dispersion modeling as discussed in Sections 6.3, 6.4, and 6.5.

6.3 VERTICAL MODELING - GENERAL

The primary impact associated with the MWDF is the possible change in ground water quality from MWDF seepage. The low seepage rate through the tailings pond liner and the underlying partially saturated glacial deposits into the ground water makes dispersion simulation using only a large areal horizontal model impractical. If the chemical constituents reach the ground water, the rate of their migration from the MWDF will be faster than the vertical movement through the partially saturated till. Modeling of radial movements on a large scale is practical only if sufficient concentration of the chemical constituents enter the ground water to produce noticeable differences in concentration at some distance from the source.

To more effectively assess the potential impacts of the MWDF, this study used one- and two-dimensional vertical modeling supplemented by two-dimensional horizontal modeling. The one-dimensional modeling was used to determine the time required for chemical constituents to move from the bottom of the tailings ponds through the partially saturated zone to the top of the fully saturated zone. Because the movement in the partially saturated zone will essentially be vertical, a one-dimensional vertical strip model, representing unitized seepage beneath all areas of the MWDF, was considered appropriate.

Using the time required for chemical constituents to reach the saturated zone, as determined by the one-dimensional model, a vertical two-dimensional model was used to assess movement of chemical constituents through the saturated glacial deposits vertically beneath the MWDF and laterally from the facility.

For vertical modeling, the assumption was made that the tailings pond liner did not mitigate chemical constituent migration. Assessments indicate that this is a conservative assumption (D'Appolonia, 1982). The D'Appolonia study showed that the full concentration of chemical constituents with a retardation factor of 1.0 would not reach the bottom of the liner for at least four years after the ponds are in operation. Chemical constituents with higher retardation factors will take proportionally longer to travel through the liner.

6.4 ONE-DIMENSIONAL VERTICAL MODELING

Because the results of the one-dimensional modeling were to be used as input for the two-dimensional vertical transient model, the characteristics of the partially saturated zone were taken from the two-dimensional model cross section. Section N-N' (Figure A-8) was selected for the two-dimensional vertical model because it approximates the path of possible contaminant migration. Therefore, the characteristics of the partially saturated zone under the MWDF along Section N-N' provide the basis for the one-dimensional modeling.

MWDF Tailings Ponds T1 and T4 are intersected by Section N-N'. The lowest bottom elevation of the tailings ponds is 499 m MSL (1,637 feet) for Pond T1. The potentiometric surface beneath the MWDF is at an approximate elevation of 486 m MSL (1,594 feet). This means that approximately 13 m (42.6 feet) of partially saturated glacial deposits are present below Ponds T1 and T4 (Figure A-12). This partially saturated zone consists primarily of till, although a discontinuous lens of coarse drift is present under portions of the MWDF. The thickness of the coarse drift lens varies from 0 to 5 m (0 to 16.4 feet) in the partially saturated zone along Section N-N', and from 0 to 9 m (0 to 29.5 feet) in other areas of the MWDF area, as shown in the geologic sections (Figures A-9 through A-12).

6.4.1 Flow Through the Partially Saturated Zone

The seepage from the MWDF will pass through 13 m (42.6 feet) of partially saturated glacial deposits to reach the top of the saturated zone. It is anticipated that the rate of movement of chemical constituents in the partially saturated zone will differ from that of the saturated zone. To examine this difference, the characteristics of partially saturated till were considered and the resultant rates for advancement of chemical constituents were simulated.

6.4.1.1 Parameters for Partially Saturated Zone Modeling

Three parameters are most sensitive in governing the rate of chemical constituent migration in partially saturated materials: dispersion, permeability, and percent saturation. For the one-dimensional modeling of the partially saturated zone beneath the MWDF, these parameters were selected by review of literature, assessment of available laboratory data, and review of the estimated MWDF seepage rates as compared to water movement in till for in situ conditions.

As discussed in Section 4.0, permeability is related to the percent saturation in partially saturated soils. If the vertical seepage rate is less than the saturated permeability of the partially saturated soil, the soil will remain partially saturated. If such seepage continues for a sufficient time, the soil will ultimately reach a uniform moisture content (limiting moisture content) and percent saturation (Rubin and Steinhardt, 1963). Defining the subsurface conditions in terms of a constant moisture content simplifies ground water flow and chemical constituent migration simulation in partially saturated media. The moisture content and, subsequently, the partially saturated permeability and suction pressure can be defined as constant without variation in depth and time.

The partially saturated zone beneath the MWDF ponds may be characterized as 8 m (26.2 feet) of till and 5 m (16.4 feet) of coarse drift. The partially saturated zone was conservatively modeled as 8 m (26.2 feet) of till, the minimum thickness of the till unit encountered along Section N-N'. This assumes that contaminant transport occurs instantaneously through the other 5 m (16.4 feet) of till or coarse drift. Although partially saturated flow through the coarse drift should be somewhat faster than flow through the till because of the coarse material's greater saturated permeability, flow rates are still largely controlled by the low MWDF seepage rates. Information pertaining to moisture contents at various seepage rates is available for the glacial till at the Crandon Project site based on laboratory tests (D'Appolonia, 1982).

To provide information about possible chemical constituent transport rates in fine-grained materials other than the till, a sensitivity analysis was also performed for the Berea Sandstone (McWhorter, 1971). Calculated transport rates for the Berea Sandstone are up to twice those calculated for the till. This sensitivity analysis therefore permits the assessment of maximum chemical constituent transport rates through a material having conservatively fast fluid flow characteristics.

Because the estimated operation phase, maximum, and steady-state seepage rates for the MWDF are much less than the saturated till permeability, the zone directly beneath the MWDF will remain partially saturated and will reach a uniform moisture content (Rubin and Steinhardt, 1963). The estimated maximum MWDF seepage rate is 1.02 x 10^{-9}m/s (2.90 x 10^{-4} feet per day) (Exxon, 1984b); the mean saturated till permeability is 6 x 10^{-6} m/s (1.70 feet per day) (STS Consultants, Ltd., 1984a), and the saturated permeability for the Berea Sandstone is 3.76 x 10^{-6} m/s (1.07 feet per day).

Assuming the seepage rate (m/s) is equal to the partially saturated soil permeability (m/s), the percent saturation at the limiting moisture content in the till beneath the MWDF can be determined for any given seepage rate using Figure A-20. For the various seepage rates, the limiting moisture content and percent saturation for the till are as follows:

SEEPAGE RATE CATEGORY	SEEPAGE RATE	PERCENT SATURATION (%)	MOISTURE CONTENT* (%)
Operation Phase	5.49 x 10^{-10} m/s (1.56 x 10^{-4} ft/day)	40.5	12.4
Maximum	1.02 x 10^{-9} m/s (2.90 x 10^{-4} ft/day)	43.5	13.4
Steady State	5.39 x 10^{-11} m/s (1.53 x 10^{-5} ft/day)	30.0	9.2

*Percent saturation times porosity (0.307) (D'Appolonia, 1982).

For the Berea Sandstone, the moisture contents corresponding to the operation, maximum, and steady-state seepage rates are 6.5, 6.7, and 6.0 percent, respectively. These values are calculated from published values (McWhorter, 1971) by the method described in Attachments A.3 and A.7.

A dispersion coefficient was calculated for each seepage rate based on the method presented in Biggar and Nielsen (1976). For the pore velocities calculated for partially saturated till, the dispersion coefficients ranged from 7.0 x 10^{-10} m^2/s (6.5 x 10^{-4} ft^2/day) for steady-state seepage to 8.6 x 10^{-10} m^2/s (8.0 x 10^{-4} ft^2/day) for the maximum seepage rate. Dispersion coefficients for the Berea Sandstone analysis ranged from 7.1 x 10^{-10} m^2/s (6.6 x 10^{-4} ft^2/day) to 1.0 x 10^{-9} m^2/s (9.3 x 10^{-4} ft^2/day). These values were used in one-dimensional chemical constituent transport predictions.

The purpose of dispersion simulation through the partially saturated till was to determine the rate of migration of chemical constituents for the site-specific conditions. This simulation provided a realistic prediction with respect to time. However, our conclusion is based on steady-state conditions which ignore the mitigation characteristics of the partially saturated till. Under steady-state conditions, the seepage rate from the MWDF is the controlling factor. Furthermore, under steady-state conditions, moisture content, thickness of the partially saturated till, and permeability of the partially saturated till do not affect the rate at which chemical constituents reach the saturated zone.

With a constant seepage rate and a uniform percent saturation, the seepage can be considered steady state, and the velocity is then equal to the pertinent seepage rate. Under these conditions, the partially saturated dispersion equation can be simplified to a modified saturated dispersion equation. The transient nature of the chemical constituents migration can then be assessed using this simplified procedure. Attachment A.3 presents more details on the simplification procedures.

6.4.1.2 Simulation Procedure and Results for Partially Saturated Zone Analysis

For partially saturated vertical ground water flow simulation beneath the MWDF, a one-dimensional grid system was developed with a vertical length of 40 m (131 feet). The grid was extended past the 13 m (42.6 feet) depth of the partially saturated zone to minimize the effects of the lower boundary. The analysis assumes that seepage from the MWDF tailings ponds instantaneously establishes a uniform flow rate field having a Darcy velocity equal to the seepage rate. The tailings ponds were specified as constant concentration sources. A retardation factor of 1.0 was used for the chemical constituents of the seepage. The predicted chemical constituents migration was calculated in time steps of one year for the first 32 years, and in time steps of ten years thereafter for several hundred years. Other input parameters are described in Attachment A.7.

Figure A-38 presents the predicted normalized concentrations for partially saturated till at depths of 8 m and 13 m (26.2 and 42.6 feet) below the MWDF. Concentrations computed using input parameters for the Berea Sandstone are also shown for a depth of 13 m (42.6 feet). The normalized concentrations (C/C_o) are presented as the ratio of the chemical constituent concentration (C) to the chemical constituent concentration in the pond (C_o).

The results presented in Figure A-38 are based on the projected seepage rates for MWDF Tailings Pond T4, which has the maximum estimated seepage rate of all the tailings ponds. Pond T4 seepage rates were incorporated into the model according to the planned MWDF schedule (Figure A-3b).

Figure A-38 indicates that chemical constituents at a normalized concentration equal to 0.1 will pass through 13 m (42.6 feet) of partially saturated till 235 years after Project initiation; this concentration will have reached a depth of 8 m (26.2 feet) at Year 70.

The partially saturated zone beneath the MWDF contains a minimum till thickness of 8 m (26.2 feet) along Section N-N'. Therefore, in areas where the coarse drift lens is present, the curve will lie between those presented for 8 m (26.2 feet) and 13 m (42.6 feet) of continuous till.

Figure A-38 also presents the results obtained using input parameters for partially saturated Berea Sandstone. A normalized concentration of 0.1 would take 60 years to reach a depth of 13 m (42.6 feet) in this material. Calculations indicate that for the estimated pond seepage rates, partially saturated flow in this uniform grain size sandstone would have pore velocities 1.5 to 2.0 times greater than similar flow in the glacial till.

The Berea Sandstone has a saturated permeability value similar to that for the till, but has lower limiting moisture contents, resulting in faster chemical constituent transport. The sensitivity analysis was performed to determine the maximum rate of chemical constituent movement under this condition. Data for this analysis are readily available from the literature. The analysis indicates that even with the Berea Sandstone as a transporting media, a normalized concentration of 0.1 will not reach the top of the saturated zone until 60 years after Project initiation.

6.4.1.3 Results for Input to the Two-Dimensional Saturated Vertical Flow Model

The results of the partially saturated chemical constituent migration simulation were used as input for the two-dimensional saturated vertical dispersion model. The partially saturated zone was conservatively modeled as the minimum observed till thickness, excluding flow through the partially saturated coarse drift lens shown in Section N-N'. The till in the partially saturated zone along Section N-N' was found to be between 8 m (26.2 feet) and 13 m (42.6 feet) thick beneath the MWDF. The results at 8 m (26.2 feet) were therefore used as input for the two-dimensional vertical model.

Figure A-39 presents normalized concentrations for 8 m (26.2 feet) of till for a chemical constituent with a retardation factor of 1.0. Analyses were performed for the seepage rate schedules of Tailings Ponds T1 and T4 as shown in Figure A-3b. The curves for these tailings ponds indicate that chemical constituents from Pond T1 reach 8 m (26.2 feet) first because of the pond's earlier operation time. At later times, normalized concentrations are higher for Pond T4 because of its temporarily higher seepage rate. However, the time it takes for the full concentration of seepage from Ponds T1 and T4 to reach the top of the saturated zone is in excess of 600 years.

6.5 TWO-DIMENSIONAL VERTICAL SIMULATION

As the chemical constituents reach the saturated till or drift beneath the MWDF, lateral migration will occur because of the predominantly horizontal movement of the ground water. To predict the rate of movement, a two-dimensional vertical cross sectional model through the saturated till and drift was used as indicated in Figures A-25 through A-27.

Initially, the model was calibrated under steady-state ground water flow conditions to simulate observed piezometric heads as described in Section 5.0. The calibrated two-dimensional ground water flow model was then used to predict normalized concentration movement resulting from seepage at the MWDF for transient and steady-state conditions.

6.5.1 Method of Simulation

Section N-N' (Figure A-8) was selected for two-dimensional vertical modeling because it approximates the center line of the predicted horizontal plumes shown in Figures A-35 to A-37. Therefore, this cross section allows evaluation of the maximum predicted influence of seepage from the MWDF in the aquifer, especially at the compliance boundary. The compliance boundary is 366 m (1,200 feet) from the outside edge of the MWDF embankment.

The two-dimensional vertical model calculated results for transient advection and dispersion from the MWDF. The results from the vertical one-dimensional partially saturated analysis for a depth of 8 m (26.2 feet), as shown in Figure A-39, were used to define transient mass influxes beneath the MWDF. The mass influxes were specified as injection sources for each node corresponding to either Tailings Ponds T1 or T4, as shown in Figure A-26. The injection rates were calculated from the one-dimensional vertical model results and took into account advective and diffusive flux. Additional details of these calculation procedures are presented in Attachment A.7.

The two-dimensional vertical model was also used to calculate the steady-state dispersion for the sensitivity analysis presented in Attachment A.4. Sensitivity analyses were performed to test various values of vertical to horizontal permeability ratios, longitudinal dispersivities, longitudinal to transverse dispersivity ratios, and recharge rates for the expected steady-state MWDF seepage rate. In addition, the model performed calculations using the expected maximum seepage rate resulting from the MWDF without a synthetic membrane in the reclamation cap. The resultant concentration profiles of these sensitivity analyses are shown in Attachment A.4.

6.5.2 Simulation Parameters

The transient two-dimensional vertical dispersion model used input parameters selected as most representative for site conditions based on the results of the sensitivity analyses. The ground water flow parameters were those described for the calibrated two-dimensional vertical model in Section 5.0. Reclamation cap recharge was incorporated at each edge of the MWDF as determined by Ayres Associates (1984). Predicted potentiometric contours and flow vectors for the transient dispersion model are shown in Figure A-43. Longitudinal dispersivity was set at 60 m (197 feet) and the ratio of longitudinal to transverse dispersivity was 50, as determined by site conditions and literature values discussed in Section 4.4.2.2. The model assumed a retardation factor of 1.0. Transient results were calculated for times up to 8,800 years, using a time step of two years for times between 0 and 800 years and an increment of 20 years for times between 800 and 8,800 years. Input parameters are discussed in greater detail in Attachment A.7.

6.5.3 Results of Two-Dimensional Vertical Modeling

Figure A-40 presents the predicted normalized concentrations at Year 800 for Section N-N'. The normalized concentrations (C/C_o) are defined as the ratio of the chemical constituent concentration (C) to the chemical constituent concentration of the pond (C_o). Figure A-40 shows that a normalized concentration of 0.1 will reach the contact between the saturated till and the stratified drift beneath the MWDF after 800 years. At this time, horizontal migration of the chemical constituents from the MWDF will occur only for normalized concentrations reaching the stratified drift (less than 0.1).

The predicted distribution of chemical constituent concentrations at Year 4800 is presented in Figure A-41. Normalized concentrations of 0.1 will reach the bottom of the aquifer and will have some lateral movement toward Hemlock Creek but will not reach the compliance boundary. Similarly, normalized concentrations of 0.1 do not reach Deep Hole Lake. The maximum normalized concentrations at this time are on the order of 0.7 in the saturated till directly underlying the MWDF.

Figure A-42 presents plots of normalized concentrations versus time at three different locations in the vertical section: (1) at the compliance boundary, 36 m (118 feet) below the water table (bottom of fine drift); (2) at the eastern edge of the MWDF embankment, 6 m (20 feet) below the water table; and (3) at Hemlock Creek, at the water table. The steady-state concentration values, as predicted by the steady-state analysis (Attachment A.4), are also given for each of the three points. The plots indicate that normalized concentrations at these locations will reach approximately one-third of their steady-state values after 2,000 years; concentrations will approach their steady-state values 8,800 years after Project initiation.

The predicted steady-state normalized concentrations using the two-dimensional vertical model are somewhat greater than those computed using the horizontal model. The reasons for this difference are as follows:

- Differences Between Horizontal and Vertical Representations of Concentrations - The horizontal model presents concentrations averaged over the saturated thickness of the aquifer, while the vertical model presents concentration variation with depth and shows the extreme values. Therefore, differences between results from the two models decrease with distance from the source as vertical mixing occurs (e.g., results are very similar at the compliance boundary).

- Dispersion Coefficients - The horizontal model uses a horizontal transverse dispersivity of 15 m (49 feet) which allows dispersive transport away from the source in directions normal to flow. The vertical model allows chemical constituent transport only in the direction of flow, essentially using zero horizontal transverse dispersivity. This results in all mass being retained within the cross sectional line.

- Flow Velocities - The horizontal model allows for radial ground water flow (flow components normal to the cross sectional line), permitting advective transport away from the center line of the plume. The vertical model, however, assumes that there is no component of flow normal to the section and, therefore, allows advective transport of the introduced mass only along the section line.

  In addition, ground water flow velocities for the area east of the MWDF are greater in the horizontal model than in the vertical due to different constant head boundary conditions at Hemlock Creek. In the horizontal model, the fixed head is assumed for the entire saturated thickness of the aquifer, thus allowing flow out at the boundary; in the vertical model, the creek is represented by a single node at the top of the aquifer, which creates reduced flow velocities. The greater velocities in the horizontal model result in lower concentrations because of increased spreading and dilution.

- Grid Size - The concentrations calculated by the horizontal model represent values averaged over relatively large elemental areas. The vertical model has smaller elements, and its results, therefore, show more detailed horizontal concentration variation along the plume center line (i.e., maximum concentrations).

- Source Representation - The horizontal model represents the MWDF as covering the facility's actual area, while the vertical model assumes a source of infinite width with a length equal to the distance of the intersection of Section N-N' and the MWDF. This cross section extends diagonally across the MWDF in order to coincide with the major ground water flow directions but, in doing so, results in a longer line source for the vertical model. As a result, a relatively larger mass is introduced in the vertical model.

In summary, the different concentrations computed by the two models generally result from different assumptions inherent in model setup; the assumptions required for the vertical model may be considered more conservative.

6.6 ANALYSIS OF HYDROLOGIC IMPACTS

The model results as discussed above predict changes in (a) potentiometric surface, (b) ground water discharge rates to adjacent streams, (c) lake recharge rates, and (d) water quality beneath and adjacent to the MWDF. This section discusses the hydrologic impact assessment of those predicted changes on the ground water and surface water regimes within and adjacent to the site area. These potential impacts are discussed separately for the construction, operation, and post-operation phases.

6.6.1 Ground Water Impacts

6.6.1.1 Flow Regime Impact

The ground water inflow to the mine will cause the existing potentiometric surface to be lowered, resulting in an impact to the ground water flow regime. The alteration in the potentiometric surface will subsequently result in changes of ground water flow direction. The drawdown will be slightly different for construction phase and operation phase conditions. During the post-operation phase, the potentiometric surface will recover to nearly preconstruction conditions.

Construction

Figures A-29 and A-30 present the predicted potentiometric surface and its decline (drawdown) at Year 3 (completion of mine construction) for the Middle Recharge case. The predicted potentiometric surface and its decline for Low and High Recharge cases are nearly identical to the Middle Recharge case. The maximum predicted potentiometric drawdown during construction is approximately 12 m (39 feet) for the three recharge rates. In most of the site area, the drawdown is less than 1 m (3.3 feet).

To assess the hydrologic impacts of mine inflow on ground water user sources and as a guide to assess the consequences on surface waters, the potentiometric drawdown zone of influence was determined and is shown in Figure A-30. The limit of the zone of influence was set at a maximum drawdown of 1 m (3.3 feet) because the annual average ground water fluctuation in the site area is approximately 1 m (3.3 feet). This implies that in areas beyond the zone of influence (1 m [3.3 feet] decline) the potentiometric decline because of mine inflow or seasonal fluctuation associated with different precipitation quantities are indistinguishable.

The area defined by the zone of influence is semi-elliptical in shape and is larger toward the south site area. The shape is caused by differences in the hydrologic parameters of the glacial deposits. In the northern portion of the site area, the aquifer consists primarily of low-permeability material, such as till. In the south, the more permeable stratified drift constitutes the primary portion of the aquifer. The lower permeability of the glacial deposits north of the mine site will minimize the effects of ground water inflow to the mine on ground water discharge to Swamp Creek.

Operations

Figure A-31 presents the predicted potentiometric surface at Year 28 (one year before end of reclamation) for the Middle Recharge case. Figure A-32 presents the corresponding potentiometric drawdown contours for Year 28. The predicted maximum drawdown around the mine is 17 m (58 feet). The potentiometric surface and decline for the other recharge cases (Low and High Recharge) are similar to those for the Middle Recharge case (Attachment A.6). The shape of the zone of influence at Year 28 changes slightly from that at Year 3; however, the purpose of the zone of influence evaluation remains the same as discussed above.

The reduction of ground water recharge caused by the mine/mill facilities construction and operation was incorporated into the hydrologic impact evaluation. No overall alteration to the ground water recharge by the proposed surface facilities is anticipated. However, there may be localized redistribution of ground water recharge in areas of surface alterations.

Post-operation

After mine inflow has ceased, the ground water recharge for potentiometric surface rebound will be primarily infiltration of precipitation. As the ground water table returns to its preconstruction condition, ground water flow will occur in the directions observed prior to construction.

The results of the horizontal two-dimensional planar model shown in Figure A-33 indicate that for the Middle Recharge case at Year 60, the potentiometric surface will rebound to the original levels in most areas. Additionally, Figure A-34 indicates that the recovery will rapidly occur during the first few years of the post-operation phase. For example, the potentiometric surface around the mine area will return to nearly preconstruction conditions after six years.

6.6.1.2 Ground Water Quality

The MWDF has the potential to change the existing water quality. One-dimensional modeling results shown in Figure A-39 indicate that full concentration ($C/C_o = 1.0$) of a chemical constituent with a retardation factor of 1.0 will reach the ground water table at 8 m (26.2 feet) below the MWDF after approximately 600 years. During 800 years of simulation using the two-dimensional vertical model, the 0.1 normalized concentration is predicted to remain in the till beneath the majority of the MWDF as shown in Figure A-40. Based on this assessment of chemical constituent migration, no adverse impact on water quality outside of the area of the ponds will occur for 800 years after Project initiation.

The two-dimensional vertical model simulation was extended until chemical constituent concentrations reached steady-state conditions (8,800 years). Figure A-41 shows the normalized concentration at Year 4800 (approximately 80 percent of steady-state condition). At this time, movement through the stratified drift will occur in a radial ground water flow direction.

The rate of movement mentioned above is applicable only to very mobile chemical constituents, such as sulfate and TDS, which have estimated retardation factors near 1.0. For other chemical constituents, such as iron, manganese, and cadmium, the retardation factors are greater than 1.0 (Table A-11). The rate of movement of these chemical constituents will be proportionally slower than the chemical constituent simulated with a retardation factor of 1.0.

Predicted sulfate concentration in the MWDF seepage (2,000 mg/l) exceeds the U.S. EPA Drinking Water Standards (250 mg/l) and also has an estimated retardation factor of 1.0. The normalized concentration of sulfate which will be in compliance with the U.S. EPA Drinking Water Standards is $C/C_0 = 0.125$ (250 mg/l divided by 2,000 mg/l). Based on analytical evaluation and two-dimensional vertical and horizontal model assessments, the average normalized long-term concentration (C/C_0) is predicted to be between 0.01 and 0.03 at the compliance boundary.

Other chemical constituents with retardation factors greater than 1.0 will move at a much slower rate and/or the source concentrations will dissipate. For example, the estimated cadmium, manganese, and iron concentrations could exceed U.S. EPA Drinking Water Standards in the initial tailings pond seepage (Table A-4). The concentrations of all constituents in seepage at the bottom of the tailings ponds are predicted to decrease to acceptable limits within 50 years after the operation phase by achieving chemical equilibrium with the tailings. Because cadmium (estimated retardation factor equal to 113.0) moves at a rate 113 times slower than sulfate, it will have traveled only a fraction of a meter beneath the MWDF during the first 50 years. As a result, based on the decrease in seepage concentration and the retardation factor, no impact from cadmium concentrations is anticipated.

Manganese and iron will also show minimal to no impact to the water quality. Manganese and iron have estimated retardation factors equal to 2.0 and greater than 14.0, respectively (Table A-11). Manganese concentration in the seepage for the first 50 years of the post-operation phase is approximately 400 times the U.S. EPA Drinking Water Standards or 50 times greater than the existing mean ground water concentration of 0.4 mg/l (Table A-7). Because of its higher retardation factor, the manganese will not have moved through more than 8 m (26 feet) of the partially saturated till below the MWDF in the first 50 years after the operation phase. It will take approximately 800 years for any measurable change in manganese concentration to be observed at the top of the ground water table. The maximum estimated manganese concentration to reach the top of the ground water table is predicted to be 3.0 mg/l (C/C_o = 0.15), but only under the MWDF. The above calculations were performed for partially saturated conditions and assumed no dilution. As the manganese enters the stratified drift, it will be appreciably diluted; therefore, little to no modification to the present ground water quality is anticipated for the following reasons:

1. Existing ground water manganese concentrations have varied from less than 0.001 to 10.2 mg/l (Table A-7), with an average concentration of 0.4 mg/l. The maximum projected manganese concentration of 3.0 mg/l at the top of the ground water table is within this range.

2. The manganese source is expected to diminish to below the U.S. EPA Secondary Drinking Water Standards within 50 years after the operation phase.

3. The seepage pH is likely to be higher than the conservative estimate (pH 7) presented in Table A-4, in which case the manganese concentration in the MWDF seepage will be lower than the projected 20 mg/l (Exxon, 1982).

4. The seepage will be migrating through approximately 13 m (42.6 feet) of partially saturated material before reaching the ground water surface. It is very probable that the manganese and other metal retardation factors will be higher in this zone as discussed in Section 4.4.2.

5. The seepage is expected to be anoxic and the retardation factors were determined under similar conditions (D'Appolonia, 1982). Initially, there should be a substantial oxygen concentration in the upper 2 m (6.6 feet) of the partially saturated till pore space beneath the MWDF. This would cause manganese to oxidize and precipitate. No credit for this oxidation-precipitation reaction in retarding the movement of manganese or other metals in the partially saturated till during this assessment was used

in evaluating when manganese and other metals in the seepage might be at their highest concentrations.

Similar discussions are valid for iron, and its movement will be less because of its relatively higher retardation factor.

6.6.2 Surface Water Impacts

A major portion of the ground water discharge flows from the site area into streams and lakes bordering the site. To the east, north, and northwest, ground water discharges into Ground Hemlock Lake, Hemlock Creek, Swamp Creek, and Rice Lake. Along the western and southwestern site area boundary, ground water discharges into Rolling Stone Lake, Pickerel Creek, and Pickerel Lake. Ground water flow in the southeastern portion of the site area is approximately parallel to the boundary. To assess the impacts on surface water quantity, the changes in the ground water base flow in bordering streams flow rates were calculated during the facilities operation phase and compared to the preconstruction flow rates.

The potential hydrologic impact of the proposed facilities on a stream is evaluated by predicting the changes in annual average total flow and base flow rates. The total flow rate represents the total stream flow rate generated by ground water discharge and surface runoff. The stream base flow rate represents only the amount of the stream flow produced by ground water discharge. Seasonal fluctuations of the base flow rate are less than that of the total flow rate and it is commonly used to assess the impact of variations in the ground water regime on a stream.

Tables A-18 through A-20 show the calculated changes in ground water discharge rates from the site area to bordering streams for the three recharge cases. Attachment A.11 presents a summary of individual nodal flows on the boundary of the model. These flows were combined to calculate the discharges shown in Tables A-18 and A-19. The segments of the site boundary where ground water discharge to streams was calculated are shown in Figure A.2-1 (Attachment A.2). A discussion of these changes during the construction and operation phases is presented below. For post-operation phase conditions, the ground water discharges will return to preconstruction conditions because the initial potentiometric surface will be restored.

Streams

Tables A-18 through A-20 show the predicted changes in the ground water discharge rate to Hemlock Creek, Swamp Creek, and Pickerel Creek at Year 3 (end of construction phase) and Year 28 (one year before end of reclamation) for the three recharge cases. The predicted ground water discharge before and after construction was evaluated by reviewing the potentiometric surfaces, gradients, ground water flow vectors, and other factors generated by the horizontal planar computer model.

Tables A-21 through A-26 present the average annual total and base flow rates for each of the streams adjacent to the site area and indicate the percent flow reduction related to mine inflow during the construction and operation phases for the three recharge cases. The data for base flow assessment were obtained from gaging station records summarized in Dames and Moore (1984a). Average total flow rate was determined by multiplying the drainage area for a particular location by the normalized average flow rate of 352 mm/y (13.87 inches per year) for the Wolf River Basin (Dames and Moore, 1984a). This corresponds to an average total stream flow rate of approximately 1.1×10^{-4} $m^3/s/ha$ (1.0 cubic foot per second per square mile). The predicted reduction in average annual stream base flow rate at Year 28 for Swamp Creek and Hemlock Creek combined is approximately 5, 8, and 10 percent for mine inflow corresponding to the Low, Middle, and High Recharge cases, respectively.

The largest predicted percent reduction in average annual base flow rate occurs in Hemlock Creek for Year 28 and varies from 6 to 13 percent for the Low and High Recharge cases, respectively. The annual average base flow rate of Hemlock Creek is small; therefore, even minor changes in the ground water discharge rate reflect a large percentage of the stream base flow rate. The calculated average annual base flow rate (0.113 m^3/s [4 cubic feet per second]) in Hemlock Creek at Point B (Figure A.2-1) is based on the average stream base flow characteristics for flow rate measurements at Staff Gage SG6 (Dames and Moore, 1984a).

Along other reaches of Swamp Creek and Hemlock Creek, the mine inflow and other projected hydrologic actions will not appreciably affect ground water discharge into the streams. These areas are outside the potentiometric drawdown zone of influence. For average annual total flow rate of these streams, the predicted percentage changes are approximately less than one-half of the base flow percentage changes, or approximately 2, 3, and 4 percent for the Low, Middle, and High Recharge cases, respectively.

The effects on ground water discharge and stream base flow rates for other stream sections are projected to be smaller than those discussed above or will be nonexistent. This conclusion was based on the predicted changes in the potentiometric surface adjacent to other streams or stream segments as indicated in Tables A-21 through A-26.

During a dry season, the stream flow might be reduced and be less than the annual average base flow; also, the recharge rate might be less than the low recharge rate used in this assessment. This reduction in the recharge rate would reduce the mine inflow proportionally. Therefore, the zone of influence will be similar to the one for the Low, Middle, and High Recharge cases (Figure A-32). However, as indicated in Tables A-21 through A-26, as the recharge rates decrease, the percent reduction of stream flow rates associated with the site ground water discharge also decreases. Additionally, other portions of the watersheds (outside the site area) will continue to contribute to stream flow. Therefore, the following can be concluded:

1. The mine inflow rate varies with the ground water recharge rate. Lower recharge will result in lower mine inflow.

2. The potentiometric surface decline will be the same for different recharge rates.

3. Reduction in the recharge rate will result in reduction of stream flow. However, as the recharge rate decreases, the percent base flow reduction from the site area will also decrease.

4. Because the site area seasonal potentiometric surface fluctuation is very small, the seasonal fluctuation of the stream base flow will also be small.

For comparison purposes, calculated base flows were determined based upon the USGS estimates of Q7,2 and Q7,10 as reported in Attachment A.2. These base flow rates and the corresponding reduction in total flow rates are presented in Tables A-28 through A-31. Tables A-28 and A-29 present results for the low recharge case for years 3 and 28, respectively. Tables A-30 and A-31 present results for the middle recharge case for years 3 and 28, respectively.

Lakes

The influence of a decline in the potentiometric surface on lakes is directly related to the degree of hydraulic connection between the lake and the ground water. Based on environmental information presented in the references to this report, Deep Hole, Duck, Little Sand, and Skunk lakes have the potential for interconnection with the potentiometric surface (Dames and Moore, 1982 and 1984a; STS Consultants, Ltd., 1984). The ground water potentiometric surface intersects the relatively impervious lacustrine deposits which underlie these lakes. Lowering the potentiometric surface will increase the hydraulic gradient in the lake bottom (lacustrine deposits), thereby increasing the ground water recharge rate from the lake.

Hydrogeologic data presented by STS Consultants, Ltd. (1984a and 1984b), indicate that Oak Lake is a perched lake and has no hydraulic connection to the potentiometric surface. Changes in its ground water recharge rate, resulting from fluctuation in the ground water potentiometric surface, will not occur.

Hydraulic interconnection also occurs at lakes on the boundaries of the study area (Crane, Ground Hemlock, Pickerel, Rice, and Rolling Stone). The hydrologic actions of mine inflow do not alter the potentiometric surface at these lakes; therefore, the influence on the hydraulic interconnection to these lake levels is predicted to be negligible.

The effects on discharge lakes (Rolling Stone, Pickerel, and Rice) are also related to the flow rate reductions in streams that feed the lakes. The reduction of ground water discharge to Rolling Stone Lake is presented in Tables A-21 through A-26. The percentage reduction of discharge for Year 28 (based on the average annual base flow rate) to Rolling Stone Lake is approximately 0.6, 0.9, and 1.1 percent for the three different mine inflow rates associated with the Low, Middle, and High Recharge cases, respectively. The effect on the lake level is therefore predicted to be negligible or nonexistent.

The major ground water discharge from the site area into Pickerel Lake is from Basin No. 7 as shown in Figure A.2-1 (Attachment A.2). The reduction in average annual stream base flow of Basin No. 7 is estimated as 3, 4, and 5 percent for the Low, Middle, and High Recharge cases, respectively. The average annual total flow reduction will be approximately one-half of the average annual base flow reduction. Therefore, no noticeable change in stream flow and lake level is projected.

The predicted impact on Rice Lake during the operation phase is a reduction of surface water inflow to the lake. Rice Lake receives an average annual stream base flow of 0.54 m^3/s (19.0 cubic feet per second) from Swamp Creek and additional discharges from Basins 3 and 4 as shown in Attachment A.2. Neglecting the surface water flow contribution for these two basins, the reduction in annual stream base flow for Year 28 will be 5, 8, and 10 percent for the three different recharge cases. However, the actual reduction will be less than these values because of the contributions from Basins 3 and 4. The predicted reduction of Swamp Creek flow rates above Rice Lake will be only 2, 3, and 4 percent of the average annual base flow rates (Tables A-22, A-24, and A-26). Therefore, the reduction in lake level will be negligible or nonexistent.

The predicted recharge rates and lake level declines for the lakes within the site area for the mine operation phase are shown in Table A-27. These values were computed using maximum decline (Year 28) potentiometric levels from the horizontal flow model and water balance calculations as described in Attachment A.10. The seepage rates and lake level changes therefore represent estimated maximum impacts for average climatic conditions. The water balance approach permitted the integration of numerous interrelated hydrologic variables and, despite simplifying assumptions, provides realistic and pertinent qualitative and quantitative results.

Using average regional (Rhinelander, Wisconsin) climatic data as input, the water balance analyses indicate that lake levels are likely to decline by between 0.15 and 0.18 m (0.5 and 0.6 foot) at Skunk Lake because of lowered ground water levels during the operation phase. Lake levels at Duck, Deep Hole, and Little Sand lakes are expected to decline by between 0.00 and 0.12 m (0.0 and 0.4 foot) during the operation phase. Oak Lake does not show a decline during the operation phase because the potentiometric surface is below the bottom of the lacustrine sediments in the preconstruction phase. Lake seepage recharge rate increases associated with Year 28 potentiometric surface declines range from 44 mm/y (1.72 inches per year) at Duck Lake to 600 mm/y (23.64 inches per year) at Skunk Lake.

For relatively dry meteorological conditions, the analyses presented in Attachment A.10 indicate that operation phase lake level declines will be similar to or somewhat greater than the predicted declines for average meteorological conditions.

The operation phase lake recharge rates shown in Table A-27 differ from those computed in the GEOFLOW horizontal flow simulations (Table A-10). The effects of the lake recharge rates computed using the water balance method on mine inflow calculated by the horizontal flow model were evaluated by an additional flow simulation (Attachment A.6). Lake sediment resistivity values for the calibrated GEOFLOW model were adjusted to provide computed seepage rates approximately equal to those estimated for the preconstruction phase by the water balance method (Dames and Moore, 1985; Table A-10). A steady-state mine inflow simulation was then performed using these revised lake bed resistivity values. The mine inflow rate increased from 0.0971 m^3/s (1540 gpm) for the calibrated flow model to 0.1129 m^3/s (1790 gpm). This increased mine inflow is derived from the generally higher lake seepage rates computed using the water balance method.

Springs

Hoffman Spring, discussed in Section 3.0, was evaluated for the different mine inflow rates associated with the three recharge rates. Review of the predicted change in the potentiometric surface indicates a reduction of approximately 0.8 m (2.6 feet) in this area for all recharge cases. In terms of ground water flow through the aquifer in the spring area, a review of the predicted change in discharge flow vectors indicates a reduction in the ground water flow rate of 29 percent, but ground water flow is still in the same direction as for preconstruction conditions. This indicates that Hoffman Spring might experience some seasonal impact.

7.0 HYDROLOGIC EVALUATIONS OF ALTERNATIVE DESIGNS

The alternative designs discussed in Section 2.2 relate only to the MWDF. The potential hydrologic impacts associated with these designs are discussed in this section. Alternatives to the mine and mine/mill surface facilities are not expected to cause different hydrologic effects than those projected for the proposed conditions, and therefore are not considered in this section.

The potential effects of the alternative MWDF designs on the site hydrologic regime are discussed in comparison to the consequences of the proposed MWDF. The details of the alternatives impact assessments are presented only to the extent required to support the conclusions regarding these impact comparisons.

7.1 MWDF 41-114B SEEPAGE CONTROL ALTERNATIVES

7.1.1 Tailings Pond Liner

For the alternative of a more permeable MWDF bottom liner (5×10^{-9} m/s versus 5×10^{-10} m/s), the seepage rate will increase substantially during operations and for the maximum post-operation phase seepage condition. The operation phase seepage rate for this alternative increases by approximately an order of magnitude above the projected seepage rates for the proposed liner system. The post-operation phase steady-state seepage rate will not change for this alternative because this rate is limited by reclamation cap design, which is identical for both cases.

As would be anticipated, the predicted transport of chemical constituents beneath the ponds for the operation and near-term post-operation phase is greater for this alternative. Because chemical constituents would reach the saturated zone sooner, subsequent transport in the stratified drift toward the compliance boundary would therefore begin at an earlier time for this alternative than for the proposed MWDF. However, for longer term evaluations, the impacts for this alternative are similar to those for the proposed

MWDF because the steady-state post-operation phase seepage rate is identical for both cases.

7.1.2 Reclamation Cap

For the alternative reclamation cap design, the long-term steady-state seepage and the maximum post-operational phase seepage rates will be greater than for the proposed MWDF. The steady-state MWDF post-operation phase seepage rate for the alternative cap design is assumed to be approximately 2.04 x 10^{-3} m^3/s (32 gallons per minute) for the total MWDF area or 39.6 mm/y (1.56 inches per year) per unit area.

Under proposed conditions, seepage is limited by the presence of a synthetic membrane. To evaluate the sensitivity of results to the projected seepage rate, a reclamation cap without a synthetic membrane was analyzed. The projected steady-state post-operation phase seepage rate for the MWDF without a synthetic membrane is approximately 8.3 x 10^{-4} m^3/s (13.3 gallons per minute) or 16.8 mm/y (0.66 inch per year) per unit area.

The simulated steady-state normalized concentrations resulting from this seepage rate are shown in Figure A.4-5. According to this figure, the maximum normalized concentration at the compliance boundary will be approximately 0.3 for steady-state conditions. This value is higher than that predicted for the proposed MWDF.

7.2 TAILINGS DISPOSAL LAYOUT AND METHOD ALTERNATIVES

7.2.1 Alternate Site Layouts

For alternate MWDF Sites 41-103 and 41-121, the distance to the water table is less than for proposed Site 41-114B. The depth to the saturated stratified drift at the alternate sites is equal to or less than that at the proposed site. Tailings pond seepage and associated chemical constituents will therefore reach the ground water and saturated stratified drift at earlier times at these two alternative sites.

Additionally, as shown in Figure A-5, the MWDF 41-121 area has little or no till beneath its southern tailings pond and is located directly on the more permeable stratified drift. This would allow faster transport of chemical constituents to surrounding areas for this alternative than for the proposed MWDF location.

7.2.2 Subaerial Disposal

Because tailings would be placed at increased density for subaerial disposal, it is possible that this alternative would result in reduced seepage during the operation phase. The long-term steady-state post-operation phase seepage would, however, be similar to that for the proposed MWDF (on a unit area basis) because precipitation infiltration is the primary cause of this seepage and a similar reclamation cap has been assumed. In studying this alternative, unit area seepage rates for the operation phase and long-term steady-state conditions have been assumed to be equal to those for the proposed MWDF. However, because subaerial disposal would require a smaller overall facility size, total seepage would be reduced. With these assumptions, it is concluded that there would be less potential for changes in ground water quality for subaerial disposal methods than for the proposed MWDF.

7.2.3 Dry Tailings Disposal

Tailings would be placed at a low moisture content for dry tailings disposal, resulting in less operation phase seepage for this alternative than for the proposed MWDF design. The long-term seepage rate would be similar, however, because precipitation infiltration is the primary cause of this seepage and, again, a similar reclamation cap has been assumed. The impacts to ground water quality for this alternative would occur at later times than those predicted for the proposed MWDF.

7.3 CONCLUSIONS

The hydrologic impacts of MWDF alternatives have been assessed and found to be similar to or greater than the hydrologic impacts which were analyzed for the proposed design. In addition, the alternatives evaluated for siting layout variations of the MWDF would result in similar or greater environmental impacts. The alternatives that were studied do not show potential for substantial long-term mitigation of the impacts projected for the proposed MWDF condition and could, for certain alternatives, increase the predicted impacts. The short- and long-term impacts (based upon the assumptions noted) could be less for the alternatives of subaerial and dry tailings disposal.

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TABLES

TABLE A-1

RANGE OF RECHARGE AND ASSOCIATED MINE INFLOW RATES

CASE	RECHARGE		MINE INFLOW	
	mm/y	in/y	m^3/s	gpm
Low Recharge	152	6.0	0.059	933
Middle Recharge	216	8.5	0.080	1,271
High Recharge	279	11.0	0.100	1,592

TABLE A-2

STEADY-STATE MINE INFLOW RATE DISTRIBUTION[a]

COMPUTER MODEL MINE INFLOW POINT NO.[b]	MINE INFLOW RATE					
	LOW RECHARGE CASE		MIDDLE RECHARGE CASE		HIGH RECHARGE CASE	
	$m^3/s \times 10^{-4}$	gpm	$m^3/s \times 10^{-4}$	gpm	$m^3/s \times 10^{-4}$	gpm
1	1.43	2.26	1.60	2.54	1.70	2.70
2	1.90	3.01	2.21	3.50	2.41	3.82
3	3.73	5.91	4.36	6.91	4.79	7.60
4	5.16	8.17	5.97	9.47	6.52	10.3
5	3.40	5.39	4.23	6.70	4.70	7.46
6	0.51	0.82	0.71	1.12	0.97	1.53
7	0	0	0	0	0	0
8	0.76	1.21	0.82	1.30	0.88	1.39
9	4.05	6.41	4.31	6.83	4.59	7.28
10	1.64	2.60	2.39	3.78	3.74	5.93
11	1.58	2.50	2.59	4.11	3.93	6.23
12	1.25	1.98	2.07	3.28	3.12	4.95
13	1.84	2.91	2.73	4.33	3.28	5.20
14	2.83	4.49	4.03	6.38	4.64	7.35
15	0.60	0.95	0.85	1.35	1.30	2.06
16	0.39	0.61	0.42	0.67	0.59	0.93
17	1.56	2.48	1.77	2.80	1.99	3.16
18	3.61	5.72	3.94	6.25	4.31	6.83
19	1.34	2.12	2.09	3.31	2.80	4.44
20	0.60	0.94	1.03	1.63	1.24	1.97
21	0.63	1.00	1.10	1.74	1.49	2.36
22	1.11	1.76	2.07	3.28	3.18	5.05
23	2.38	3.78	4.50	7.13	6.53	10.4
24	0.49	0.77	1.30	2.06	1.76	2.79
25	0.32	0.51	0.44	0.70	0.59	0.94
26	1.55	2.46	1.74	2.76	2.13	3.37
27	4.85	7.68	5.27	8.35	5.78	9.16
28	7.36	11.67	12.5	19.9	9.89	15.7
29	0	0	0	0	0	0
30	0	0	0	0	0	0
31	1.52	2.41	3.48	5.51	2.11	3.34
32	24.8	39.3	40.0	63.4	40.4	64.1
33	42.8	67.8	61.8	97.9	72.3	115
34	1.56	2.47	1.73	2.75	1.87	2.97
35	2.73	4.34	5.01	7.95	7.32	11.6
36	8.59	13.6	9.05	14.3	9.70	15.4
37	40.6	64.4	51.5	81.6	82.6	131
38	38.3	60.7	53.1	84.2	67.0	106
39	37.7	59.7	54.9	87.0	60.9	96.5
40	57.2	90.6	77.3	123	101	160
41	71.0	112	88.8	141	140	222
42	7.16	11.3	7.38	11.7	7.29	11.6
43	5.90	9.36	6.08	9.63	6.19	9.82
44	78.8	125	108	171	134	212
45	114	180	156	248	183	290
TOTAL	590	933	801	1271	1004	1592

[a]Source: TAP Associates, 1984.

[b]Refer to Figure A-2 for location of mine inflow points and Figure A-3a for mine inflow schedule.

TABLE A-3

PROJECTED SEEPAGE RATES OF MWDF[a,b]

POND NO.	SURFACE AREA		OPERATION SEEPAGE RATE[c]				MAXIMUM POST-OPERATION SEEPAGE RATE[c]				POST-OPERATION STEADY-STATE CONDITION SEEPAGE RATE[c]			
			POND		PER UNIT AREA		POND		PER UNIT AREA		POND		PER UNIT AREA	
	ha	acre	m^3/s	gpm	mm/y	in/y	m^3/s	gpm	mm/y	in/y	m^3/s	gpm	mm/y	in/y
T1	33.08	81.7	0.00018	2.9	17.3	0.68	0.00018	2.9	17.3	0.68	0.000018	0.29	1.68	0.066
T2	43.86	108.4	0.00024	3.8	17.3	0.68	0.00024	3.8	17.3	0.68	0.000023	0.37	1.68	0.066
T3	40.29	99.6	0.00022	3.5	17.3	0.68	0.00022	3.5	17.3	0.68	0.000021	0.34	1.68	0.066
T4	39.98	98.8	0.00022	3.5	17.3	0.68	0.00041	6.5	32.3	1.27	0.000021	0.34	1.68	0.066
TOTAL	157.21	388.5	-[d]	-	-	-	-	-	-	-	0.000083	1.33	1.68	0.066

[a]Source: Exxon, 1984b.

[b]Refer to Figure A-2 for location of ponds and Figure A-3b for seepage rate distribution.

[c]Refer to Figure A-3b for period of each rate.

[d]Operational seepage rates are not cumulative because of tailings ponds operation schedule (Figure A-3b).

TABLE A-4

PROJECTED MWDF TAILING PONDS SEEPAGE CHEMISTRY

PARAMETER	UNITS	YEARS 5 THROUGH 79		YEAR 80 AND BEYOND		U.S. EPA PRIMARY DRINKING WATER STANDARDS[c]	U.S. EPA SECONDARY DRINKING WATER STANDARDS[d]
		C[a]	C/DW[b]	C[a]	C/DW[b]		
pH	pH units	7	-	7-8	-	-	6.5-8.5
Filterable residue (TDS)	mg/l[e]	3,000	6	3,000	6	-	500
Sulfate	mg/l	2,000	8	2,000	8	-	250
Arsenic	mg/l	0.50	10	0.03	<1	0.05	-
Barium	mg/l	0.03	0.03	0.1	<1	1.0	-
Cadmium	mg/l	0.50	50	<0.001	<0.1	0.01	-
Chromium	mg/l	0.06	1.2	0.001	<0.1	0.05	-
Copper	mg/l	0.10	0.1	<0.01	<0.01	-	1.0
Iron	mg/l	30	100	0.02	<0.1	-	0.3
Lead	mg/l	0.04	0.8	0.01	<1	0.05	-
Manganese	mg/l	20	400	0.02	<1	-	0.05
Mercury	mg/l	0.01	5	<0.001	<1	0.002	-
Selenium	mg/l	0.10	10	<0.001	<0.1	0.01	-
Silver	mg/l	0.03	0.6	<0.001	<0.1	0.05	-
Zinc	mg/l	10	2	0.2	<0.1	-	5.0

[a]Projected tailing ponds seepage concentration (Exxon, 1982).

[b]Projected tailing ponds seepage concentration (C) divided by the U.S. EPA Drinking Water Standard (DW); dilution ratio required to reach drinking water standard.

[c]U.S. EPA (1975), 40 CFR, Part 141.

[d]U.S. EPA (1979), 40 CFR, Part 143.

[e]mg/l = parts per million.

TABLE A-5

RANGE OF HYDROLOGIC VALUES FOR VARIOUS GEOLOGIC UNITS[a]

UNIT	HORIZONTAL PERMEABILITY RANGE[a]		AVERAGE VALUE[a]		VERTICAL PERMEABILITY		STORAGE COEFFICIENT	POROSITY
	m/s x 10^{-5}	ft/day	m/s x 10^{-5}	ft/day	m/s x 10^{-5}	ft/day	Dimensionless	%
Coarse-grained stratified drift	1.0-10.0 (0.1-2000)[b]	2.8-28 (0.28-5669)[b]	4.0 (13.0)[b]	11 (37)[b]	1.3[c]	3.7[c]	0.05-0.07[b]	30.7[d]
Fine-grained stratified drift	0.7-6.0	2.0-17	2.0	5.7	-	-	-	-
Glacial Till	0.009-3.0	0.026-8.5	0.6	1.7	0.094[c]	0.26[c]	0.0015-0.054[b]	22.60-30.7[d]
Lake Lacustrine	0.000068-0.0023[e]	0.0002-0.0065[e]	0.0003[e]	0.0008[e]	0.0003[b]	0.0008[b]	-	-
Glacial Lacustrine	0.01-0.50	0.028-1.4	0.2	0.57	-	-	-	-
Bedrock	0.000018-0.12[f]	0.00005-0.34[f]	0.0057[f]	0.016[f]	-	-	-	-

[a]Source: STS Consultants, Ltd. (1984a).

[b]Source: Golder Associates (1982b).

[c]Source: Golder Associates (1981).

[d]The value of 30.7 has been measured as part of the partially saturated permeability assessment (refer to Attachment A.1).

[e]Source: STS Consultants, Ltd. (1984b).

[f]Source: Exxon (1984c).

TABLE A-6

PERMEABILITY RANGE FOR THE PUMPING TEST IN THE STRATIFIED DRIFT[a]

BORING NO.[b]	TEST ZONE ELEVATION m	MAXIMUM PERMEABILITY m/s	MAXIMUM PERMEABILITY ft/day	MINIMUM PERMEABILITY m/s	MINIMUM PERMEABILITY ft/day
G41 - G14A	462.35 - 446.81	5.00×10^{-4}	142	4.18×10^{-4}	118
G41 - G14B	440.07 - 410.47	2.09×10^{-4}	59	1.18×10^{-4}	33
G41 - G14D	454.33 - 441.53	1.91×10^{-4}	54	1.54×10^{-4}	44
G41 - G14E	480.55 - 469.58	9.09×10^{-4}	258	2.73×10^{-4}	77
G41 - G14F	433.57 - 418.03	2.18×10^{-4}	62	1.54×10^{-4}	44
G41 - G15A	487.91 - 481.51	1.18×10^{-3}	333	1.06×10^{-4}	30
G41 - G15B	471.25 - 463.93	1.65×10^{-4}	47	1.24×10^{-4}	35
G41 - G15	444.24 - 412.54	2.39×10^{-4}	68	1.13×10^{-4}	32
G41 - E13	427.42 - 419.65	6.50×10^{-4}	184	1.95×10^{-4}	55
DMB - 1A	489.0 - 471.8	1.20×10^{-3}	340	4.00×10^{-4}	113
G41 - K13	444.91 - 431.19	5.76×10^{-4}	163	2.48×10^{-4}	70
RANGE	-	1.20×10^{-3}	340	1.06×10^{-4}	30

[a]Permeability values were determined the from pumping test transmissivities as reported in Golder Associates (1981) and aquifer thicknesses as presented in Golder Associates (1982b).

[b]Refer to Figure A-8 for boring locations.

TABLE A-7

SUMMARY OF GROUND WATER QUALITY FOR THE MAIN AQUIFER[a]

PARAMETER	UNITS	RANGE	MEAN ($\bar{x}$)	STANDARD DEVIATION (S)	NUMBER OF SAMPLES	U.S. EPA PRIMARY DRINKING WATER STANDARDS[b]	U.S. EPA SECONDARY DRINKING WATER STANDARDS[c]
Field temperature	°C	3.0 - 12.0	7.1	1.8[d]	220	-	-
Total laboratory alkalinity	mg/ℓ $CaCO_3$	14 - 453	123	50	234	-	-
Total field alkalinity	mg/ℓ $CaCO_3$	11 - 487	127	53	221	-	-
Specific conductance	μmhos/cm	50 - 1,300	237	107	235	-	-
Field conductivity	μmhos/cmf	29 - 1,150	178	92	218	-	-
Laboratory pH	standard units	6.09 - 11.02	7.6[e]	0.69	204	-	6.5-8.5
Field pH	standard units	5.5 - 12.2	7.7[e]	1.0	222	-	6.5-8.5
Total hardness	mg/ℓ $CaCO_3$	16 - 452	125	53	236	-	-
Total dissolved solids	mg/ℓ	14 - 836	166	84	235	-	500
Chemical oxygen demand	mg/ℓ	<1 - 365[f]	<29	<56	143	-	-
Total phosphorus	mg/ℓ P	<0.01 - 0.84	<0.06	<0.10	135	-	-
Anions:							
Arsenic	mg/ℓ	<0.001 - 0.004	<0.001	<0.001	236	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	-
Nitrate	mg/ℓ N	<0.01 - 11.0	<0.37	<1.04	235	10	-
Phosphate	mg/ℓ PO_4	<0.01 - 0.31	<0.06	<0.06	101	-	-
Sulfate	mg/ℓ	<1 - 86	<9	<9	232	-	250

TABLE A-7
(Continued)

PARAMETER	UNITS	RANGE	MEAN ($\bar{x}$)	STANDARD DEVIATION (S)	NUMBER OF SAMPLES	U.S. EPA PRIMARY DRINKING WATER STANDARDS[b]	U.S. EPA SECONDARY DRINKING WATER STANDARDS[c]
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	-
Cadmium	mg/ℓ	<0.001 - 0.015	<0.002	<0.002	169	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	-
Cobalt	mg/ℓ	<0.01	<0.01	0	169	-	-
Copper	mg/ℓ	<0.001 - 0.09	<0.007	<0.011	232	-	1
Iron	mg/ℓ	<0.01 - 38.9	<1.74	<4.34	236	-	0.3
Lead	mg/ℓ	<0.01 - 0.10	<0.01	<0.01	235	0.05	-
Magnesium	mg/ℓ	0.279 - 29.6	12.0	5.12	169	-	-
Manganese	mg/ℓ	<0.001 - 10.2	<0.423	<0.989	236	-	0.05
Mercury	mg/ℓ	<0.0001 - 0.0010	<0.0001	<0.0001	169	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	-
Silver	mg/ℓ	<0.001	<0.001	0	142	0.05	-
Zinc	mg/ℓ	<0.001 - 2.60	<0.052	<0.214	235	-	5

[a] Source: Dames and Moore (1982).

[b] U.S. EPA (1975), 40 CFR, Part 141.

[c] U.S. EPA (1979), 40 CFR, Part 143.

[d] Reflects seasonal temperature variation.

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

[f] "<" indicates less than.

TABLE A-8

SUMMARY OF CHARACTERISTICS FOR THE SWAMP CREEK DRAINAGE BASIN IN THE STUDY AREA[a]

SURFACE WATER CATEGORY / WATER BODY	DRAINAGE BASIN AREA		AVERAGE WIDTH		AVERAGE DEPTH		MAXIMUM DEPTH		SURFACE AREA		MAXIMUM RECORDED SURFACE ELEVATION[b]		MINIMUM RECORDED SURFACE ELEVATION[b]		ESTIMATED ANNUAL AVERAGE BASE FLOW[c]		HIGHEST RECORDED DISCHARGE[c]		LOWEST RECORDED DISCHARGE[c]	
	ha	acres	m	ft	m	ft	m	ft	ha	acres	m	ft	m	ft	m^3/s	cfs[d]	m^3/s	cfs[d]	m^3/s	cfs[d]
Drainage Lake and Associated Streams																				
Rice Lake	-[e]	-	-	-	-	-	1.8	6	84.2	208	467.92	1,535.16	467.25	1,532.98	-	-	-	-	-	-
Hemlock Creek[f]	910	2,240	4.3	14	0.3	1.0	-	-	-	-	-	-	-	-	0.11	4	>0.50	>17.5[g]	<0.02	<0.7[g]
Swamp Creek[h]	11,970	29,570	7.0	23	0.3	1.0	-	-	-	-	-	-	-	-	0.54	19	4.28	151	0.23	8
Swamp Creek[i]	14,690	36,290	7.0	23	0.3	1.0	-	-	-	-	-	-	-	-	0.93	33	5.92	209	0.48	17
Outlet Creek[j]	2,900	7,170	4.0	13	0.3	1.0	-	-	-	-	-	-	-	-	0.20	7	>0.85	>30.0[g]	<0.08	<3.0[g]
Hoffman Creek[k]	440	1,090	2.4	8	0.2	0.5	-	-	-	-	-	-	-	-	-	-	0.34	11.9	0.01	0.4
Spring Lake																				
Ground Hemlock Lake	-	-	-	-	-	-	13	42	36	88	481.31	1,579.10	481.13	1,578.52	-	-	-	-	-	-
Seepage Lake																				
Oak Lake	-	-	-	-	-	-	14	47	21	51	498.11	1,634.21	497.47	1,632.11	-	-	-	-	-	-

[a] Source: Dames and Moore (1984a).

[b] Elevation expressed as meters (feet) above mean sea level.

[c] For period between April 1977 and November 1980.

[d] cfs = cubic feet per second.

[e] Not applicable.

[f] Flow measurements taken at gaging location SG 6. Refer to Figure A.2-1 of Attachment A.2 for gaging station location.

[g] ">" or "<" indicates that the actual discharge rate was greater than or less than, respectively, the measured rate.

[h] Flow measurements from the USGS gaging station at Highway 55.

[i] Flow measurements from the USGS gaging station at County Road M.

[j] Flow measurements from gaging location SG 4.

[k] Flow measurements from gaging locations SG E and F.

TABLE A-9

SUMMARY OF CHARACTERISTICS FOR THE PICKEREL CREEK DRAINAGE BASIN IN THE STUDY AREA[a]

SURFACE WATER CATEGORY/ WATER BODY	DRAINAGE BASIN AREA		AVERAGE WIDTH		AVERAGE DEPTH		MAXIMUM DEPTH		SURFACE AREA		MAXIMUM RECORDED SURFACE ELEVATION[b]		MINIMUM RECORDED SURFACE ELEVATION[b]		ESTIMATED ANNUAL AVERAGE BASE FLOW[c]		HIGHEST RECORDED DISCHARGE[c]		LOWEST RECORDED DISCHARGE[c]	
	ha	acres	m	ft	m	ft	m	ft	ha	acres	m	ft	m	ft	m^3/s	cfs[d]	m^3/s	cfs[d]	m^3/s	cfs[d]
Drainage Lake and Associated Streams																				
Rolling Stone Lake	-[e]	-	-	-	-	-	3.7	12	272	672	468.12	1,535.84	467.85	1,534.95	-	-	-	-	-	-
Pickerel Creek[f]	3,650	9,020	14	45	0.53	1.75	-	-	-	-	-	-	-	-	0.20	7	2.10	74.0	<0.14	<4.9[g]
Creek 12-9[h]	1,550	3,840	2.7	9.0	0.3	1.0	-	-	-	-	-	-	-	-	0.08	3	1.20	42.2	<0.06	<2.2[g]
Creek 11-4	105	260	1.5	5.0	0.1	0.3	-	-	-	-	-	-	-	-	(not available)		(not available)		(not available)	
Seepage Lakes																				
Little Sand Lake	-	-	-	-	-	-	6.4	21	100	248	485.53	1,592.96	484.88	1,590.82	-	-	-	-	-	-
Duck Lake	-	-	-	-	-	-	3.0	10	11	26	491.41	1,612.25	490.80	1,610.23	-	-	-	-	-	-
Deep Hole Lake	-	-	-	-	-	-	3.0	10	39	97	489.84	1,607.10	489.19	1,604.96	-	-	-	-	-	-
Skunk Lake	-	-	-	-	-	-	1.8	6	2.4	6	487.15	1,598.26	486.61	1,596.48	-	-	-	-	-	-
Mole Lake	-	-	-	-	-	-	5.2	17	30	73	(not available)		(not available)		-	-	-	-	-	-
Walsh Lake	-	-	-	-	-	-	4.6	15	18	45	487.68	1,600.00	487.44	1,599.21	-	-	-	-	-	-
St. Johns Lake	-	-	-	-	-	-	6.1	20	39	96	484.85	1,590.70	484.66	1,590.10	-	-	-	-	-	-

[a] Source: Dames and Moore (1984a).

[b] Elevation expressed as meters (feet) above mean sea level.

[c] For period between April 1977 and November 1980.

[d] cfs = cubic feet per second.

[e] Not applicable.

[f] Flow measurements from gaging location SG 22. Refer to Figure A.2-1 of Attachment A.2 for gaging station location.

[g] "<" indicates that the actual discharge rate was less than the measured rate.

[h] Flow measurements from gaging location SG 23.

TABLE A-10

GEOFLOW INPUT DATA AND CALCULATED RECHARGE RATES FOR SITE AREA LAKES

ITEM	UNITS	SEEPAGE RECHARGE LAKES: DUCK	DEEP HOLE	LITTLE SAND	OAK	SKUNK
GEOFLOW SIMULATIONS:						
Area[a]	ha	9.1	41.4	92.4	21.4	3.5
	acres	22.5	102	228	52.9	8.6
Lacustrine Unit Thickness[b]	m	10-15	6-8	5-9	5	2
	ft	33-49	20-26	16-30	16	7
Calibrated Potentiometric Level Difference[c]	m	6.7	5.8	2.8	12.9	1.3
	ft	22.0	19.0	9.2	42.3	4.3
Calibrated Preconstruction Recharge Rate Per Unit Area (calculated by GEOFLOW)	mm/y	88.9	142	71.1	406[d]	94.0
	in/y	3.5	5.6	2.8	16.0[d]	3.7
Maximum Operation Phase Recharge Rate Per Unit Area (Calculated by GEOFLOW)	mm/y	213	254	297	406	320
	in/y	8.4	10.0	11.7	16.0	12.6
WATER BALANCE CALCULATIONS:						
Preconstruction Recharge Rate Per Unit Area[e]	mm/y	541	203	203	231	1011
	in/y	21.3	8.0	8.0	9.1[d]	39.8
Operation Phase Recharge Rate Per Unit Area[f]	mm/y	585	274	573	232	1611
	in/y	23.0	10.8	22.5	9.1[d]	63.4

[a]Lake area as simulated in finite element grid system (Figure A-22).
[b]GEOFLOW simulations considered both organic silt and lacustrine clay deposits.
[c]Head differential between lake water level and the average nodal potentiometric level for the calibrated model.
[d]The potentiometric surface is below the Oak Lake bottom; therefore, maximum seepage occurs.
[e]From Dames and Moore, 1985; values computed through water balance calculations.
[f]From Attachment A.10; values computed by extension of water balance calculations for Operation Phase ground water potentiometric elevations.

TABLE A-11

REPRESENTATIVE RETARDATION FACTORS (R_d)
FOR THE GLACIAL DRIFT

PARAMETER	R_d [a]
Filterable residue (TDS)	1
Sulfate	1
Arsenic	111
Barium	BD [b]
Cadmium	113
Chromium	BD
Copper	32
Iron	>14
Lead	>14
Manganese	2
Mercury	BD
Selenium	>14
Silver	>14
Zinc	>14

[a]From D'Appolonia (1982) for projected tailing seepage pH of 7 to 8, extrapolated from pH = 6 and 9 attenuation data.

[b]R_d values reported as "BD" represent soluble metal concentrations which were below the detection limit before the tailings leachate was allowed to react with the glacial drift or which were too low to allow the determination of changes in concentration as a result of the interaction of the tailings leachate with the glacial drift, thus below EPA drinking water standards.

TABLE A-12

SUMMARY OF HORIZONTAL MODEL CALIBRATION

MIDDLE RECHARGE CASE

CALIBRATION ANALYSIS NUMBER	PERMEABILITY ZONE 1 (m/s)	PERMEABILITY ZONE 1 (ft/day)	PERMEABILITY ZONE 2 (m/s)	PERMEABILITY ZONE 2 (ft/day)	POTENTIOMETRIC SURFACE[a]	CALCULATED GROUND WATER DISCHARGE TO SWAMP CREEK[b] (m^3/s)	CALCULATED GROUND WATER DISCHARGE TO SWAMP CREEK[b] (cfs)	CHANGES FOR SUBSEQUENT CALIBRATION ANALYSIS
1	1.13×10^{-4}	32.0	-	-	High overall.	0.125	4.43	Increase permeability to 1.24×10^{-4} m/s.
2	1.24×10^{-4}	35.0	-	-	General agreement overall; poor match in southern wetlands area and north-central area.	0.127	4.49	Assign constant head values to eight nodes in the southern wetlands area.
3	1.24×10^{-4}	35.0	-	-	o Poor match in north-central area. o Southern wetlands area improved, but still high.	0.123	4.34	o Add Zone 2 with a permeability of 2.00×10^{-6} m/s. o Add six additional constant head nodes (14 total).
4	1.24×10^{-4}	35.0	2.00×10^{-6}	0.6	o Extreme mounding in north-central area. o Slight improvement to southern wetlands area. o Poor match in northern wetlands.	0.120	4.24	o Increase permeability of Zone 2 to 6.18×10^{-5} m/s. o Change configuration and values of constant head nodes in southern wetlands area. o Add seven constant head nodes in northern wetlands.
5	1.24×10^{-4}	35.0	6.18×10^{-5}	17.5	o Low within north-central area. o High in southern wetlands area. o Slight change to northern wetlands area.	0.115	4.06	o Decrease permeability of Zone 2 to 3.17×10^{-5} m/s. o Remove four constant head nodes in southern wetlands area (10 total). o Change configuration of constant head nodes in northern wetlands area.
6	1.24×10^{-4}	35.0	3.17×10^{-5}	9.0	o Low in northwestern area. o High within north-central area. o Slight change in northern wetlands area.	0.115	4.08	o Decrease Zone 1 permeability to 1.19×10^{-4} m/s. o Increase permeability of Zone 2 to 4.76×10^{-5}. o Remove constant head nodes in northern wetlands area.
7	1.19×10^{-4}	33.7	4.76×10^{-5}	13.5	o High in midwestern area. o High within north-central area.	0.118	4.17	o Increase Zone 1 permeability to 1.22×10^{-4} m/s. o Increase permeability of Zone 2 to 5.64×10^{-5} m/s.
8	1.22×10^{-4}	34.5	5.64×10^{-5}	16.0	General agreement overall, except north-central area and southern wetlands area.	0.119	4.19	o Increase area of Zone 2. o Change configuration of ten constant head nodes in southern wetlands.
9	1.22×10^{-4}	34.5	5.64×10^{-5}	16.0	High within north-central area.	0.115	4.06	Increase permeability of Zone 2 to 7.23×10^{-5} m/s.
10	1.22×10^{-4}	34.5	7.23×10^{-5}	20.5	Good agreement overall.	0.118	4.15	End of horizontal model calibration for Middle Recharge rate.

[a]Calculated potentiometric surface as compared to observed; refer to Figure A-13 for observed potentiometric surface.

[b]The calculated ground water discharge from the site area to Swamp Creek includes the discharge rate to Hemlock Creek (Segment A'D). Refer to Figure A.2-1 of Attachment 2.0 for stream segment location.

TABLE A-13

COMPARISON OF OBSERVED AND CALIBRATED HORIZONTAL MODEL POTENTIOMETRIC HEADS AT SELECTED BORINGS FOR MIDDLE RECHARGE CASE

BORING NUMBER[a]	OBSERVED POTENTIOMETRIC HEAD[b]		CALIBRATED POTENTIOMETRIC HEAD[c]		DIFFERENCE BETWEEN POTENTIOMETRIC HEADS	
	m	ft	m	ft	m	ft
WP-3U	468.24	1536.2	468.0	1535.4	+0.2	+0.8
DMA-48	468.61	1537.4	469.6	1540.7	-1.0	-3.3
DMB-23	474.04	1555.2	473.5	1553.5	+0.5	+1.7
DMB-20A	476.52	1563.4	475.7	1560.7	+0.8	+2.7
G40-K13	477.18	1565.6	476.6	1563.6	+0.6	+2.0
G40-J15	476.56	1563.5	476.8	1564.3	-0.2	-0.8
G40-M15	478.61	1570.2	478.2	1568.9	+0.4	+1.3
G40-H16	475.77	1560.9	476.0	1561.7	-0.2	-0.8
DMB-21	474.19	1555.7	474.2	1555.8	0.0	-0.1
DMA-18	476.28	1562.6	476.6	1563.6	-0.3	-1.0
DMB-18	474.73	1557.5	475.3	1559.4	-0.6	-1.9
WP-1U	473.55	1553.6	474.1	1555.4	-0.5	-1.8
DMA-13	473.70	1554.1	474.1	1555.4	-0.4	-1.3
G40-L23	476.30	1562.7	475.9	1561.4	+0.4	+1.3
G40-D24	473.62	1553.9	473.0	1551.8	+0.6	+2.1
DMB-13	473.57	1553.7	473.7	1554.1	-0.1	-0.4
G40-H27	472.31	1549.6	471.7	1547.6	+0.6	+2.0
DMB-25	472.14	1549.0	471.1	1545.6	+1.0	+3.4
EX-1BU	472.11	1548.9	471.0	1545.3	+1.1	+3.6
DMB-24	469.31	1539.7	468.1	1535.8	+1.2	+3.9
DMB-10	476.30	1562.7	473.5	1553.5	+2.8	+9.2
DMA-20	476.28	1562.6	473.0	1551.8	+3.3	+10.8

See footnotes at end of table.

TABLE A-13
(Continued)

BORING NUMBER[a]	OBSERVED POTENTIOMETRIC HEAD[b]		CALIBRATED POTENTIOMETRIC HEAD[c]		DIFFERENCE BETWEEN POTENTIOMETRIC HEADS	
	m	ft	m	ft	m	ft
G40-P10A	478.43	1569.7	477.2	1565.6	+1.2	+4.1
WP-5U	472.11	1548.9	472.6	1550.5	-0.5	-1.6
EX-4BU	474.83	1557.8	474.8	1557.7	0.0	+0.1
G40-Q7	477.19	1565.6	475.8	1561.0	+1.4	+4.6
DW-3U	480.91	1577.8	480.4	1576.1	+0.5	+1.7
G40-P20	479.16	1572.0	478.8	1570.9	+0.4	+1.1
DMB-11	478.83	1571.0	478.5	1569.9	+0.3	+1.1
G40-R23	478.41	1569.6	477.7	1567.3	+0.7	+2.3
DMB-12	477.35	1566.1	476.1	1562.0	+1.3	+4.1
DMA-47	474.17	1555.7	475.8	1561.0	-1.6	-5.3
EX-5CL	479.55	1573.3	479.7	1573.8	-0.1	-0.5
DW-1U	482.08	1581.6	482.1	1581.7	0.0	-0.1
G40-S17A	481.29	1579.0	480.9	1577.8	+0.4	+1.2
DMA-10	480.41	1576.1	479.6	1573.5	+0.8	+2.6
G40-X1A	479.95	1574.6	480.4	1576.1	-0.4	-1.5
G40-X1	482.76	1583.9	482.1	1581.7	+0.7	+2.2
DMS-2	485.38	1592.5	483.2	1585.3	+2.2	+7.2
DMS-1	486.15	1595.0	484.3	1588.9	+1.9	+6.1
DMP-1	484.52	1589.6	484.4	1589.2	+0.1	+0.4
DMI-1	485.14	1591.7	484.8	1590.6	+0.3	+1.1
DMI-2U	484.59	1589.9	484.6	1589.9	0.0	0.0
DMP-2	483.74	1587.1	483.9	1587.6	-0.2	-0.5
G40-Y15A	485.22	1591.9	483.9	1587.6	+1.3	+4.3
EX-15BL	484.30	1588.9	484.1	1588.3	+0.2	+0.6
G40-Y21	482.55	1583.2	482.1	1581.7	+0.5	+1.5

See footnotes at end of table.

TABLE A-13
(Continued)

BORING NUMBER[a]	OBSERVED POTENTIOMETRIC HEAD[b]		CALIBRATED POTENTIOMETRIC HEAD[c]		DIFFERENCE BETWEEN POTENTIOMETRIC HEADS	
	m	ft	m	ft	m	ft
G40-Y22	480.45	1576.3	481.2	1578.7	-0.8	-2.4
G40-Y26	482.01	1581.4	480.4	1576.1	+1.6	+5.3
G40-T30	481.33	1579.2	478.8	1570.9	+2.5	+8.3
DMA-12	485.68	1593.4	485.9	1594.2	-0.2	-0.8
TW-1	485.59	1593.1	485.5	1592.8	+0.1	+0.3
DW-2U	485.70	1593.5	485.4	1592.5	+0.3	+1.0
G41-B12	485.96	1594.4	485.3	1592.2	+0.7	+2.2
DMA-19	485.11	1591.6	484.5	1589.6	+0.6	+2.0
DMA-4	484.22	1588.6	484.0	1587.9	+0.2	+0.7
G41-A23	482.67	1583.6	482.4	1582.7	+0.3	+0.9
G41-A24	482.87	1584.2	482.3	1582.3	+0.6	+1.9
DMA-31	483.46	1586.2	484.3	1588.9	-0.8	-2.8
DMB-1A	486.15	1595.0	485.2	1591.9	+1.0	+3.1
G41-E13	486.01	1594.5	485.2	1591.9	+0.8	+2.6
EX-16BL	485.86	1594.0	484.9	1590.9	+1.0	+3.1
G41-C15	485.65	1593.3	484.9	1590.9	+0.7	+2.4
G41-E17	485.51	1592.9	484.9	1590.9	+0.6	+2.0
DMB-6	485.79	1593.8	484.9	1590.9	+0.9	+2.9
EX-13DL	485.46	1592.7	484.8	1590.6	+0.7	+2.1
G41-E19A	484.90	1590.9	484.6	1589.9	+0.3	+1.0
G41-E22A	484.67	1590.1	484.2	1588.6	+0.5	+1.5
DMB-26	483.11	1585.0	483.1	1585.0	0.0	0.0
G41-C32	482.89	1584.3	481.6	1580.1	+1.3	+4.2
DMB-4	486.02	1594.6	484.1	1588.3	+1.9	+6.3
EX-9BU	486.10	1594.8	484.3	1588.9	+1.8	+5.9

See footnotes at end of table.

TABLE A-13
(Continued)

BORING NUMBER[a]	OBSERVED POTENTIOMETRIC HEAD[b]		CALIBRATED POTENTIOMETRIC HEAD[c]		DIFFERENCE BETWEEN POTENTIOMETRIC HEADS	
	m	ft	m	ft	m	ft
G41-G13	486.22	1595.2	484.6	1589.9	+1.6	+5.3
EX-10BL	486.21	1595.2	484.9	1590.9	+1.3	+4.3
G41-G14C	486.03	1594.6	485.0	1591.2	+1.0	+3.4
G41-G15A	485.85	1594.0	485.0	1591.2	+0.8	+2.8
EX-11BU	485.79	1593.8	485.0	1591.2	+0.8	+2.6
EX-12BU	485.95	1594.3	485.0	1591.2	+1.0	+3.1
DMB-5	485.70	1593.5	484.9	1590.9	+0.8	+2.6
G41-H18B	485.49	1592.8	484.9	1590.9	+0.6	+1.9
G41-G21	484.77	1590.5	484.7	1590.2	+0.1	+0.3
DMB-27	484.28	1588.8	484.4	1589.2	-0.1	-0.4
G41-F24	483.89	1587.6	484.1	1588.3	-0.2	-0.7
DMB-28	484.30	1588.9	484.5	1589.6	-0.2	-0.7
EX-7BU	481.50	1579.7	481.9	1581.0	-0.4	-1.3
DMB-3	481.65	1580.2	481.9	1581.0	-0.3	-0.8
EX-8BU	481.59	1580.0	482.0	1581.4	-0.4	-1.4
G41-M11	481.52	1579.8	481.9	1581.0	-0.4	-1.2
G41-K13A	485.97	1594.4	484.2	1588.6	+1.8	+5.8
G41-P16	481.57	1580.0	482.8	1584.0	-1.2	-4.0
DMA-32A	482.85	1584.1	483.5	1586.3	-0.7	-2.2
G41-P18	483.78	1587.2	484.3	1588.9	-0.5	-1.7
G41-P18B	484.31	1588.9	484.4	1589.2	-0.1	-0.3
DMB-9A,B,C	485.06	1591.4	484.8	1590.6	+0.3	+0.8
EX-14BU	485.08	1591.5	484.9	1590.9	+0.2	+0.6
G41-N21	484.76	1590.4	484.8	1590.6	0.0	-0.2
G41-Q22	484.86	1590.7	484.6	1589.9	+0.3	+0.8

See footnotes at end of table.

TABLE A-13
(Continued)

BORING NUMBER[a]	OBSERVED POTENTIOMETRIC HEAD[b]		CALIBRATED POTENTIOMETRIC HEAD[c]		DIFFERENCE BETWEEN POTENTIOMETRIC HEADS	
	m	ft	m	ft	m	ft
G41-P24	484.73	1590.3	484.6	1589.9	+0.1	+0.4
DMB-7	484.78	1590.5	484.6	1589.9	+0.2	+0.6
DMB-29	484.52	1589.6	484.4	1589.2	+0.1	+0.4
Mean of the algebraic differences					0.45	1.48
Mean of the absolute differences					0.69	2.26
Standard deviation of the algebraic differences					0.83	2.72
Root mean square (RMS) of differences					0.94	3.08

[a]Refer to Figure A-8 for boring locations.

[b]Measured potentiometric heads, April 1984, STS Consultants, Ltd. (1984a).

[c]Potentiometric heads from calibrated horizontal model for Middle Recharge rate.

TABLE A-14

COMPUTED MAXIMUM MINE INFLOW RATE AND CHANGES IN GROUND WATER DISCHARGE RATE TO SWAMP CREEK FOR MIDDLE RECHARGE CASE

CALIBRATION CONDITION[a]	MAXIMUM MINE INFLOW RATE		DISCHARGE RATE TO SWAMP CREEK[b] PRECONSTRUCTION		DISCHARGE RATE TO SWAMP CREEK[b] MAXIMUM MINE INFLOW		REMAINING PERCENTAGE OF STREAM FLOW[c]
	m^3/s	gpm	m^3/s	cfs	m^3/s	cfs	
TWO PERMEABILITY ZONES:							
Constant Head Boundary Condition[d]	0.0971	1,540	0.118	4.15	0.0825	2.91	70
Combined Constant Head and No-Flow Boundary Conditions[e]	0.0968	1,534	0.119	4.21	0.0819	2.89	69
Swamp Creek No-Flow Condition	0.1121	1,777	0	0	0	0	-
Increased Lake Bottom Permeability	0.1020	1,617	0.119	4.21	0.0842	2.98	71
UNIFORM PERMEABILITY ZONE:							
Constant Head Boundary Condition	0.0944	1,496	0.119	4.19	0.0836	2.95	71

[a]Refer to Attachment A.6 for detailed description of model conditions.

[b]The discharge rate to Swamp Creek is calculated along segment A'D as depicted in Figure A.2-1 of Attachment A.2.

[c]Remaining percentage of flow equals the amount of ground water discharge rate to Swamp Creek corresponding to the computed maximum mine inflow divided by the preconstruction ground water discharge rate to the Creek.

[d]Best calibration.

[e]Based on Golder (1982c).

TABLE A-15

SUMMARY OF INPUT PARAMETERS FOR HORIZONTAL MODEL CALIBRATION[a]

PARAMETER	ZONE[b]	INPUT VALUES AND UNITS: LOW RECHARGE CASE		MIDDLE RECHARGE CASE		HIGH RECHARGE CASE	
Horizontal Permeability		m/s	ft/day	m/s	ft/day	m/s	ft/day
	Zone 1: Drift	8.88×10^{-5}	25.2	1.22×10^{-4}	34.5	1.55×10^{-4}	44.0
	Zone 2: Till and Drift Mixture	4.76×10^{-5}	13.5	7.23×10^{-5}	20.5	7.70×10^{-5}	21.8
Recharge Zones							
Inverse of Lake Bottom Resistivity[c,d]				(ft per year/ft)			
	Zone A: Duck Lake			0.010 0.016			
	Deep Hole Lake			0.026 0.020			
	Little Sand Lake			0.023 0.018 0.032			
	Oak Lake			0.032			
	Skunk Lake			0.079			
Precipitation Recharge Rate		mm/y	in/y	mm/y	in/y	mm/y	in/y
	Zone B	152	6	216	8.5	279	11
Aquifer Thickness[d]	Entire Site Area			Figure A-14			
Aquifer Bottom Elevation[d]	Entire Site Area			Figure A-18			
Storage Coefficient[d]				Dimensionless			
	Zone 1			0.05			
	Zone 2			0.05			
Constant Potentiometric Head[d]				Figure A-13			

[a]Refer to Attachment A.7 for detailed discussion of input parameters and conditions.

[b]Refer to Figure A-22 for location of recharge and permeability zones.

[c]Lake bottom recharge data were input as the inverse of lake bottom resistivity. Aquitard resistivity equals the thickness of a unit divided by its permeability.

[d]Input values are the same for the three recharge rates.

TABLE A-16A

COMPARISON OF OBSERVED AND CALIBRATED VERTICAL MODEL POTENTIOMETRIC HEADS AT SELECTED BORINGS FOR MIDDLE RECHARGE CASE

BORING NUMBER[a]	OBSERVED POTENTIOMETRIC HEAD[b]		CALIBRATED POTENTIOMETRIC HEAD[c]		DIFFERENCE BETWEEN POTENTIOMETRIC HEADS	
	m	ft	m	ft	m	ft
G40-Y22	480.61	1576.8	480.49	1576.5	+0.12	+0.3
G41-E22	484.65	1590.0	484.03	1588.0	+0.62	+2.0
G41-E19A	484.96	1591.1	484.62	1589.9	+0.34	+1.2
EX-13AL	485.46	1592.7	485.33	1592.3	+0.13	+0.4
EX-13BL	485.51	1592.9	485.33	1592.3	+0.18	+0.6
EX-13BU	485.50	1592.8	485.35	1592.3	+0.15	+0.5
EX-13CL	485.50	1592.8	485.38	1592.4	+0.12	+0.4
EX-13DL	485.58	1593.1	485.38	1592.4	+0.20	+0.7
EX-12AU	485.84	1593.9	485.55	1593.0	+0.29	+0.9
EX-12BL	485.87	1594.0	486.57	1593.1	+0.30	+0.9
EX-12BU	485.95	1594.3	485.60	1593.2	+0.35	+1.1
G41-K13	485.76	1593.7	484.62	1589.9	+1.14	+3.8
EX-8AL	482.98	1584.6	482.56	1583.2	+0.42	+1.4
EX-8AU	482.44	1582.8	482.56	1583.2	-0.12	-0.4
EX-8BL	481.48	1579.6	482.52	1583.1	-1.04	-3.5
EX-8BU	481.48	1579.6	482.13	1581.8	-0.65	-2.2
WP-7L	481.54	1597.8	482.29	1582.3	-0.75	-2.5
WP-7U	481.17	1578.6	482.28	1582.3	-1.11	-3.7
Mean of the differences					0.03	0.1
Root mean square of difference[d]					0.56	1.8

[a]Refer to Figure A-8 for boring locations.

[b]Measured potentiometric heads, April 1984, STS Consultants, Ltd. (1984a).

[c]Potentiometric heads from calibrated vertical model for Middle Recharge rate.

[d]Root mean square value is defined by $RMS = (\Sigma x_i^2/n)^{0.5}$ where x_i are the head differences and n = 18.

TABLE A-16B

COMPARISON OF OBSERVED AND CALCULATED POTENTIOMETRIC HEADS
AT SELECTED BORINGS FOR CALIBRATION RUNS OF VERTICAL MODEL

WELL	DIFFERENCE BETWEEN CALCULATED AND OBSERVED POTENTIOMETRIC HEADS (Feet)						
	RUN NO. 1	RUN NO. 2	RUN NO. 3	RUN NO. 4(a)	RUN NO. 5(c)	RUN NO. 6	RUN NO. 7
G40-Y22	+0.12	+0.16	-0.24	-0.30	-0.12	+0.07	+0.18
G41-E22	+0.61	+0.74	+0.08	-0.05	+0.62	+0.49	+0.72
G41-E19A	+0.34	+0.50	-0.19	-0.34	+0.34	+0.26	+0.42
EX-13AL	+0.12	+0.30	-0.39	-0.58	+0.13	+0.09	+0.18
EX-13BL	+0.17	+0.35	-0.34	-0.53	+0.18	+0.14	+0.23
EX-13BU	+0.14	+0.34	-0.36	-0.55	+0.15	+0.11	+0.20
EX-13CL	+0.12	+0.32	-0.37	-0.56	+0.12	+0.08	+0.18
EX-13DL	+0.19	+0.39	-0.30	-0.49	+0.20	+0.16	+0.25
EX-12AU	+0.28	+0.51	-0.11	-0.35	+0.29	+0.30	+0.32
EX-12BL	+0.29	+0.53	-0.09	-0.33	+0.30	+0.31	+0.33
EX-12BU	+0.35	+0.59	-0.03	-0.27	+0.35	+0.36	+0.38
G41-K13	+1.14	+1.42	+1.00	+0.70	+1.14	+1.17	+1.15
EX-8AL	+0.41	+0.85	+0.76	+0.30	+0.42	+0.44	+0.42
EX-8AU	-0.12	+0.32	+0.22	-0.23	-0.12	-0.10	-0.12
EX-8BL	-1.04	-0.62	-0.70	-1.14	-1.04	-1.02	-1.04
EX-8BU	-0.66	-0.42	-0.49	-0.78	-0.65	-0.64	-0.65
WP-7L	-0.76	-0.50	-0.56	-1.34	-0.75	-0.74	-0.75
WP-7U	-1.11	-0.86	-0.92	-1.70	-1.11	-1.09	-1.11
Average	+0.03	+0.27	-0.17	-0.48	0.03	0.02	0.07
RMS(b)	0.56	0.61	0.49	0.72	0.56	0.55	0.58

(a)Calculated heads at Well EX-6 were approximately 6m high for Run No. 4 for remaining Runs Well Ex-6 lies on a fixed head boundary.

(b)Root mean square value is defined by RMS = $(S\ x_i^2/n)^{0.5}$ where x_i are the head differences and n = 18.

(c)Best calibration based on overall comparison.

TABLE A-17A

SUMMARY OF CALIBRATION RUNS OF VERTICAL MODEL

RUN NO.	HORIZONTAL(a) PERMEABILITY, Kh (m/yr)	RATIO OF HORIZONTAL(a) TO VERTICAL PERMEABILITY Kv/Kh	RECHARGE RATE (in/yr)	DESCRIPTION OF NORTHEAST BOUNDARY
1	3840	1/50	8.5	Constant head = 482.22 at Well EX-6 (Nodes 1082-1089)
2	3840	1/20	8.5	Same as Run 1
3	3456	1/20	8.5	Same as Run 1
4	3456	1/20	8.5	No-flow boundary located at ground water divide
5	3840	1/50	8.5	Specified heads at Well EX-6 varying with depth
6	2800	1/50	6.0	Same as Run 5
7	4900	1/50	11.0	Same as Run 5

(a)Permeability is that of coarse drift, permeability of fine drift equal one-half of coarse drift permeability.

TABLE A-17B

SUMMARY OF INPUT PARAMETERS FOR VERTICAL MODEL CALIBRATION[a]

PARAMETER	ZONE	INPUT VALUES AND UNITS					
		LOW RECHARGE CASE		MIDDLE RECHARGE CASE		HIGH RECHARGE CASE	
		m/s	ft/day	m/s	ft/day	m/s	ft/day
Horizontal Permeability	Coarse Drift	8.9×10^{-5}	25.2	1.2×10^{-4}	34.5	1.6×10^{-4}	44.0
	Fine Drift	4.4×10^{-5}	12.6	6.1×10^{-5}	17.3	7.8×10^{-5}	22.0
	Till	4.0×10^{-6}	1.2	6.0×10^{-6}	1.7	8.0×10^{-6}	2.2
Vertical Permeability	Coarse Drift	1.8×10^{-6}	5.0×10^{-1}	2.4×10^{-6}	6.9×10^{-1}	3.1×10^{-6}	8.8×10^{-1}
	Fine Drift	8.9×10^{-7}	2.5×10^{-1}	1.2×10^{-6}	3.4×10^{-1}	1.6×10^{-6}	4.4×10^{-1}
	Till	4.0×10^{-6}	1.2	6.0×10^{-6}	1.7	8.0×10^{-6}	2.2
Lake Recharge Rate[b]				mm/y	in/y		
	Deep Hole Lake			144	5.7		
Precipitation Recharge Rate		mm/y	in/y	mm/y	in/y	mm/y	in/y
	Entire Section	152	6	216	8.5	279	11
				Dimensionless			
Storage Coefficient[b]	Coarse Drift			0.050			
	Fine Drift			0.050			
	Till			0.054			

[a]Refer to Attachment A.7 for detailed discussion of input parameters and conditions for the vertical models.

[b]Input values are the same for the three recharge cases.

TABLE A-18

ESTIMATED GROUND WATER DISCHARGE FROM SITE AREA
AT YEARS 3 AND 28 FOR LOW RECHARGE CASE

SEGMENT DESCRIPTION	SEGMENT[a]	PRECONSTRUCTION DISCHARGE RATE		PROJECT YEAR 3 DISCHARGE RATE		PROJECT YEAR 3 DIFFERENCE[b]		PROJECT YEAR 28 DISCHARGE RATE		PROJECT YEAR 28 DIFFERENCE[b]	
		m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	m^3/s	cfs
Upper Hemlock Creek	AB	0.018	0.65	0.017	0.60	0.001	0.05	0.011	0.40	0.007	0.25
Lower Hemlock Creek and Swamp Creek Below Hemlock Creek Confluence	BC	0.028	0.98	0.026	0.90	0.002	0.08	0.018	0.64	0.010	0.34
Swamp Creek Above Rice Lake	CD	0.044	1.55	0.040	1.42	0.004	0.13	0.033	1.16	0.011	0.39
Hemlock and Swamp Creeks	ABCD	0.090	3.18	0.083	2.92	0.007	0.26	0.062	2.20	0.028	0.98
Rice and Mole Lakes	DE	0.016	0.55	0.014	0.50	0.002	0.05	0.010	0.36	0.006	0.19
Pickerel Creek, Upstream of Rolling Stone Lake	EF	0.019	0.67	0.018	0.63	0.001	0.04	0.014	0.50	0.005	0.17
Rolling Stone Lake and Lower Portion of Pickerel Creek	FG	0.049	1.72	0.048	1.71	0.001	0.01	0.048	1.68	0.001	0.04
Rolling Stone Lake and Pickerel Creek	EFG	0.068	2.39	0.066	2.34	0.002	0.05	0.062	2.18	0.006	0.21
Pickerel Creek to Ground Hemlock Lake	GA	0.045	1.58	0.044	1.55	0.001	0.03	0.039	1.36	0.006	0.22

[a]Refer to Figure A.2-1 of Attachment A.2 for segment locations.

[b]The difference is calculated by subtracting the specific project year discharge rate from the preconstruction value.

TABLE A-19

ESTIMATED GROUND WATER DISCHARGE FROM SITE AREA
AT YEARS 3 AND 28 FOR MIDDLE RECHARGE CASE

SEGMENT DESCRIPTION	SEGMENT[a]	PRECONSTRUCTION DISCHARGE RATE		PROJECT YEAR 3 DISCHARGE RATE		PROJECT YEAR 3 DIFFERENCE[b]		PROJECT YEAR 28 DISCHARGE RATE		PROJECT YEAR 28 DIFFERENCE[b]	
		m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	m^3/s	cfs
Upper Hemlock Creek	AB	0.026	0.93	0.023	0.82	0.003	0.11	0.014	0.51	0.012	0.42
Lower Hemlock Creek and Swamp Creek Below Hemlock Creek Confluence	BC	0.039	1.39	0.035	1.23	0.004	0.16	0.024	0.86	0.015	0.53
Swamp Creek Above Rice Lake	CD	0.062	2.18	0.055	1.94	0.007	0.24	0.046	1.64	0.016	0.54
Hemlock and Swamp Creeks	ABCD	0.127	4.50	0.113	3.99	0.014	0.51	0.084	3.01	0.043	1.49
Rice and Mole Lakes	DE	0.022	0.78	0.019	0.67	0.003	0.11	0.014	0.52	0.008	0.26
Pickerel Creek, Upstream of Rolling Stone Lake	EF	0.027	0.94	0.024	0.86	0.003	0.08	0.020	0.71	0.007	0.23
Rolling Stone Lake and Lower Portion of Pickerel Creek	FG	0.068	2.40	0.068	2.38	0.000	0.02	0.066	2.34	0.002	0.06
Rolling Stone Lake and Pickerel Creek	EFG	0.095	3.34	0.092	3.24	0.003	0.10	0.860	3.05	0.009	0.29
Pickerel Creek to Ground Hemlock Lake	GA	0.064	2.27	0.062	2.19	0.002	0.08	0.055	1.93	0.009	0.34

[a]Refer to Figure A.2-1 of Attachment A.2 for segment locations.

[b]The difference is calculated by subtracting the specific project year discharge rate from the preconstruction value.

TABLE A-20

ESTIMATED GROUND WATER DISCHARGE FROM SITE AREA
AT YEARS 3 AND 28 FOR HIGH RECHARGE CASE

SEGMENT DESCRIPTION	SEGMENT[a]	PRECONSTRUCTION DISCHARGE RATE		PROJECT YEAR 3 DISCHARGE RATE		PROJECT YEAR 3 DIFFERENCE[b]		PROJECT YEAR 28 DISCHARGE RATE		PROJECT YEAR 28 DIFFERENCE[b]	
		m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	m^3/s	cfs
Upper Hemlock Creek	AB	0.034	1.21	0.029	1.02	0.005	0.19	0.019	0.68	0.015	0.53
Lower Hemlock Creek and Swamp Creek Below Hemlock Creek Confluence	BC	0.048	1.71	0.042	1.47	0.006	0.24	0.031	1.11	0.017	0.60
Swamp Creek Above Rice Lake	CD	0.078	2.76	0.063	2.21	0.015	0.55	0.059	2.07	0.019	0.69
Hemlock and Swamp Creeks	ABCD	0.160	5.68	0.134	4.70	0.026	0.98	0.109	3.86	0.051	1.82
Rice and Mole Lakes	DE	0.028	1.01	0.024	0.84	0.004	0.17	0.019	0.67	0.009	0.34
Pickerel Creek, Upstream of Rolling Stone Lake	EF	0.034	1.22	0.030	1.08	0.004	0.14	0.026	0.92	0.008	0.30
Rolling Stone Lake and Lower Portion of Pickerel Creek	FG	0.087	3.08	0.086	3.05	0.001	0.03	0.085	3.00	0.002	0.08
Rolling Stone Lake and Pickerel Creek	EFG	0.121	4.30	0.116	4.13	0.005	0.17	0.111	3.92	0.010	0.38
Pickerel Creek to Ground Hemlock Lake	GA	0.083	2.94	0.079	2.80	0.004	0.14	0.071	2.50	0.012	0.44

[a]Refer to Figure A.2-1 of Attachment A.2 for segment locations.

[b]The difference is calculated by subtracting the specific project year discharge rate from the preconstruction value.

TABLE A-21

STREAM FLOW RATES - PROJECT YEAR 3 FOR LOW RECHARGE CASE

SEGMENT DESCRIPTION	SEGMENT[a]	REDUCTION OF FLOW RATE[b]		CALCULATED AVERAGE ANNUAL TOTAL FLOW RATE: PRECONSTRUCTION		PROJECT YEAR 3		PERCENT REDUCTION	AVERAGE ANNUAL BASE FLOW RATE: PRECONSTRUCTION		PROJECT YEAR 3		PERCENT REDUCTION
		m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	%	m^3/s	cfs	m^3/s	cfs	%
Upper Hemlock Creek	AB	0.001	0.05	--[c]	--[c]	0.098	3.45	--[c]	0.113	4.0	0.112	3.95	1.3
Lower Hemlock Creek and Swamp Creek Below Hemlock Creek Confluence	BC	0.002	0.08	1.034	36.5	1.032[d]	36.42[d]	0.2[d]	0.652	23.0	0.650[d]	22.92[d]	0.3[d]
Swamp Creek Above Rice Lake	CD	0.004	0.13	1.308	46.2	1.304[d]	46.09[d]	0.3[d]	0.538	19.0	0.534[d]	18.87[d]	0.7[d]
Hemlock and Swamp Creeks	ABCD	0.007	0.26	1.308	46.2	1.301	45.94	0.6	0.538	19.0	0.531	18.74	1.4
Pickerel Creek, Upstream of Rolling Stone Lake	EF	0.001	0.04	--[c]	--[c]	0.070	2.46	--[c]	0.113	4.0	0.112	3.96	1.0
Rolling Stone Lake and Lower Portion of Pickerel Creek	FG	0.001	0.01	0.399	14.1	0.398[d]	14.09[d]	0.1[d]	0.198	7.0	0.197[d]	6.99[d]	0.1[d]
Rolling Stone Lake and Pickerel Creek	EFG	0.002	0.05	0.399	14.1	0.397	14.05	0.4	0.198	7.0	0.196	6.95	0.7

[a]Refer to Figure A.2-1 of Attachment A.2 for segment locations.

[b]Refer to Table A-18. The reduction in stream flow rate is assumed to be only from changes in ground water discharge from the site area.

[c]Average annual total stream flow is not included for the lower portion of Hemlock Creek and Pickerel Creek upstream of Rolling Stone Lake because the method of calculation is not applicable to these small watersheds.

[d]The actual total reduction in this segment will be greater, resulting from reduction in the upstream segment.

TABLE A-22

STREAM FLOW RATES - PROJECT YEAR 28 FOR LOW RECHARGE CASE

SEGMENT DESCRIPTION	SEGMENT[a]	REDUCTION OF FLOW RATE[b]		CALCULATED AVERAGE ANNUAL TOTAL FLOW RATE: PRECONSTRUCTION		CALCULATED AVERAGE ANNUAL TOTAL FLOW RATE: PROJECT YEAR 28		CALCULATED AVERAGE ANNUAL TOTAL FLOW RATE: PERCENT REDUCTION	AVERAGE ANNUAL BASE FLOW RATE: PRECONSTRUCTION		AVERAGE ANNUAL BASE FLOW RATE: PROJECT YEAR 28		AVERAGE ANNUAL BASE FLOW RATE: PERCENT REDUCTION
		m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	%	m^3/s	cfs	m^3/s	cfs	%
Upper Hemlock Creek	AB	0.007	0.25	--[c]	--[c]	0.092	3.25	--[c]	0.113	4.0	0.106	3.75	6.2
Lower Hemlock Creek and Swamp Creek Below Hemlock Creek Confluence	BC	0.010	0.34	1.034	36.5	1.024[d]	36.16[d]	1.0[d]	0.652	23.0	0.642[d]	22.66[d]	1.5[d]
Swamp Creek Above Rice Lake	CD	0.011	0.39	1.308	46.2	1.297[d]	45.81[d]	0.8[d]	0.538	19.0	0.527[d]	18.61[d]	2.0[d]
Hemlock and Swamp Creeks	ABCD	0.028	0.96	1.308	46.2	1.280	45.24	2.1	0.538	19.0	0.510	18.04	5.2
Pickerel Creek, Upstream of Rolling Stone Lake	EF	0.005	0.17	--[c]	--[c]	0.066	2.33	--[c]	0.113	4.0	0.108	3.83	4.2
Rolling Stone Lake and Lower Portion of Pickerel Creek	FG	0.001	0.04	0.399	14.1	0.398[d]	14.06[d]	0.3[d]	0.198	7.0	0.197[d]	6.96[d]	0.6[d]
Rolling Stone Lake and Pickerel Creek	EFG	0.006	0.21	0.399	14.1	0.393	13.89	1.5	0.198	7.0	0.192	6.79	3.0

[a]Refer to Figure A.2-1 of Attachment A.2 for segment locations.

[b]Refer to Table A-18. The reduction in stream flow rate is assumed to be only from changes in ground water discharge from the site area.

[c]Average annual total stream flow is not included for the lower portion of Hemlock Creek and Pickerel Creek upstream of Rolling Stone Lake because the method of calculation is not applicable to these small watersheds.

[d]The actual total reduction in this segment will be greater, resulting from reduction in the upstream segment.

TABLE A-23

STREAM FLOW RATES - PROJECT YEAR 3 FOR MIDDLE RECHARGE CASE

SEGMENT DESCRIPTION	SEGMENT[a]	REDUCTION OF FLOW RATE[b]		CALCULATED AVERAGE ANNUAL TOTAL FLOW RATE: PRECONSTRUCTION		CALCULATED AVERAGE ANNUAL TOTAL FLOW RATE: PROJECT YEAR 3		CALCULATED AVERAGE ANNUAL TOTAL FLOW RATE: PERCENT REDUCTION	AVERAGE ANNUAL BASE FLOW RATE: PRECONSTRUCTION		AVERAGE ANNUAL BASE FLOW RATE: PROJECT YEAR 3		AVERAGE ANNUAL BASE FLOW RATE: PERCENT REDUCTION
		m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	%	m^3/s	cfs	m^3/s	cfs	%
Upper Hemlock Creek	AB	0.003	0.11	--[c]	--[c]	0.096	3.39	--[c]	0.113	4.0	0.110	3.89	2.8
Lower Hemlock Creek and Swamp Creek Below Hemlock Creek Confluence	BC	0.004	0.16	1.034	36.5	1.030[d]	36.34[d]	0.4[d]	0.652	23.0	0.648[d]	22.84[d]	0.7[d]
Swamp Creek Above Rice Lake	CD	0.007	0.24	1.308	46.2	1.301[d]	45.96[d]	0.5[d]	0.538	19.0	0.531[d]	18.76[d]	1.3[d]
Hemlock and Swamp Creeks	ABCD	0.014	0.51	1.308	46.2	1.294	45.69	1.1	0.538	19.0	0.524	18.49	2.7
Pickerel Creek, Upstream of Rolling Stone Lake	EF	0.003	0.08	--[c]	--[c]	0.068	2.42	--[c]	0.113	4.0	0.110	3.92	2.0
Rolling Stone Lake and Lower Portion of Pickerel Creek	FG	0.000	0.02	0.399	14.1	0.399[d]	14.08[d]	0.1[d]	0.198	7.0	0.198[d]	6.98[d]	0.3[d]
Rolling Stone Lake and Pickerel Creek	EFG	0.003	0.10	0.399	14.1	0.396	14.00	0.7	0.198	7.0	0.195	6.90	1.4

[a]Refer to Figure A.2-1 of Attachment A.2 for segment locations.

[b]Refer to Table A-19. The reduction in stream flow rate is assumed to be only from changes in ground water discharge from the site area.

[c]Average annual total stream flow is not included for the lower portion of Hemlock Creek and Pickerel Creek upstream of Rolling Stone Lake because the method of calculation is not applicable to these small watersheds.

[d]The actual total reduction in this segment will be greater, resulting from reduction in the upstream segment.

TABLE A-24

STREAM FLOW RATES - PROJECT YEAR 28 FOR MIDDLE RECHARGE CASE

SEGMENT DESCRIPTION	SEGMENT[a]	REDUCTION OF FLOW RATE[b]		CALCULATED AVERAGE ANNUAL TOTAL FLOW RATE: PRECONSTRUCTION		CALCULATED AVERAGE ANNUAL TOTAL FLOW RATE: PROJECT YEAR 28		CALCULATED AVERAGE ANNUAL TOTAL FLOW RATE: PERCENT REDUCTION	AVERAGE ANNUAL BASE FLOW RATE: PRECONSTRUCTION		AVERAGE ANNUAL BASE FLOW RATE: PROJECT YEAR 28		AVERAGE ANNUAL BASE FLOW RATE: PERCENT REDUCTION
		m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	%	m^3/s	cfs	m^3/s	cfs	%
Upper Hemlock Creek	AB	0.012	0.42	--[c]	--[c]	0.087	3.08	--[c]	0.113	4.0	0.101	3.58	10.5
Lower Hemlock Creek and Swamp Creek Below Hemlock Creek Confluence	BC	0.015	0.53	1.034	36.5	1.019[d]	35.97[d]	1.4[d]	0.652	23.0	0.637[d]	22.47[d]	2.3[d]
Swamp Creek Above Rice Lake	CD	0.016	0.54	1.308	46.2	1.292[d]	45.66[d]	1.2[d]	0.538	19.0	0.522[d]	18.46[d]	2.8[d]
Hemlock and Swamp Creeks	ABCD	0.043	1.49	1.308	46.2	1.265	44.71	3.2	0.538	19.0	0.495	17.51	7.8
Pickerel Creek, Upstream of Rolling Stone Lake	EF	0.007	0.23	--[c]	--[c]	0.064	2.27	--[c]	0.113	4.0	0.106	3.77	5.8
Rolling Stone Lake and Lower Portion of Pickerel Creek	FG	0.002	0.06	0.399	14.1	0.397[d]	14.04[d]	0.4[d]	0.198	7.0	0.196[d]	6.94[d]	0.9[d]
Rolling Stone Lake and Pickerel Creek	EFG	0.009	0.29	0.399	14.1	0.390	13.81	2.1	0.198	7.0	0.189	6.71	4.1

[a]Refer to Figure A.2-1 of Attachment A.2 for segment locations.

[b]Refer to Table A-19. The reduction in stream flow rate is assumed to be only from changes in ground water discharge from the site area.

[c]Average annual total stream flow is not included for the lower portion of Hemlock Creek and Pickerel Creek upstream of Rolling Stone Lake because the method of calculation is not applicable to these small watersheds.

[d]The actual total reduction in this segment will be greater, resulting from reduction in the upstream segment.

TABLE A-25

STREAM FLOW RATES - PROJECT YEAR 3 FOR HIGH RECHARGE CASE

SEGMENT DESCRIPTION	SEGMENT[a]	REDUCTION OF FLOW RATE[b]		CALCULATED AVERAGE ANNUAL TOTAL FLOW RATE: PRECONSTRUCTION		PROJECT YEAR 3		PERCENT REDUCTION	AVERAGE ANNUAL BASE FLOW RATE: PRECONSTRUCTION		PROJECT YEAR 3		PERCENT REDUCTION
		m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	%	m^3/s	cfs	m^3/s	cfs	%
Upper Hemlock Creek	AB	0.005	0.19	--[c]	--[c]	0.094	3.31	--[c]	0.113	4.0	0.108	3.81	4.8
Lower Hemlock Creek and Swamp Creek Below Hemlock Creek Confluence	BC	0.006	0.24	1.034	36.5	1.028[d]	36.26[d]	0.6[d]	0.652	23.0	0.646[d]	22.76[d]	1.0[d]
Swamp Creek Above Rice Lake	CD	0.015	0.55	1.308	46.2	1.293[d]	45.65[d]	1.2[d]	0.538	19.0	0.523[d]	18.45[d]	2.9[d]
Hemlock and Swamp Creeks	ABCD	0.026	0.98	1.308	46.2	1.282	45.22	2.1	0.538	19.0	0.512	18.02	5.2
Pickerel Creek, Upstream of Rolling Stone Lake	EF	0.004	0.14	--[c]	--[c]	0.067	2.36	--[c]	0.113	4.0	0.109	3.86	3.5
Rolling Stone Lake and Lower Portion of Pickerel Creek	FG	0.001	0.03	0.399	14.1	0.398[d]	14.07[d]	0.2[d]	0.198	7.0	0.197[d]	6.97[d]	0.4[d]
Rolling Stone Lake and Pickerel Creek	EFG	0.005	0.17	0.399	14.1	0.394	13.93	1.2	0.198	7.0	0.193	6.83	2.4

[a]Refer to Figure A.2-1 of Attachment A.2 for segment locations.

[b]Refer to Table A-20. The reduction in stream flow rate is assumed to be only from changes in ground water discharge from the site area.

[c]Average annual total stream flow is not included for the lower portion of Hemlock Creek and Pickerel Creek upstream of Rolling Stone Lake because the method of calculation is not applicable to these small watersheds.

[d]The actual total reduction in this segment will be greater, resulting from reduction in the upstream segment.

TABLE A-26

STREAM FLOW RATES - PROJECT YEAR 28 FOR HIGH RECHARGE CASE

SEGMENT DESCRIPTION	SEGMENT[a]	REDUCTION OF FLOW RATE[b]		CALCULATED AVERAGE ANNUAL TOTAL FLOW RATE: PRECONSTRUCTION		CALCULATED AVERAGE ANNUAL TOTAL FLOW RATE: PROJECT YEAR 28		CALCULATED AVERAGE ANNUAL TOTAL FLOW RATE: PERCENT REDUCTION	AVERAGE ANNUAL BASE FLOW RATE: PRECONSTRUCTION		AVERAGE ANNUAL BASE FLOW RATE: PROJECT YEAR 28		AVERAGE ANNUAL BASE FLOW RATE: PERCENT REDUCTION
		m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	%	m^3/s	cfs	m^3/s	cfs	%
Upper Hemlock Creek	AB	0.015	0.53	--[c]	--[c]	0.084	2.97	--[c]	0.113	4.0	0.098	3.47	13.2
Lower Hemlock Creek and Swamp Creek Below Hemlock Creek Confluence	BC	0.017	0.60	1.034	36.5	1.017[d]	35.90[d]	1.6[d]	0.652	23.0	0.635[d]	22.40[d]	2.6[d]
Swamp Creek Above Rice Lake	CD	0.019	0.69	1.308	46.2	1.289[d]	45.51[d]	1.5[d]	0.538	19.0	0.519[d]	18.31[d]	3.6[d]
Hemlock and Swamp Creeks	ABCD	0.051	1.82	1.308	46.2	1.257	44.38	3.9	0.538	19.0	0.487	17.18	9.6
Pickerel Creek, Upstream of Rolling Stone Lake	EF	0.008	0.30	--[c]	--[c]	0.063	2.20	--[c]	0.113	4.0	0.105	3.70	7.5
Rolling Stone Lake and Lower Portion of Pickerel Creek	FG	0.002	0.08	0.399	14.1	0.397[d]	14.02[d]	0.6[d]	0.198	7.0	0.196[d]	6.92[d]	1.1[d]
Rolling Stone Lake and Pickerel Creek	EFG	0.010	0.38	0.399	14.1	0.389	13.72	2.7	0.198	7.0	0.188	6.62	5.4

[a]Refer to Figure A.2-1 of Attachment A.2 for segment locations.

[b]Refer to Table A-20. The reduction in stream flow rate is assumed to be only from changes in ground water discharge from the site area.

[c]Average annual total stream flow is not included for the lower portion of Hemlock Creek and Pickerel Creek upstream of Rolling Stone Lake because the method of calculation is not applicable to these small watersheds.

[d]The actual total reduction in this segment will be greater, resulting from reduction in the upstream segment.

TABLE A-27

PREDICTED RECHARGE RATE AND LEVEL FOR LAKES WITHIN SITE AREA[a]

LAKE	PRECONSTRUCTION PHASE RECHARGE RATE[b] (per unit area)		OPERATION PHASE RECHARGE RATE[c] (per unit area)		DIFFERENCE		ESTIMATED AVERAGE LAKE LEVEL DECLINE[d]	
	mm/y	in/y	mm/y	in/y	mm/y	in/y	m	ft
Deep Hole	203	8.00	274	10.80	71	2.80	0.01	0.04
Duck	541	21.30	585	23.02	44	1.72	0.06	0.21
Skunk	1011	39.80	1611	63.44	600	23.64	0.18	0.58
Little Sand	203	8.00	573	22.54	370	14.54	0.07	0.23
Oak[e]	231	9.10	232	9.12	1	0.02	0.00	0.00

[a]Lake recharge rates and levels are maximum seepage values for the Year 28 potentiometric surface; procedures presented in Attachment A.10.

[b]From Dames and Moore, 1985.

[c]Recharge rates presented are calculated assuming uniform lake bed sediment permeabilities for each lake; see Attachment A.10.

[d]Average decline is the mean value of the monthly differences between computed preconstruction and operation phase lake levels (see Attachment A.10).

[e]Oak Lake is a perched lake and is not in direct contact with the potentiometric surface; differences in seepage rates result solely from different calculation methods.

TABLE A-28

Q7,2, AND Q7,10 STREAM BASE FLOW RATES - PROJECT YEAR 3 FOR LOW RECHARGE CASE

SEGMENT DESCRIPTION	SEGMENT[a]	REDUCTION OF FLOW RATE[b]		BASE FLOW RATE, Q7,2[c] PRECONSTRUCTION		BASE FLOW RATE, Q7,2[c] PROJECT YEAR 3		BASE FLOW RATE, Q7,2[c] PERCENT REDUCTION	BASE FLOW RATE, Q7,10[c] PRECONSTRUCTION		BASE FLOW RATE, Q7,10[c] PROJECT YEAR 3		BASE FLOW RATE, Q7,10[c] PERCENT REDUCTION
		m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	%	m^3/s	cfs	m^3/s	cfs	%
Upper Hemlock Creek	AB	0.001	0.05	0.057	2.0	0.056	1.95	2.5	0.040	1.4	0.039	1.35	3.6
Lower Hemlock Creek and Swamp Creek Below Hemlock Creek Confluence	BC	0.002	0.08	0.190	6.7	0.188[d]	6.62[d]	1.2[d]	0.133	4.7	0.131[d]	4.62[d]	1.7[d]
Swamp Creek Above Rice Lake	CD	0.004	0.13	0.311	11.0	0.307[d]	10.87[d]	1.2[d]	0.226	8.0	0.222[d]	7.87[d]	1.6[d]
Hemlock and Swamp Creeks	ABCD	0.007	0.26	0.311	11.0	0.304	10.74	2.4	0.226	8.0	0.219	7.74	3.3
Pickerel Creek, Upstream of Rolling Stone Lake	EF	0.001	0.04	0.017	0.6	0.016	0.56	6.7	0.011	0.4	0.010	0.36	10.0
Rolling Stone Lake and Lower Portion of Pickerel Creek	FG	0.001	0.01	0.184	6.5	0.183[d]	6.49[d]	0.2[d]	0.133	4.7	0.132[d]	4.69	0.2[d]
Rolling Stone Lake and Pickerel Creek	EFG	0.002	0.05	0.184	6.5	0.182	6.45	0.8	0.133	4.7	0.131	4.65	1.1

[a]Refer to Figure A.2-1 of Attachment A.2 for segment locations.

[b]Refer to Table A-18. The reduction in stream flow rate is assumed to be only from changes in ground water discharge from the site area.

[c]Flow rates Q7,2 and Q7,10 are average low flows over a 7-day period and having a 2- and 10-year recurrence period, respectively (USGS, 1984).

[d]The actual total reduction in this segment will be greater, resulting from reduction in the upstream segment.

TABLE A-29

Q7,2, AND Q7,10 STREAM BASE FLOW RATES - PROJECT YEAR 28 FOR LOW RECHARGE CASE

SEGMENT DESCRIPTION	SEGMENT[a]	REDUCTION OF FLOW RATE[b]		BASE FLOW RATE, Q7,2[c] PRECONSTRUCTION		BASE FLOW RATE, Q7,2[c] PROJECT YEAR 28		BASE FLOW RATE, Q7,2[c] PERCENT REDUCTION	BASE FLOW RATE, Q7,10[c] PRECONSTRUCTION		BASE FLOW RATE, Q7,10[c] PROJECT YEAR 28		BASE FLOW RATE, Q7,10[c] PERCENT REDUCTION
		m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	%	m^3/s	cfs	m^3/s	cfs	%
Upper Hemlock Creek	AB	0.007	0.25	0.057	2.0	0.050	1.75	12.5	0.040	1.4	0.033	1.15	17.9
Lower Hemlock Creek and Swamp Creek Below Hemlock Creek Confluence	BC	0.010	0.34	0.190	6.7	0.180[d]	6.36[d]	5.1[d]	0.133	4.7	0.123[d]	4.36[d]	7.2[d]
Swamp Creek Above Rice Lake	CD	0.011	0.39	0.311	11.0	0.300[d]	10.61[d]	3.5[d]	0.226	8.0	0.215[d]	7.61[d]	4.9[d]
Hemlock and Swamp Creeks	ABCD	0.028	0.98	0.311	11.0	0.283	10.02	8.9	0.226	8.0	0.198	7.02	12.3
Pickerel Creek, Upstream of Rolling Stone Lake	EF	0.005	0.17	0.017	0.6	0.012	0.43	28.3	0.011	0.4	0.006	0.23	42.5
Rolling Stone Lake and Lower Portion of Pickerel Creek	FG	0.001	0.04	0.184	6.5	0.183[d]	6.46[d]	0.6[d]	0.133	4.7	0.132[d]	4.66[d]	0.9[d]
Rolling Stone Lake and Pickerel Creek	EFG	0.006	0.21	0.184	6.5	0.178	6.29	3.2	0.133	4.7	0.127	4.49	4.5

[a]Refer to Figure A.2-1 of Attachment A.2 for segment locations.

[b]Refer to Table A-18. The reduction in stream flow rate is assumed to be only from changes in ground water discharge from the site area.

[c]Flow rates Q7,2 and Q7,10 are average low flows over a 7-day period and having a 2- and 10-year recurrence period, respectively (USGS, 1984).

[d]The actual total reduction in this segment will be greater, resulting from reduction in the upstream segment.

TABLE A-30

Q7,2, AND Q7,10 STREAM BASE FLOW RATES - PROJECT YEAR 3 FOR MIDDLE RECHARGE CASE

SEGMENT DESCRIPTION	SEGMENT[a]	REDUCTION OF FLOW RATE[b]		BASE FLOW RATE, Q7,2[c] PRECONSTRUCTION		BASE FLOW RATE, Q7,2[c] PROJECT YEAR 3		BASE FLOW RATE, Q7,2[c] PERCENT REDUCTION	BASE FLOW RATE, Q7,10[c] PRECONSTRUCTION		BASE FLOW RATE, Q7,10[c] PROJECT YEAR 3		BASE FLOW RATE, Q7,10[c] PERCENT REDUCTION
		m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	%	m^3/s	cfs	m^3/s	cfs	%
Upper Hemlock Creek	AB	0.003	0.11	0.057	2.0	0.054	1.89	5.5	0.040	1.4	0.037	1.29	7.9
Lower Hemlock Creek and Swamp Creek Below Hemlock Creek Confluence	BC	0.004	0.16	0.190	6.7	0.186[d]	6.54[d]	2.4[d]	0.133	4.7	0.129[d]	4.54[d]	3.4[d]
Swamp Creek Above Rice Lake	CD	0.007	0.24	0.311	11.0	0.304[d]	10.76[d]	2.2[d]	0.226	8.0	0.219[d]	7.76[d]	3.0[d]
Hemlock and Swamp Creeks	ABCD	0.014	0.51	0.311	11.0	0.297	10.49	4.6	0.226	8.0	0.212	7.49	6.4
Pickerel Creek, Upstream of Rolling Stone Lake	EF	0.003	0.08	0.017	0.6	0.014	0.52	13.3	0.011	0.4	0.008	0.32	20.0
Rolling Stone Lake and Lower Portion of Pickerel Creek	FG	0.0005	0.02	0.184	6.5	0.1835[d]	6.48[d]	0.3[d]	0.133	4.7	0.1325[d]	4.68[d]	0.4[d]
Rolling Stone Lake and Pickerel Creek	EFG	0.003	0.10	0.184	6.5	0.181	6.40	1.5	0.133	4.7	0.130	4.60	2.1

[a]Refer to Figure A.2-1 of Attachment A.2 for segment locations.

[b]Refer to Table A-19. The reduction in stream flow rate is assumed to be only from changes in ground water discharge from the site area.

[c]Flow rates Q7,2 and Q7,10 are average low flows over a 7-day period and having a 2- and 10-year recurrence period, respectively (USGS, 1984).

[d]The actual total reduction in this segment will be greater, resulting from reduction in the upstream segment.

TABLE A-31

Q7,2, AND Q7,10 STREAM BASE FLOW RATES - PROJECT YEAR 28 FOR MIDDLE RECHARGE CASE

SEGMENT DESCRIPTION	SEGMENT[a]	REDUCTION OF FLOW RATE[b]		BASE FLOW RATE, Q7,2[c]					BASE FLOW RATE, Q7,10[c]				
				PRECONSTRUCTION		PROJECT YEAR 28		PERCENT REDUCTION	PRECONSTRUCTION		PROJECT YEAR 28		PERCENT REDUCTION
		m^3/s	cfs	m^3/s	cfs	m^3/s	cfs	%	m^3/s	cfs	m^3/s	cfs	%
Upper Hemlock Creek	AB	0.012	0.42	0.057	2.0	0.045	1.58	21.0	0.040	1.4	0.028	0.98	30.0
Lower Hemlock Creek and Swamp Creek Below Hemlock Creek Confluence	BC	0.015	0.53	0.190	6.7	0.175[d]	6.17[d]	7.9[d]	0.133	4.7	0.078[d]	2.77	16.1
Swamp Creek Above Rice Lake	CD	0.016	0.54	0.311	11.0	0.295[d]	10.46[d]	4.9[d]	0.226	8.0	0.077	2.76	16.4
Hemlock and Swamp Creeks	ABCD	0.043	1.49	0.311	11.0	0.268	9.51	13.5	0.226	8.0	0.183	6.51	18.6
Pickerel Creek, Upstream of Rolling Stone Lake	EF	0.007	0.23	0.017	0.6	0.010	0.37	38.3	0.011	0.4	0.004	0.17	57.5
Rolling Stone Lake and Lower Portion of Pickerel Creek	FG	0.002	0.06	0.184	6.5	0.182[d]	6.44[d]	0.9[d]	0.133	4.7	0.120	4.24	1.4
Rolling Stone Lake and Pickerel Creek	EFG	0.009	0.29	0.184	6.5	0.175	6.21	4.5	0.133	4.7	0.124	4.41	6.1

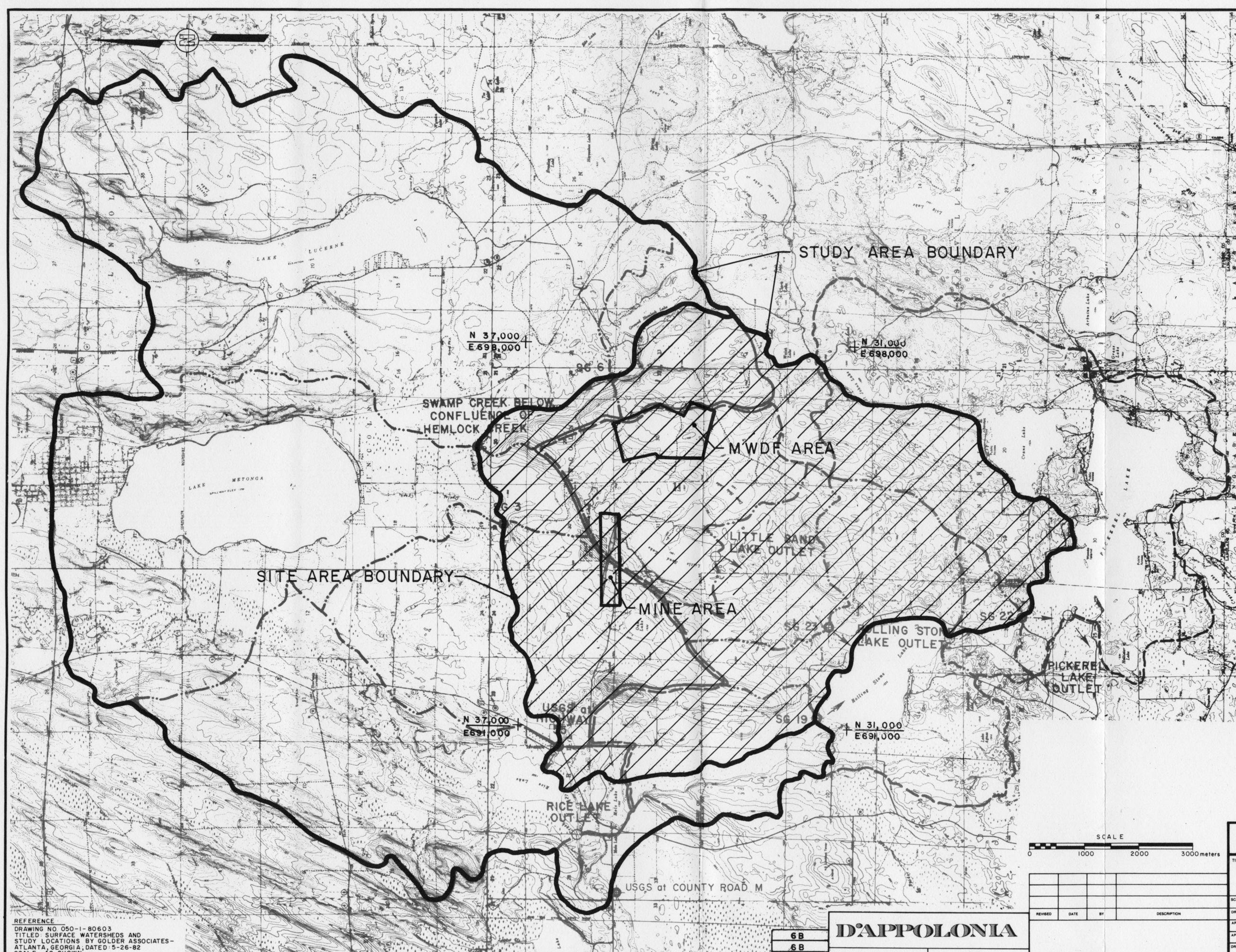
[a]Refer to Figure A.2-1 of Attachment A.2 for segment locations.

[b]Refer to Table A-19. The reduction in stream flow rate is assumed to be only from changes in ground water discharge from the site area.

[c]Flow rates Q7,2 and Q7,10 are average low flows over a 7-day period and having a 2- and 10-year recurrence period, respectively (USGS, 1984).

[d]The actual total reduction in this segment will be greater, resulting from reduction in the upstream segment.

FIGURES



REFERENCE
DRAWING NO. 050-1-80603
TITLED SURFACE WATERSHEDS AND
STUDY LOCATIONS BY GOLDER ASSOCIATES-
ATLANTA, GEORGIA, DATED 5-26-82
SCALE: AS SHOWN

FIGURE A-1

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
LOCATION OF SITE AND STUDY AREA BOUNDARIES

SCALE AS SHOWN	STATE	COUNTY

DRAWN BY J. LOGRECO	DATE 9-5-84	CHECKED BY MMR	DATE 12/10/85
APPROVED BY	DATE	APPROVED SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO.		SHEET ___ OF ___	REVISION NO.

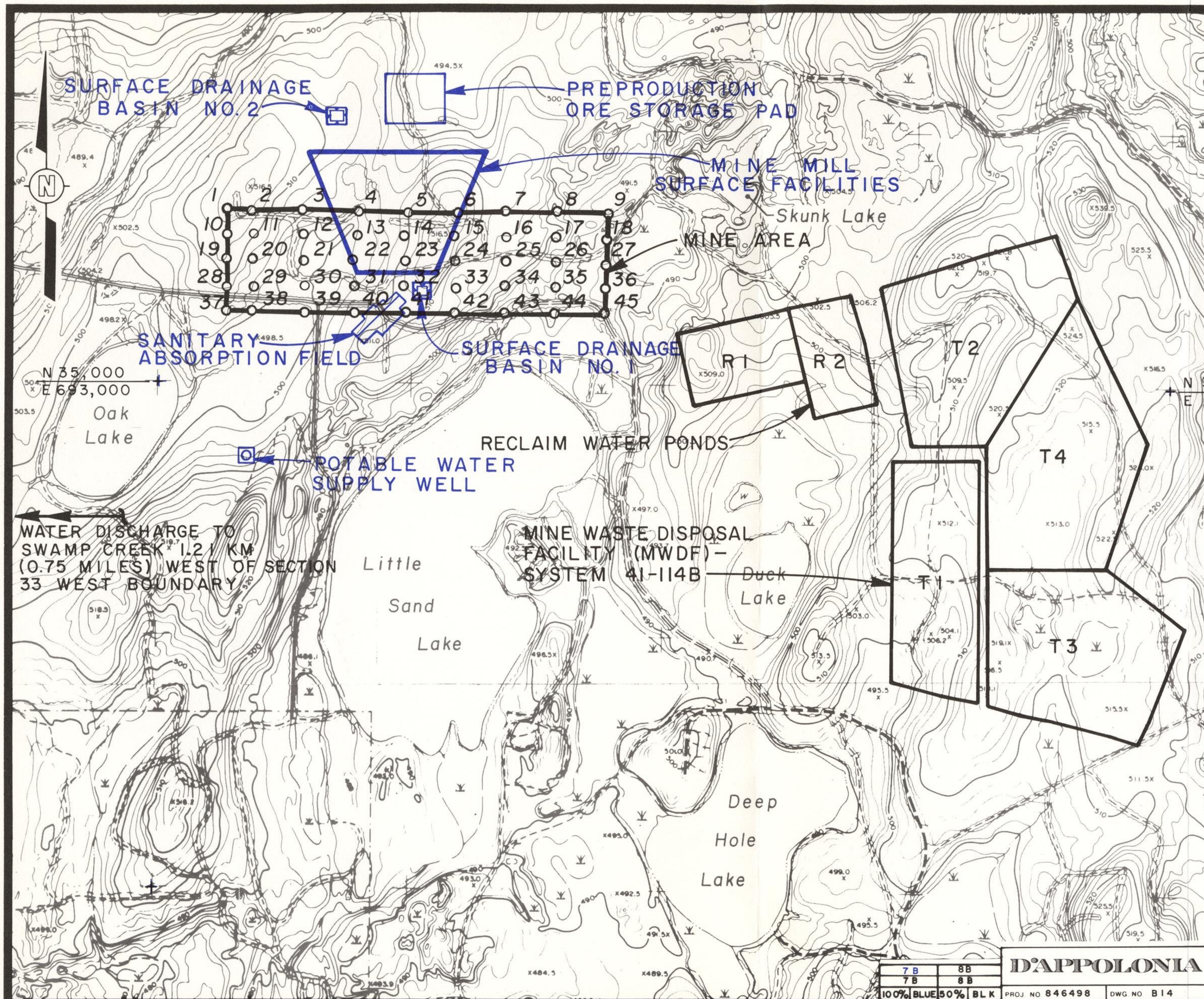
REVISED	DATE	BY	DESCRIPTION

D'APPOLONIA

6B
6B
50% BLK

PROJ. NO 846498 DWG. NO. B7

GSB 5/1961



LEGEND

O^{45} POINTS FOR MINE INFLOW CONSISTENT WITH TAP ASSOCIATES (1984) GROUND WATER INFLOW MODEL

NOTES:

1. REFER TO TABLE A-2 FOR MINE INFLOW RATE DISTRIBUTION.
2. SEE ATTACHMENT A.7 FOR COORDINATES AND NODE NUMBERS

250 0 250 500 750
SCALE IN METERS

FIGURE A-2

EXXON MINERALS COMPANY
CRANDON PROJECT

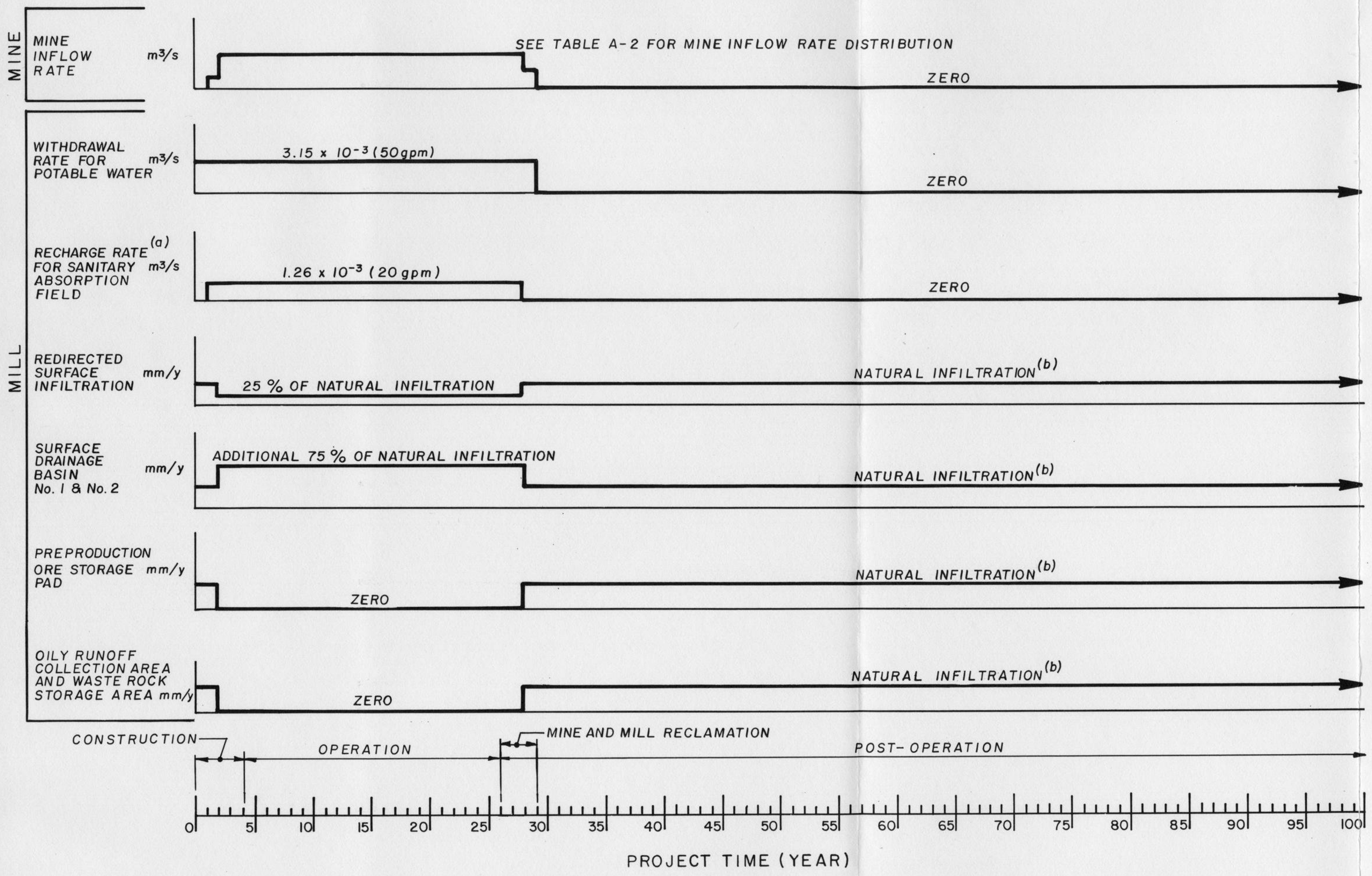
TITLE
LOCATION OF PROJECT FACILITIES AND MINE AREA

SCALE AS SHOWN	STATE		COUNTY		
DRAWN BY J. LOGRECO	DATE 9-24-84	CHECKED BY MMR		DATE 12/10/85	
APPROVED BY	DATE	APPROVED BY SHD		DATE 12/10/85	
APPROVED BY	DATE	EXXON		DATE	
DRAWING NO			SHEET ___ OF ___	REVISION NO.	

7B	8B
7B	8B
100% BLUE	50% BLK

D'APPOLONIA

PROJ. NO 846498 DWG NO B14



NOTES:

(a) PRECIPITATION RECHARGE ALSO OCCURS IN SANITARY ABSORPTION FIELD.

(b) MINE/MILL SURFACE FACILITIES REMOVED, INFILTRATION RESTORED

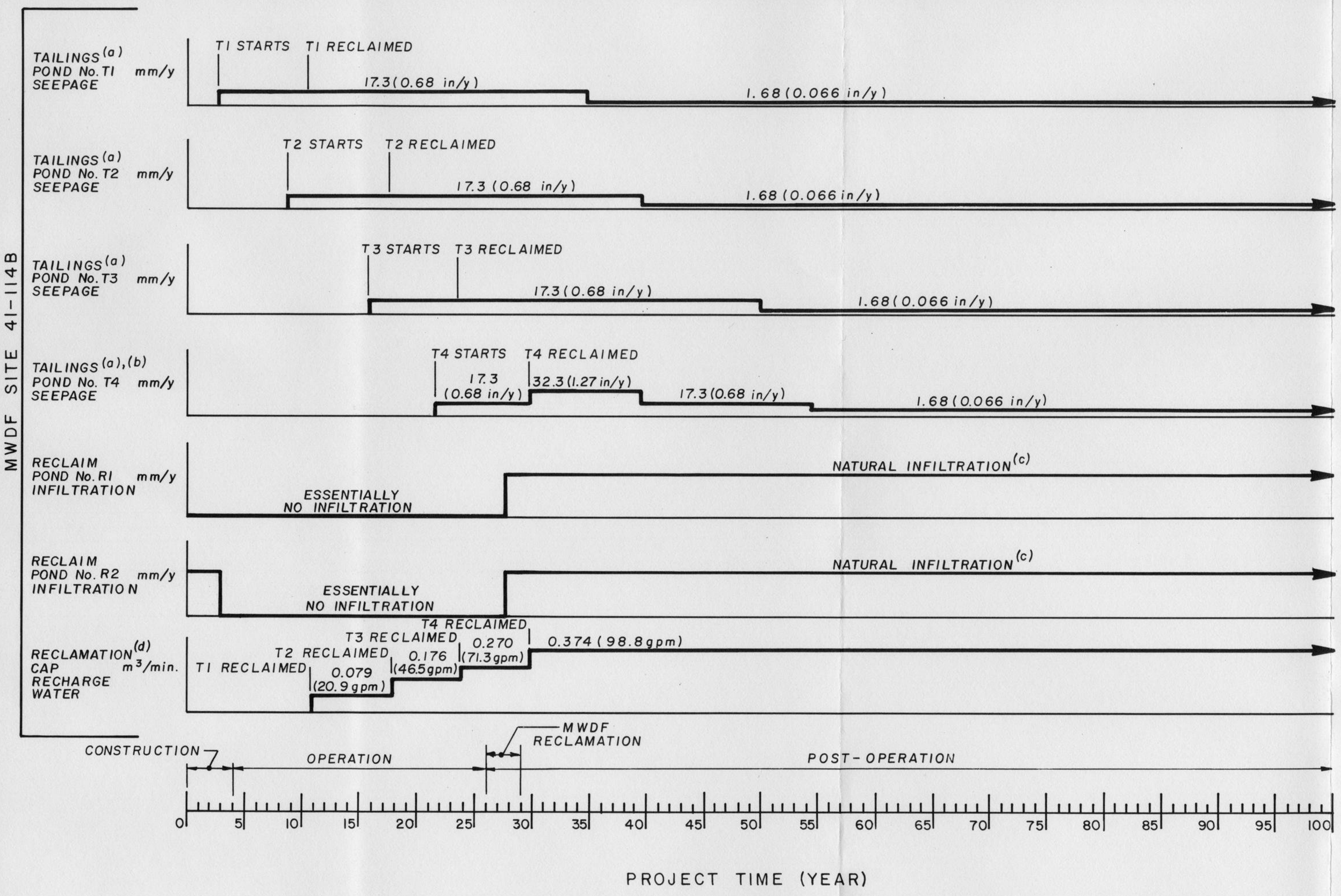
FIGURE A-3a

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
MINE AND MILL FACILITIES SCHEDULE AND HYDROLOGIC DATA

SCALE AS SHOWN	STATE	COUNTY	
DRAWN BY RW	DATE 8-10-84	CHECKED BY MMR	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET ___ OF ___	REVISION NO.

D'APPOLONIA
PROJ NO 846498 DWG NO B2



NOTES:

(a) REFER TO TABLE A-3 FOR DISTRIBUTION OF TAILINGS POND SEEPAGE RATES.

(b) SCHEDULE FOR T4 ASSUMES FULL CAPACITY OF POND IS UTILIZED.

(c) RECLAIM PONDS REMOVED INFILTRATION RESTORED.

(d) RECLAMATION CAP RECHARGE WATER IS DISTRIBUTED ALONG THE MWDF PERIMETER.

FIGURE A-3b

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: MWDF SCHEDULE AND HYDROLOGIC DATA

SCALE: AS SHOWN	STATE	COUNTY	
DRAWN BY: RW	DATE: 8-10-84	CHECKED BY: MMR	DATE: 12/10/85
APPROVED BY	DATE	APPROVED BY: SHD	DATE: 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET ___ OF ___	REVISION NO.

D'APPOLONIA
PROJ. NO. 846498 DWG. NO. B1

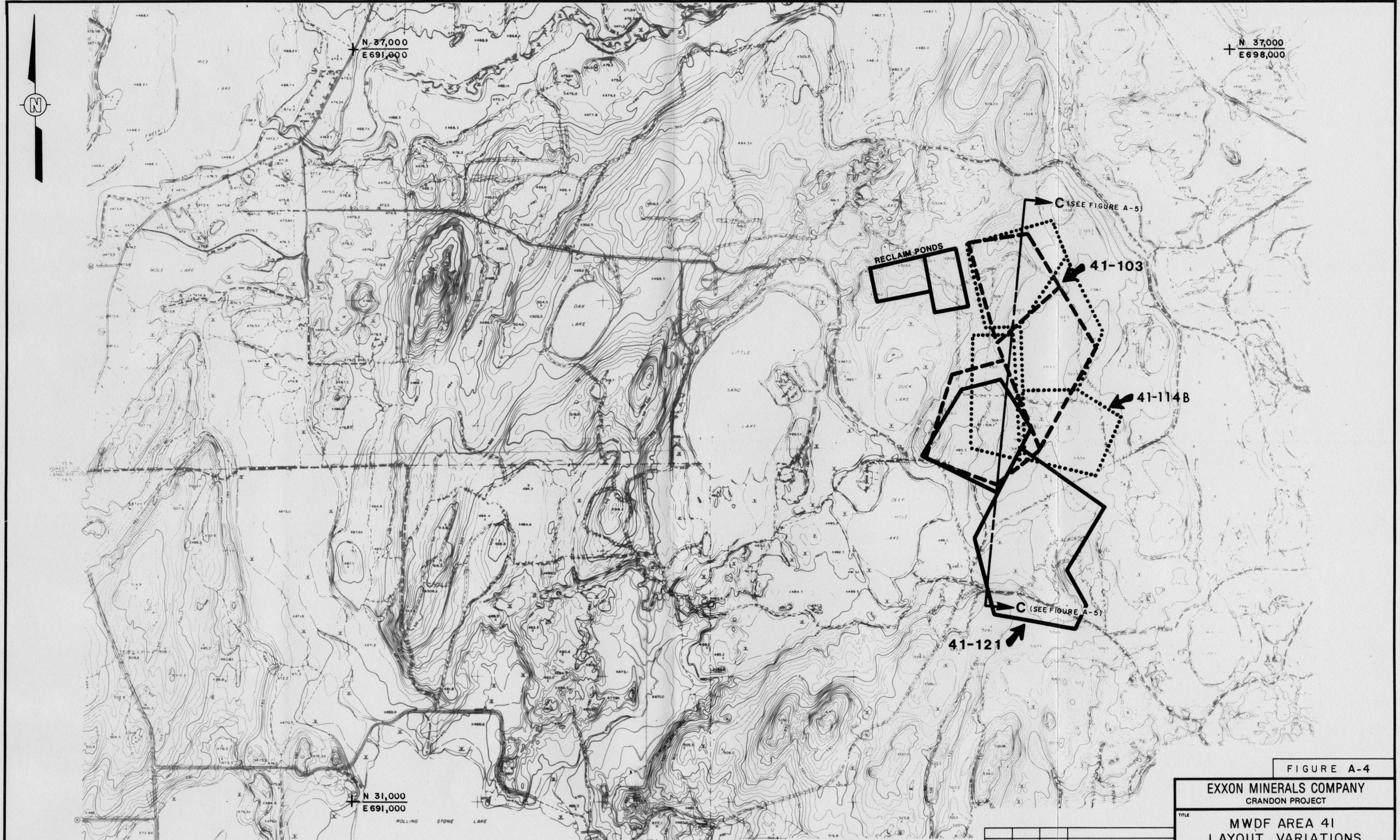


FIGURE A-4

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
MWDF AREA 41
LAYOUT VARIATIONS

SCALE AS SHOWN	STATE		COUNTY
DRAWN BY JJL	DATE 9-25-84	CHECKED BY MMR	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO.		SHEET ___ OF ___	REVISION NO.

REVISED	DATE	BY	DESCRIPTION

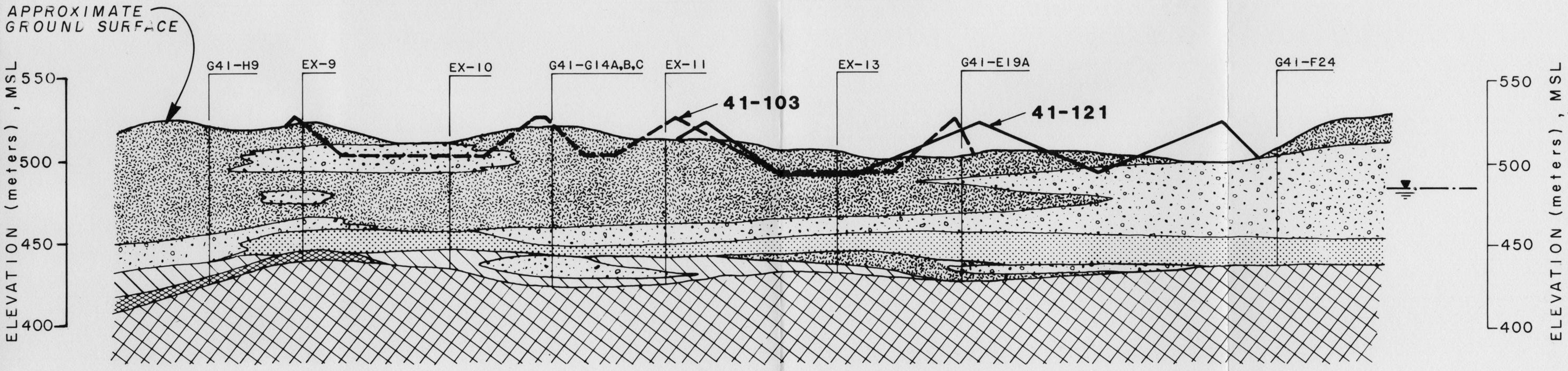
D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B15

27B
27B
50% BLK

REFERENCE:
EXXON MINERALS COMPANY, AUGUST 1984,
"MWDF AREA 41 LAYOUT VARIATIONS"
CRANDON PROJECT, SCALE AS SHOWN.

GSB 5/1981



SECTION C-C

LEGEND

- LACUSTRINE
- TILL
- COARSE GRAINED STRATIFIED DRIFT
- FINE GRAINED STRATIFIED DRIFT
- BASAL TILL
- BEDROCK

NOTES:

1. REFER TO FIGURE A-4 FOR PLAN LOCATION OF SECTION C-C. REFER TO FIGURE A-8 FOR BORING LOCATIONS.
2. SECTION C-C STRATIGRAPHY SIMILAR TO SECTION K-K STRATIGRAPHY FROM STS CONSULTANTS LTD. REPORT, "HYDROLOGIC STUDY UPDATE", JUNE 1984, DWG. 12959-5

0 250 500 750
SCALE IN METERS
VERTICAL SCALE EXAGGERATED 5x

REFERENCE:
EXXON MINERALS COMPANY, AUGUST 1984. "VERTICAL SECTION OF MWDF AREA 41 LAYOUT VARIATIONS", CRANDON PROJECT, SCALE AS SHOWN.

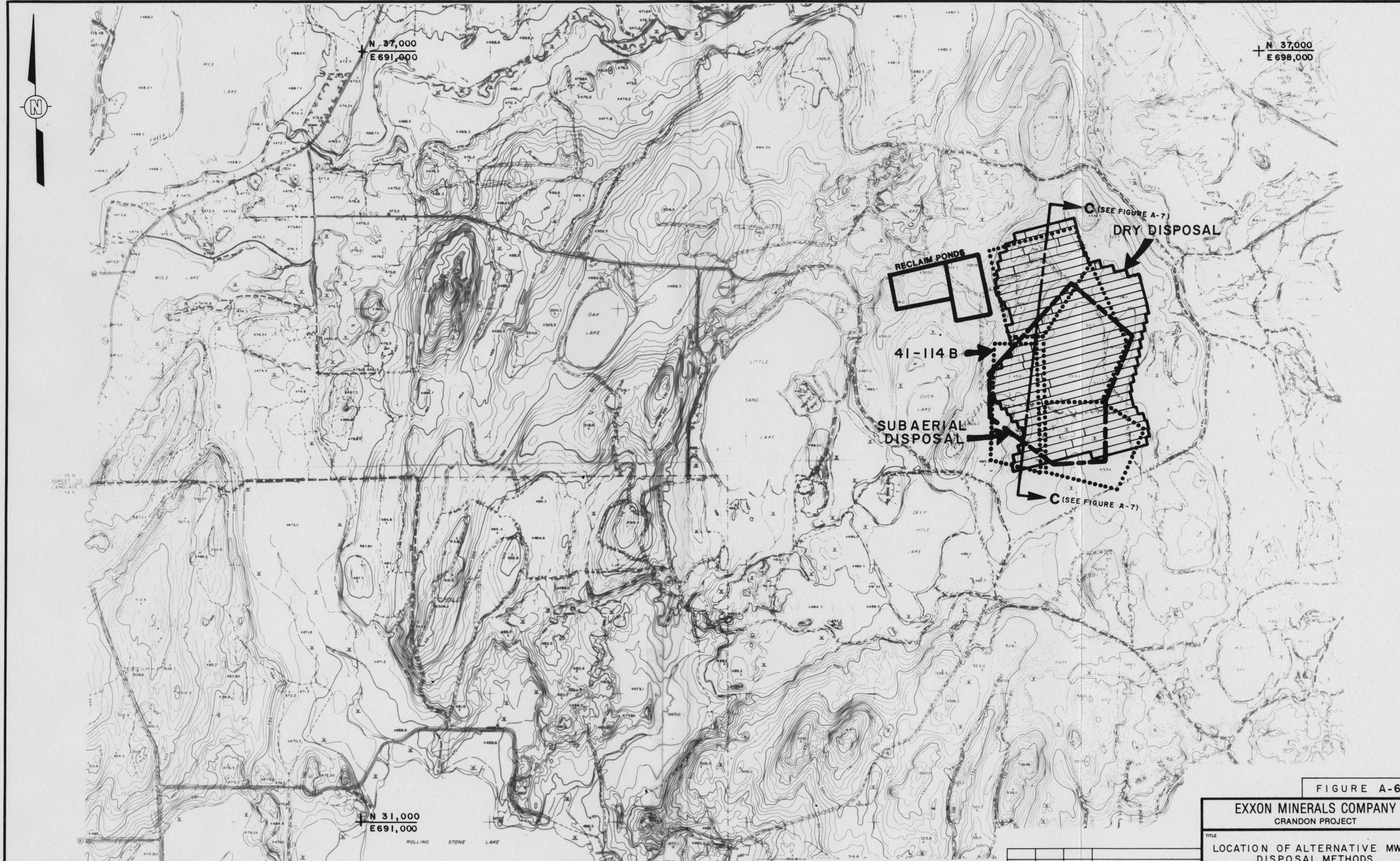
D'APPOLONIA
PROJ. NO. 846498 DWG. NO. B16

FIGURE A-5

EXXON MINERALS COMPANY
CRANDON PROJECT

VERTICAL SECTION OF MWDF AREA 41 LAYOUT VARIATIONS

SCALE SHOWN	STATE WISCONSIN		COUNTY FOREST		
DRAWN BY DR SPRINGBORN	DATE 9/84	CHECKED BY MMR		DATE 12/10/85	
APPROVED BY	DATE	APPROVED BY SHD		DATE 12/10/85	
APPROVED BY	DATE	EXXON		DATE	
DRAWING NO			SHEET		REVISION NO



REFERENCE:
EXXON MINERALS COMPANY, AUGUST 1984,
"LOCATION OF ALTERNATIVE MWDF
DISPOSAL METHODS", CRANDON PROJECT
SCALE AS SHOWN.

FIGURE A-6

EXXON MINERALS COMPANY
CRANDON PROJECT

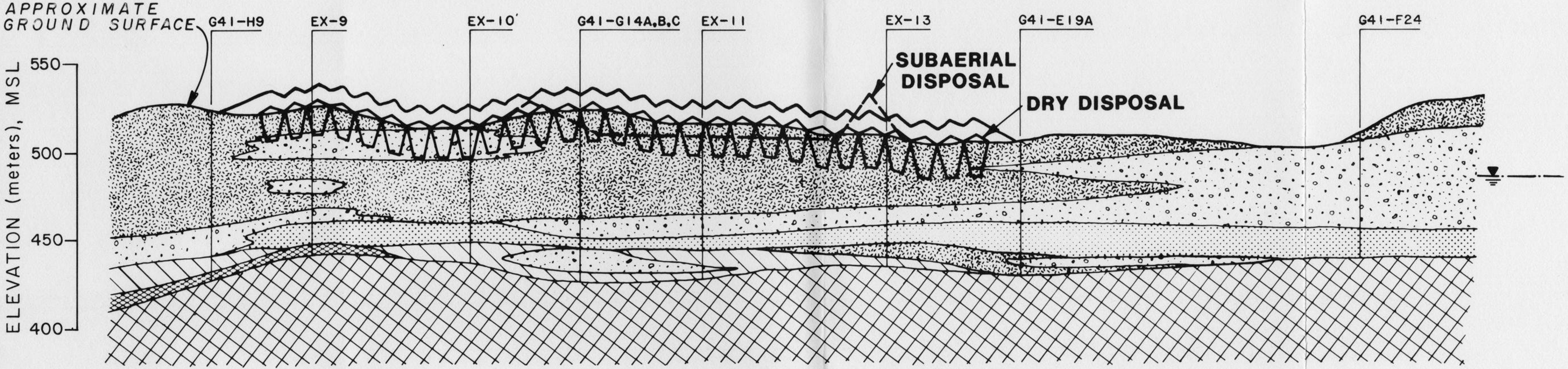
TITLE: LOCATION OF ALTERNATIVE MWDF DISPOSAL METHODS

SCALE: AS SHOWN
DRAWN BY: JJL DATE: 9-25-84 CHECKED BY: MMR
APPROVED BY: SHD

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B 17

27B
27B
50% BLK



SECTION C-C

NOTES:

1. REFER TO FIGURE A-6 FOR PLAN LOCATION OF SECTION C-C. REFER TO FIGURE A-8 FOR BORING LOCATIONS.
2. SECTION C-C STRATIGRAPHY SIMILIAR TO SECTION K-K STRATIGRAPHY FROM STS CONSULTANTS LTD. REPORT, "HYDROLOGIC STUDY UPDATE", JUNE 1984, DWG. 12959-5

0 250 500 750

SCALE IN METERS
VERTICAL EXAGGERATED 5x

LEGEND

- LACUSTRINE
- TILL
- COARSE GRAINED STRATIFIED DRIFT
- FINE GRAINED STRATIFIED DRIFT
- BASAL TILL
- BEDROCK

REFERENCE:
EXXON MINERALS COMPANY, AUGUST 1984, "VERTICAL SECTION OF MWDF AREA 41 DISPOSAL METHODS" CRANDON PROJECT, SCALE AS SHOWN.

FIGURE A-7

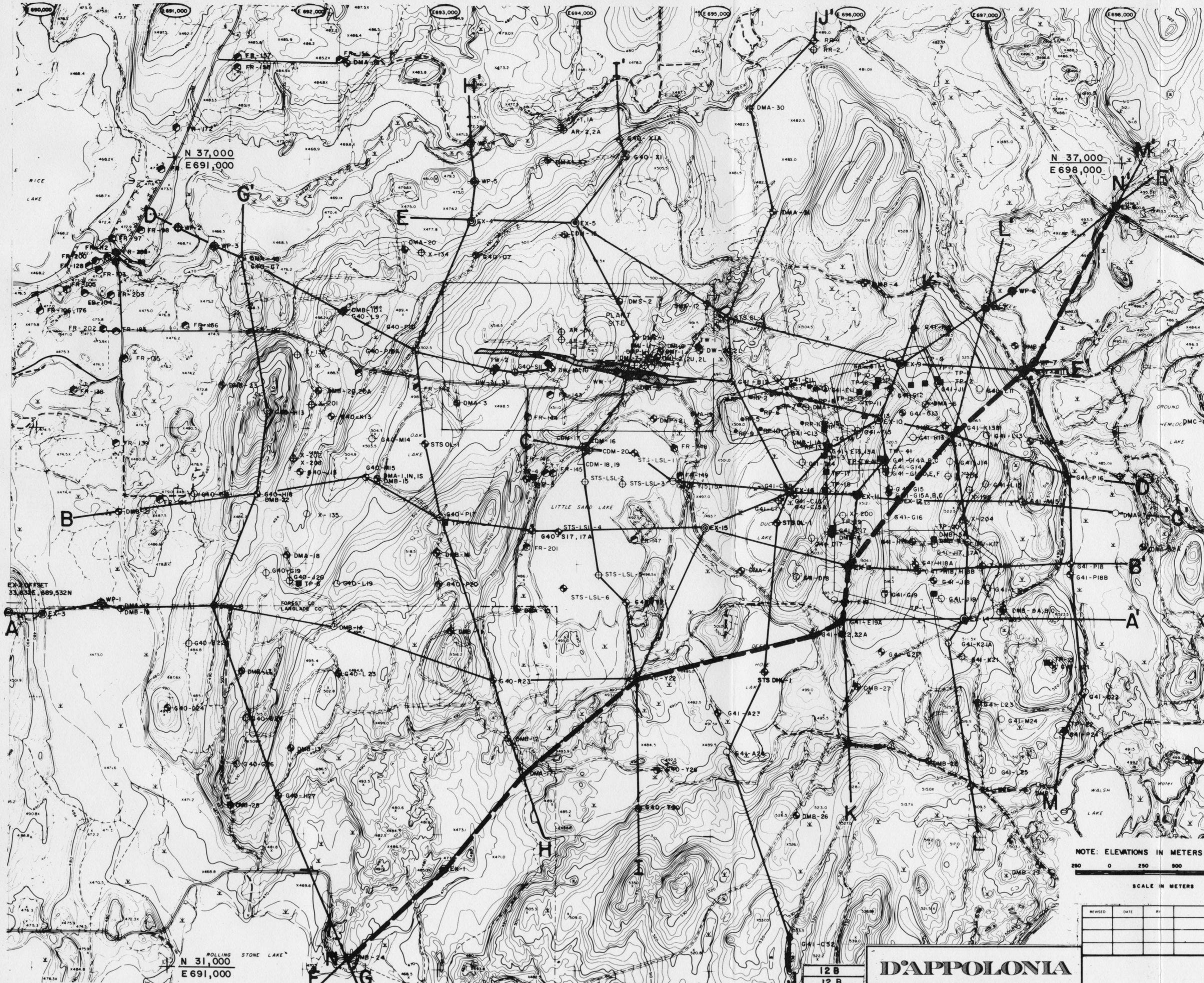
EXXON MINERALS COMPANY
CRANDON PROJECT

VERTICAL SECTION OF ALTERNATIVE MWDF AREA 41 DISPOSAL METHODS

SHOWN	WISCONSIN		FOREST
DR SPRINGBORN	9/84	MMK	12/10/85
		SHD	12/10/85

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B18



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.

REFERENCE:

STS CONSULTANTS LTD. DWG. NO. 12959-2 TITLED: "GEOLOGIC CROSS-SECTION INDEX", DATED: 4-12-82, REVISED 6-21-84, SCALE: AS SHOWN.

FIGURE A-8

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE: LOCATION OF GEOLOGIC SECTIONS

SCALE: AS SHOWN	STATE: WISCONSIN	COUNTY: FOREST, LANGLADE	
DRAWN BY: RW	DATE: 9-4-84	CHECKED BY: MMR	DATE: 12/10/85
APPROVED BY:	DATE:	APPROVED BY: SHD	DATE: 12/10/85
APPROVED BY:	DATE:	EXXON:	DATE:
DRAWING NO.		SHEET: OF	REVISION NO.

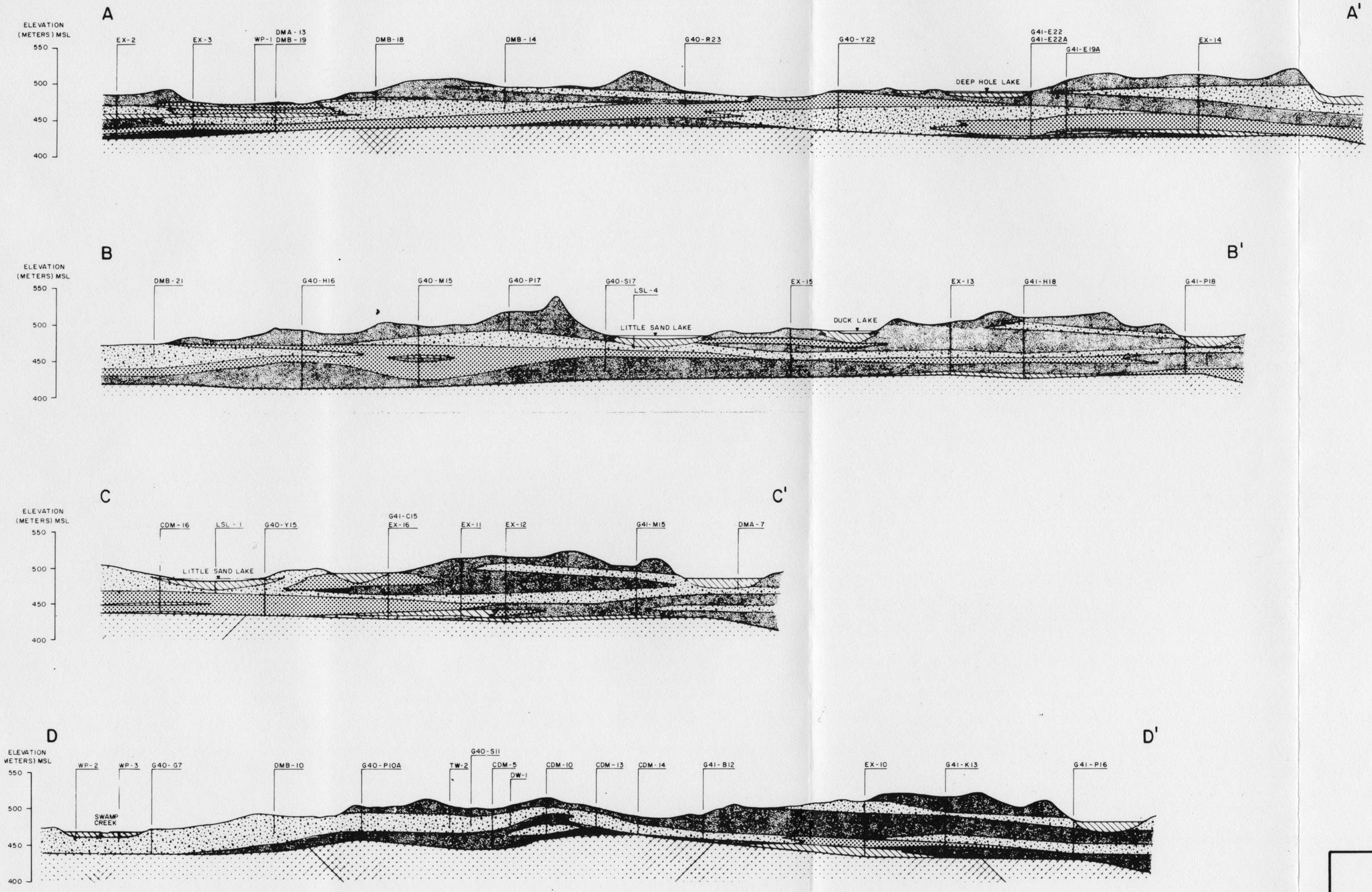
REVISED	DATE	BY	DESCRIPTION

12 B
12 B
400% BLK

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B9

DESIGN PRODUCTS CO.



LEGEND

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

NOTE:

1. FOR SECTION LOCATION, SEE FIGURE A-8.

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

REFERENCE:
DRAWING NO. 12959-3
TITLED: GEOLOGIC CROSS-SECTIONS A-A', B-B', C-C', D-D'; BY: STS CONSULTANTS LTD., GREEN BAY, WISCONSIN.; SCALE: AS SHOWN

D'APPOLONIA

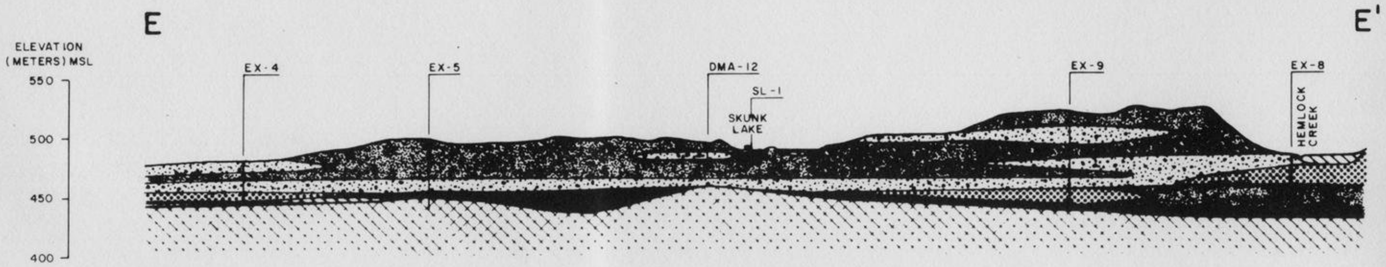
PROJ NO 846498 DWG NO B10

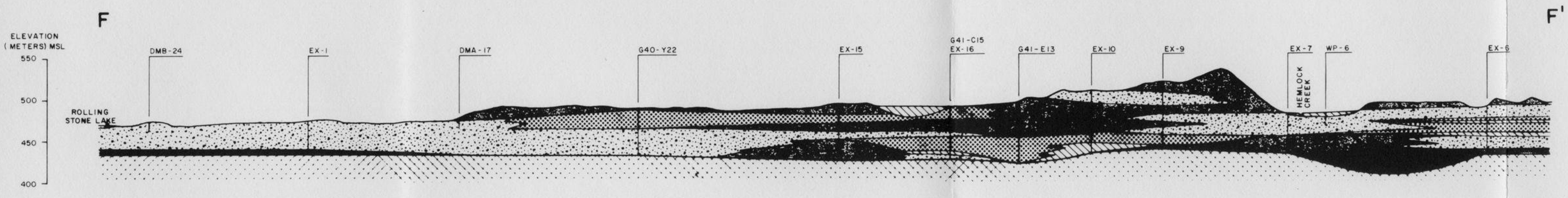
FIGURE A-9

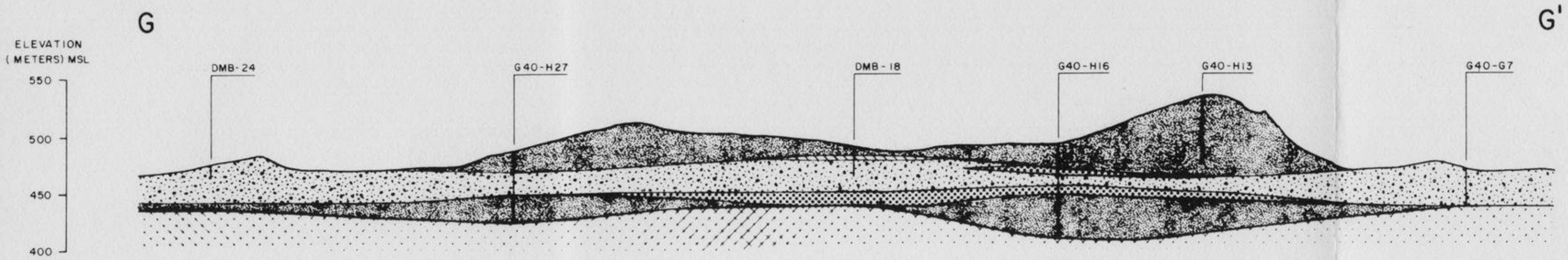
EXXON MINERALS COMPANY
CRANDON PROJECT

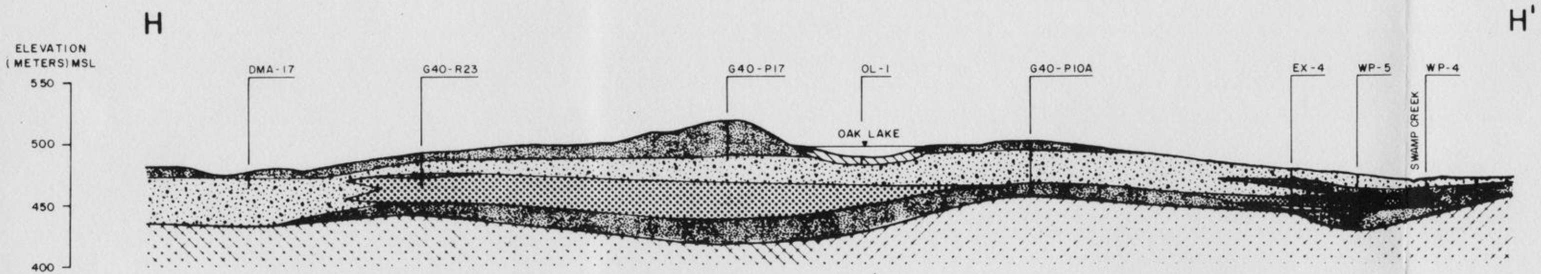
TITLE
GEOLOGIC SECTIONS A-A' THROUGH D-D'

SCALE AS SHOWN	STATE	COUNTY	
DRAWN BY D.Weick	DATE 9·5·84	CHECKED BY MMR	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET ___ OF ___	REVISION NO









LEGEND

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

NOTE:

1. FOR SECTION LOCATION, SEE FIGURE A-8.

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

FIGURE A-10

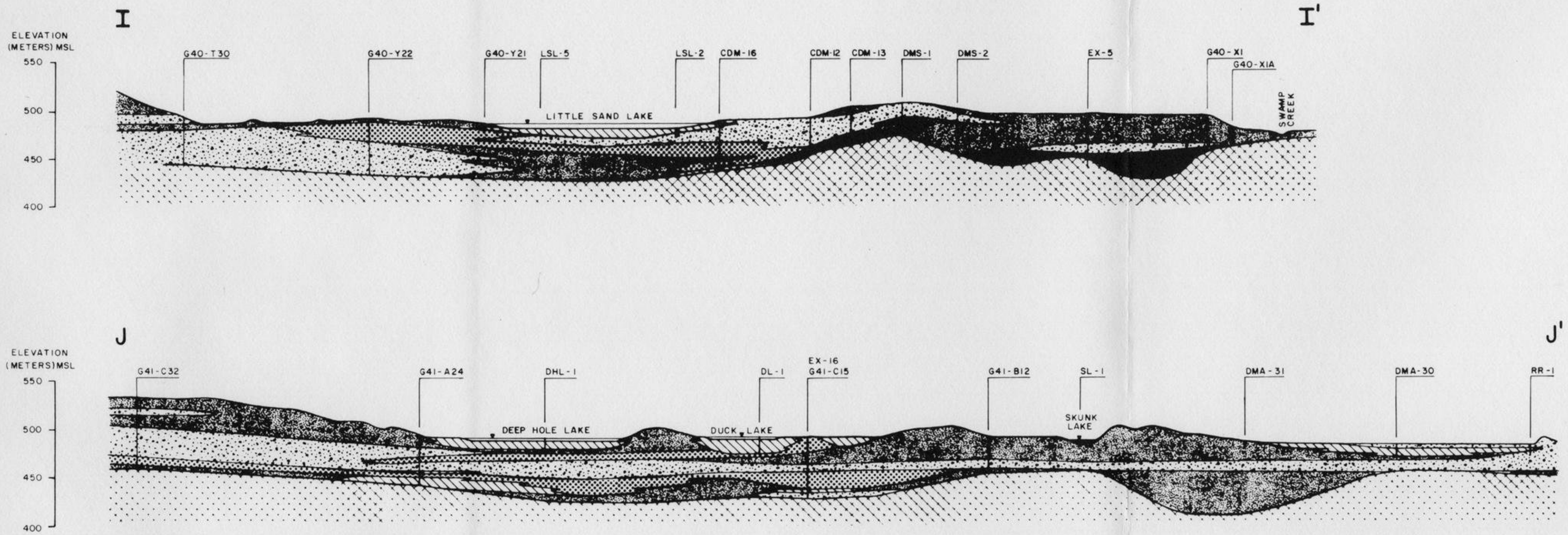
EXXON MINERALS COMPANY
CRANDON PROJECT

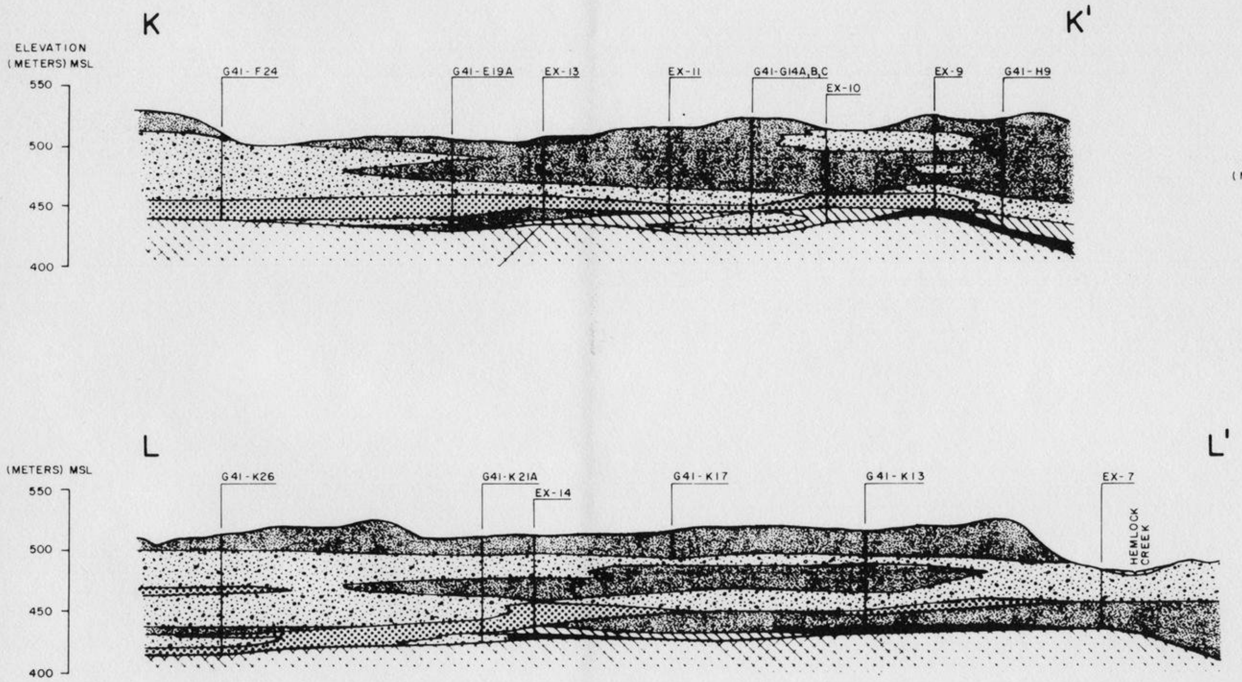
TITLE
GEOLOGIC SECTIONS E-E' THROUGH H-H'

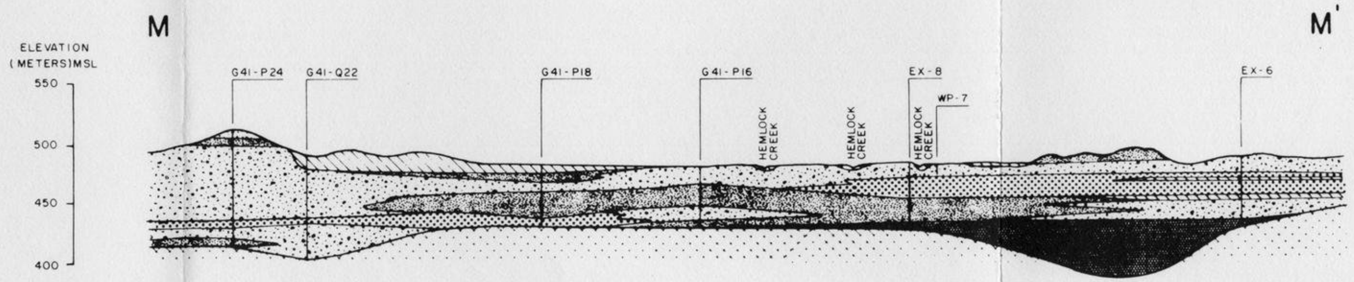
SCALE AS SHOWN	STATE	COUNTY	
DRAWN BY D. Weick	DATE 9·5·84	CHECKED BY MMR	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET ___ OF ___	REVISION NO

D'APPOLONIA
PROJ NO 846498 DWG NO B11

REFERENCE:
DRAWING NO. 12959-4
TITLED: GEOLOGIC CROSS-SECTIONS E-E', F-F' G-G', H-H'; BY: STS CONSULTANTS LTD., GREEN BAY, WISCONSIN; SCALE: AS SHOWN







LEGEND

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

NOTE:

1. FOR SECTION LOCATION, SEE FIGURE A-8.

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

REFERENCE:
DRAWING NO. 12959-5
TITLED: GEOLOGIC CROSS-SECTIONS I-I', J-J'
K-K', L-L', M-M'; BY: STS CONSULTANTS LTD.
GREEN BAY, WISCONSIN; SCALE: AS SHOWN

D'APPOLONIA

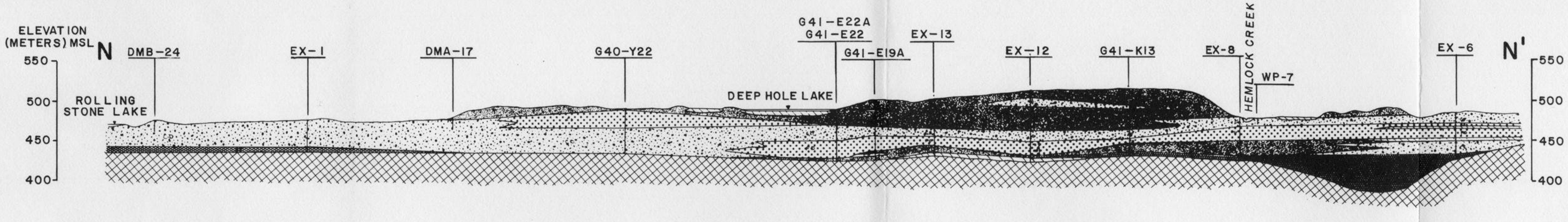
PROJ NO 846498 DWG NO B12

FIGURE A-11

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
GEOLOGIC SECTIONS I-I' THROUGH M-M'

SCALE AS SHOWN	STATE		COUNTY	
DRAWN BY D. Weick	DATE 9-5-84	CHECKED BY MMR		DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD		DATE 12/10/85
APPROVED BY	DATE	EXXON		DATE
DRAWING NO			SHEET ___ OF ___	REVISION NO



LEGEND

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

NOTE:

1. FOR SECTION LOCATION SEE FIGURE A-8.

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

FIGURE A-12

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE

GEOLOGIC SECTION N-N'

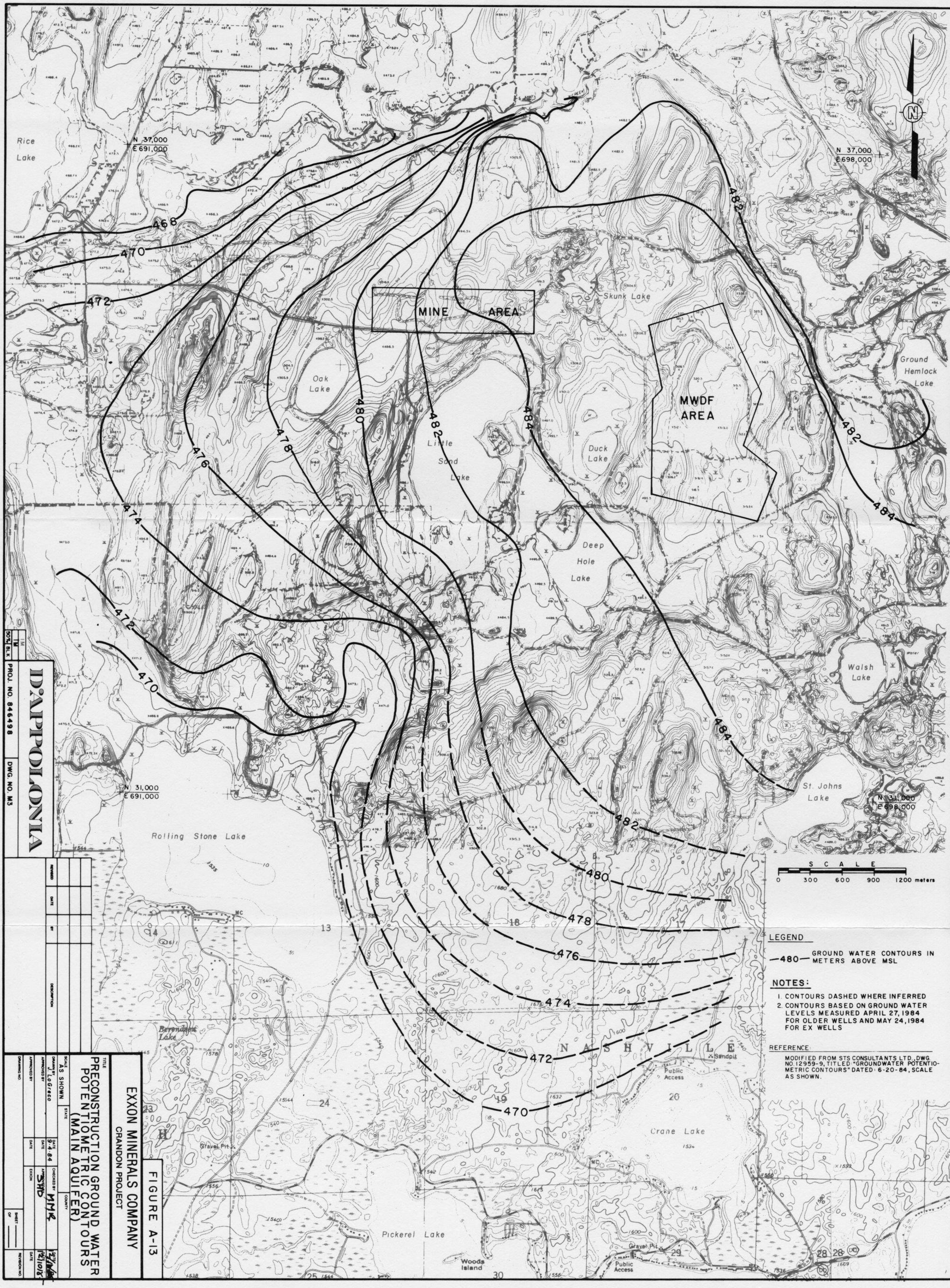
SCALE AS SHOWN	STATE		COUNTY	
DRAWN BY mel	DATE 9-17-84	CHECKED BY MMK		DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD		DATE 12/10/85
APPROVED BY	DATE	EXXON		DATE
DRAWING NO			SHEET ____ OF ____	REVISION NO

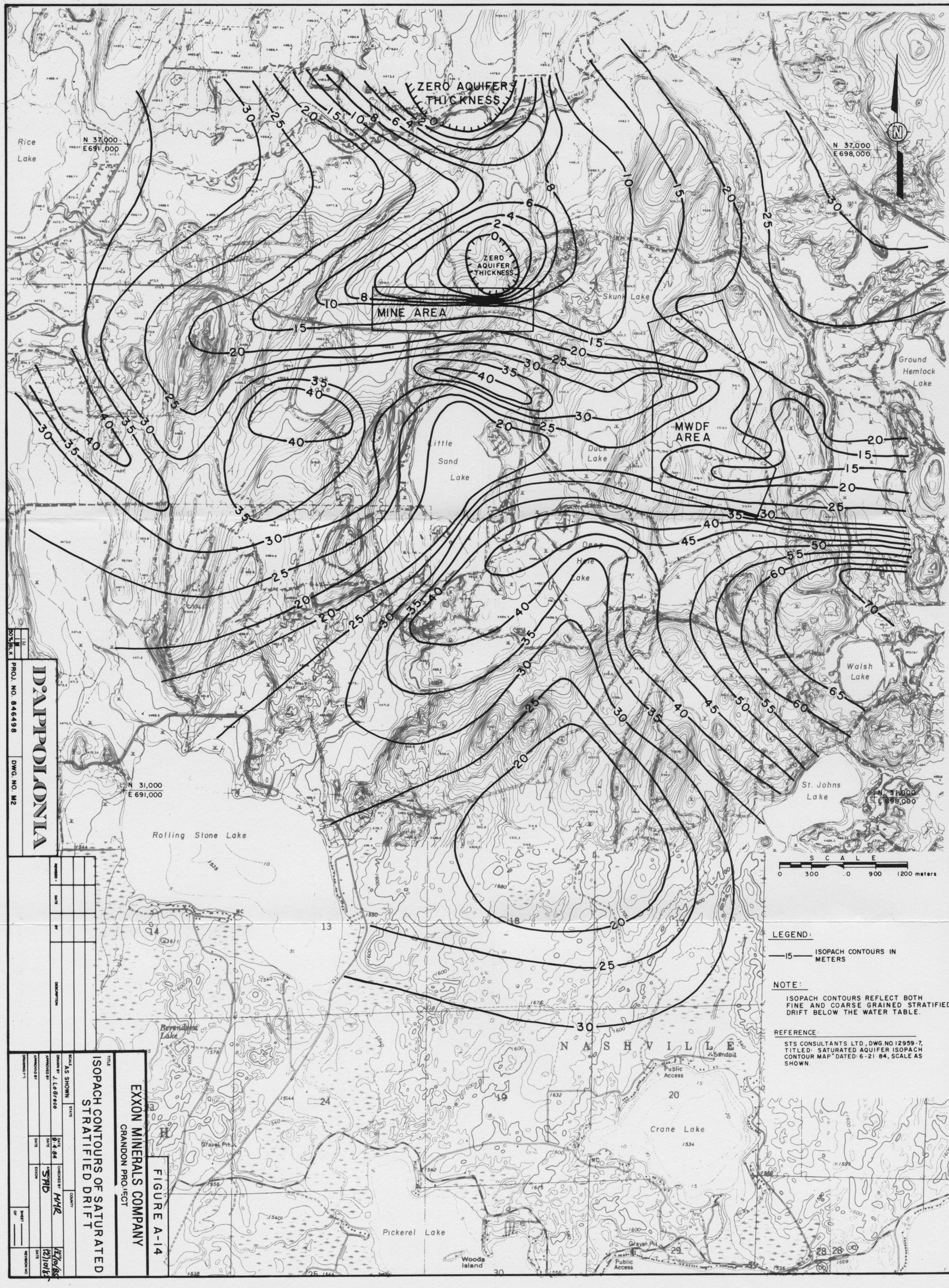
D'APPOLONIA

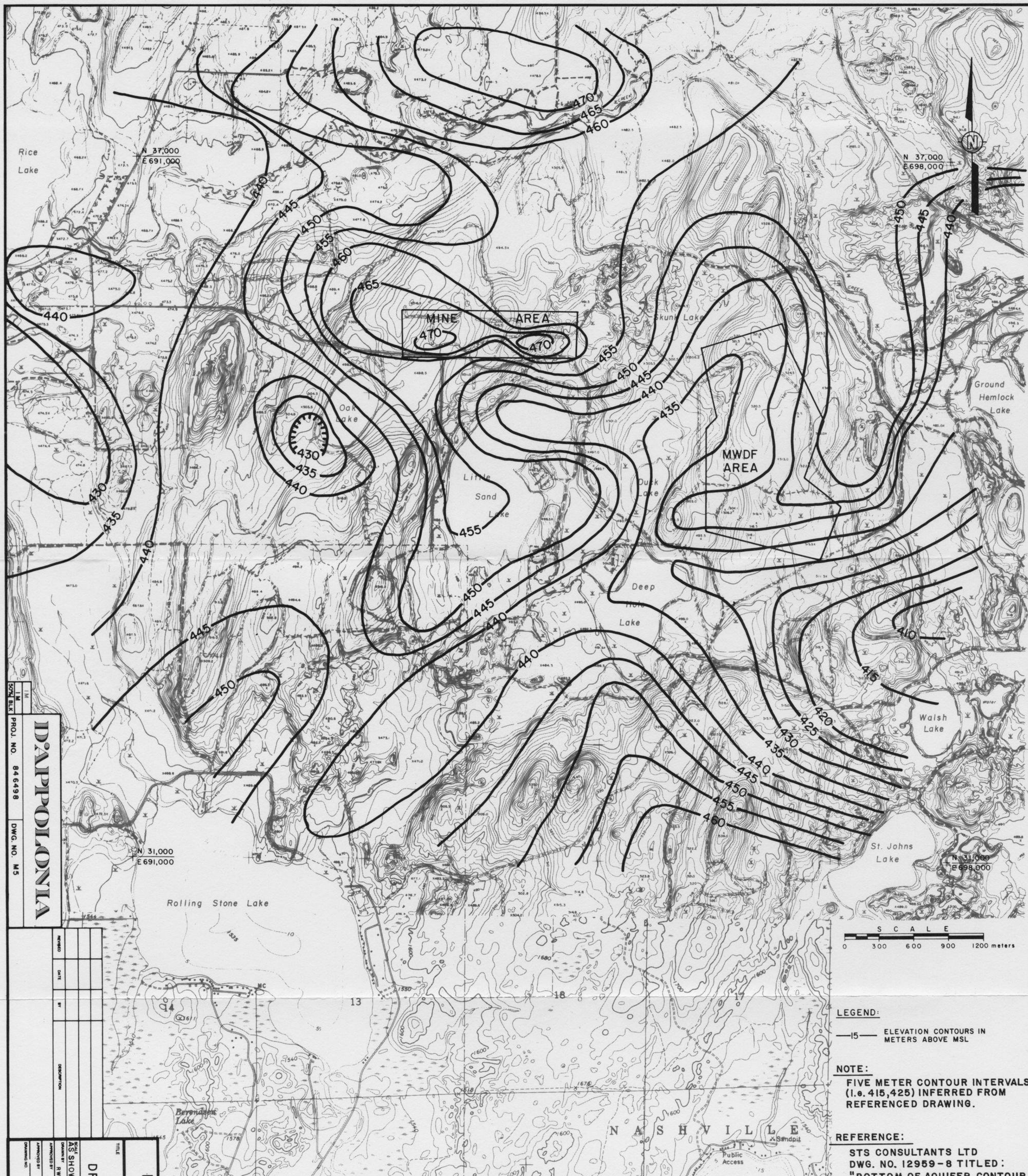
PROJ NO 846498 DWG NO B20

REFERENCE:

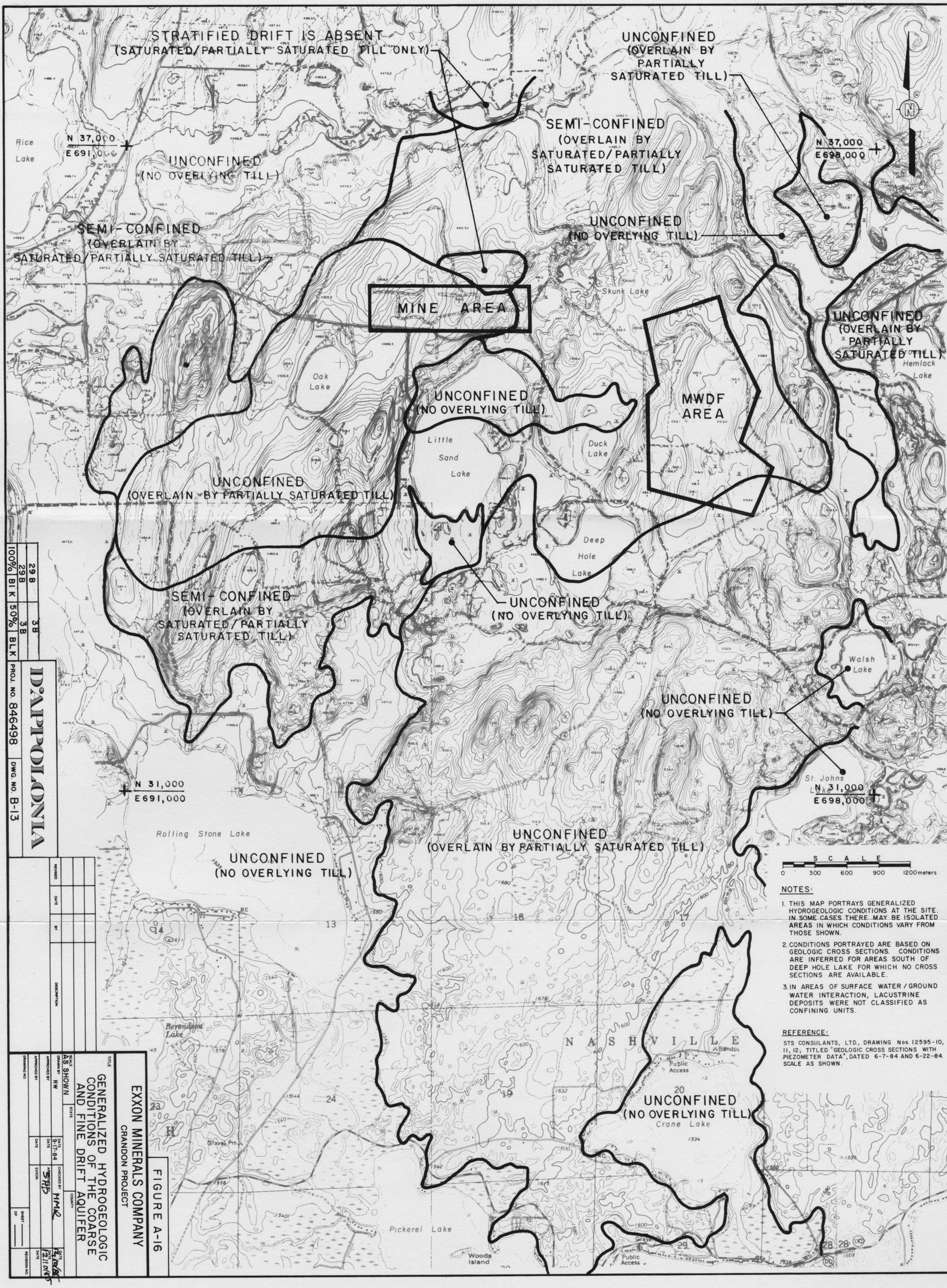
EXXON MINERALS COMPANY, AUGUST 1984.
"GEOLOGIC SECTION N-N'", CRANDON PROJECT.
SCALE AS SHOWN.

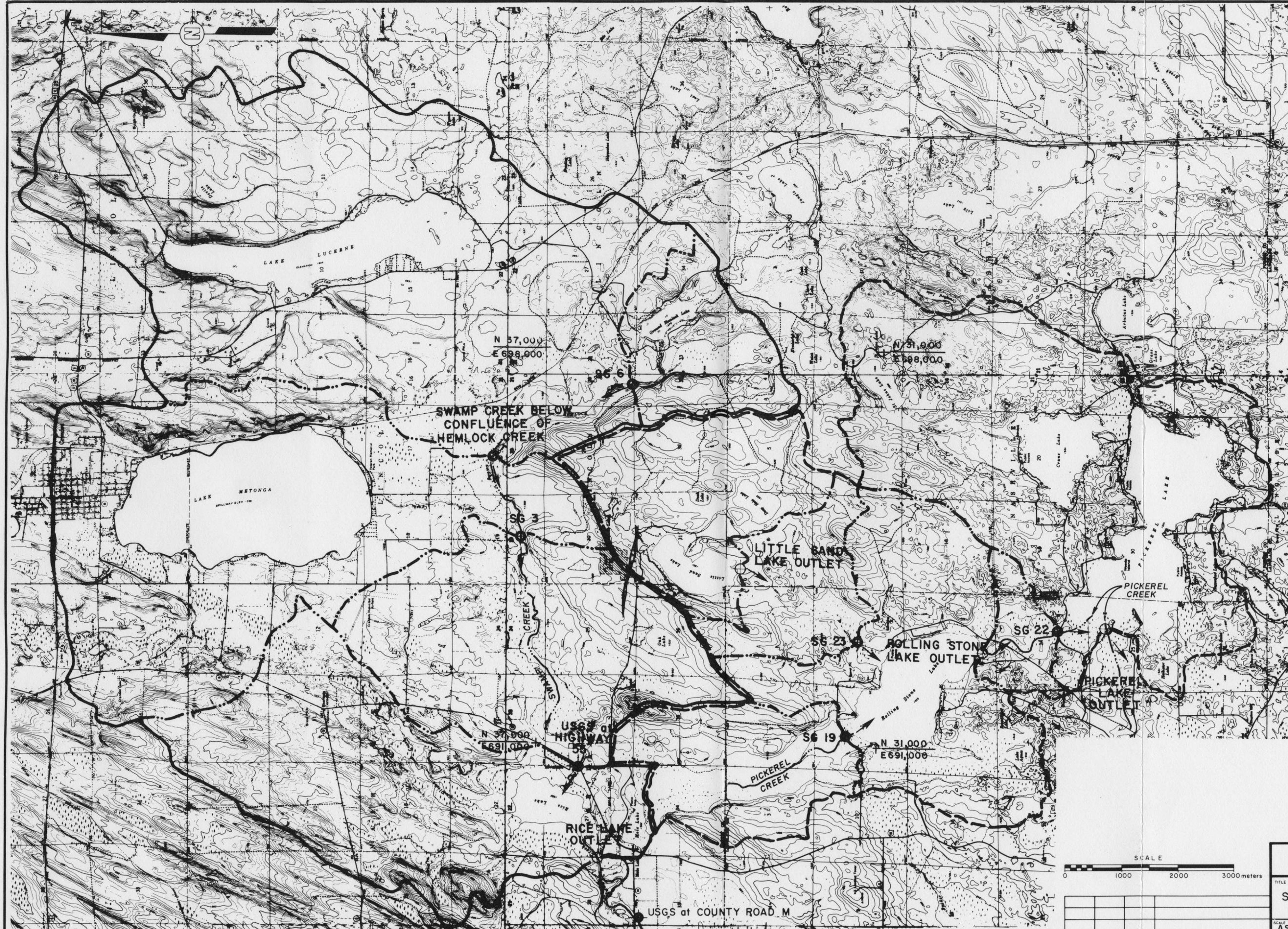

MINE AREA
MWDF AREA
Rice Lake
Oak Lake
Little Sand Lake
Skunk Lake
Duck Lake
Deep Hole Lake
Ground Hemlock Lake
Walsh Lake
St. Johns Lake
Rolling Stone Lake
Crane Lake
Pickerel Lake
Woods Island
Gravel Pit
Public Access
N A S H V I L L E
N 37,000 E 691,000
N 37,000 E 698,000
N 31,000 E 691,000
N 31,000 E 698,000
468
470
472
474
476
478
480
482
484
SCALE
0 300 600 900 1200 meters
LEGEND
—480— GROUND WATER CONTOURS IN METERS ABOVE MSL
NOTES:
1. CONTOURS DASHED WHERE INFERRED
2. CONTOURS BASED ON GROUND WATER LEVELS MEASURED APRIL 27, 1984 FOR OLDER WELLS AND MAY 24, 1984 FOR EX WELLS
REFERENCE:
MODIFIED FROM STS CONSULTANTS LTD., DWG NO. 12959-9, TITLED "GROUNDWATER POTENTIOMETRIC CONTOURS" DATED 6-20-84, SCALE AS SHOWN.
D'APPOLONIA
PROJ. NO. 846498
DWG. NO. M3
FIGURE A-13
EXXON MINERALS COMPANY
CRANDON PROJECT
PRECONSTRUCTION GROUND WATER POTENTIOMETRIC CONTOURS (MAIN AQUIFER)
SCALE AS SHOWN
DRAWN BY J. LoGreco
DATE 9-4-84


ZERO AQUIFER THICKNESS
ZERO AQUIFER THICKNESS
MINE AREA
MWDF AREA
Rice Lake
N 37,000
E 691,000
N 37,000
E 698,000
N 31,000
E 691,000
N 31,000
E 698,000
Skunk Lake
Ground Hemlock Lake
Little Sand Lake
Duck Lake
Deep Hole Lake
Walsh Lake
St. Johns Lake
Rolling Stone Lake
Berendsen Lake
NASHVILLE
Public Access
Crane Lake
Pickerel Lake
Woods Island
Gravel Pit
SCALE
0 300 600 900 1200 meters
LEGEND:
—15— ISOPACH CONTOURS IN METERS
NOTE:
ISOPACH CONTOURS REFLECT BOTH FINE AND COARSE GRAINED STRATIFIED DRIFT BELOW THE WATER TABLE.
REFERENCE:
STS CONSULTANTS LTD., DWG. NO. 12959-7, TITLED: SATURATED AQUIFER ISOPACH CONTOUR MAP" DATED: 6-21-84, SCALE AS SHOWN.
D'APPOLONIA
PROJ. NO. 846498
DWG. NO. M2
FIGURE A-14
EXXON MINERALS COMPANY
CRANDON PROJECT
ISOPACH CONTOURS OF SATURATED STRATIFIED DRIFT
SCALE AS SHOWN
DRAWN BY J. LaGreco
CHECKED BY MWR
APPROVED BY SMD



MINE AREA
MWDF AREA
Rice Lake
Oak Lake
Little Sand Lake
Skunk Lake
Duck Lake
Deep Hole Lake
Ground Hemlock Lake
Walsh Lake
St. Johns Lake
Rolling Stone Lake
Berendsen Lake
Crane Lake
Pickerel Lake
Woods Island
NASHVILLE
Public Access
Gravel Pit
Sandpit
N 37,000 E691,000
N 37,000 E698,000
N 31,000 E691,000
N 31,000 E698,000
SCALE
0 300 600 900 1200 meters
LEGEND:
—15— ELEVATION CONTOURS IN METERS ABOVE MSL
NOTE:
FIVE METER CONTOUR INTERVALS (I.e. 415,425) INFERRED FROM REFERENCED DRAWING.
REFERENCE:
STS CONSULTANTS LTD
DWG. NO. 12959-8 TITLED: "BOTTOM OF AQUIFER CONTOUR MAP" DATED: 6-20-84; SCALE AS SHOWN.
D'APPOLONIA
PROJ. NO. 846498
DWG. NO. M5
REVISED
DATE
BY
DESCRIPTION
FIGURE A-15
EXXON MINERALS COMPANY
CRANDON PROJECT
TITLE
BASE OF STRATIFIED DRIFT ELEVATION CONTOURS
SCALE AS SHOWN
STATE
COUNTY
DRAWN BY RW
DATE 9-21-84
CHECKED BY MHR
APPROVED BY
DRAWING NO.


STRATIFIED DRIFT IS ABSENT
(SATURATED/PARTIALLY SATURATED TILL ONLY)
UNCONFINED
(OVERLAIN BY PARTIALLY SATURATED TILL)
SEMI-CONFINED
(OVERLAIN BY SATURATED/PARTIALLY SATURATED TILL)
N 37,000
E 691,000
UNCONFINED
(NO OVERLYING TILL)
SEMI-CONFINED
(OVERLAIN BY SATURATED/PARTIALLY SATURATED TILL)
UNCONFINED
(NO OVERLYING TILL)
N 37,000
E 698,000
MINE AREA
MWDF AREA
UNCONFINED
(OVERLAIN BY PARTIALLY SATURATED TILL)
UNCONFINED
(NO OVERLYING TILL)
UNCONFINED
(OVERLAIN BY PARTIALLY SATURATED TILL)
SEMI-CONFINED
(OVERLAIN BY SATURATED/PARTIALLY SATURATED TILL)
UNCONFINED
(NO OVERLYING TILL)
UNCONFINED
(NO OVERLYING TILL)
N 31,000
E 691,000
N 31,000
E 698,000
UNCONFINED
(OVERLAIN BY PARTIALLY SATURATED TILL)
UNCONFINED
(NO OVERLYING TILL)
UNCONFINED
(NO OVERLYING TILL)
Rice Lake
Oak Lake
Skunk Lake
Hemlock Lake
Little Sand Lake
Duck Lake
Deep Hole Lake
Walsh Lake
St. Johns Lake
Rolling Stone Lake
Berendsen Lake
Crane Lake
Pickerel Lake
Woods Island
NASHVILLE
Public Access
Gravel Pit
SCALE
0 300 600 900 1200 meters
NOTES:
1. THIS MAP PORTRAYS GENERALIZED HYDROGEOLOGIC CONDITIONS AT THE SITE. IN SOME CASES THERE MAY BE ISOLATED AREAS IN WHICH CONDITIONS VARY FROM THOSE SHOWN.
2. CONDITIONS PORTRAYED ARE BASED ON GEOLOGIC CROSS SECTIONS. CONDITIONS ARE INFERRED FOR AREAS SOUTH OF DEEP HOLE LAKE FOR WHICH NO CROSS SECTIONS ARE AVAILABLE.
3. IN AREAS OF SURFACE WATER / GROUND WATER INTERACTION, LACUSTRINE DEPOSITS WERE NOT CLASSIFIED AS CONFINING UNITS.
REFERENCE:
STS CONSULTANTS, LTD., DRAWING Nos. 12595-10, 11, 12; TITLED "GEOLOGIC CROSS SECTIONS WITH PIEZOMETER DATA", DATED 6-7-84 AND 6-22-84. SCALE AS SHOWN.
D'APPOLONIA
PROJ. NO. 846498
DWG. NO. B-13
100% BLK 50% BLK
29B 29B 3B 3B
FIGURE A-16
EXXON MINERALS COMPANY
CRANDON PROJECT
GENERALIZED HYDROGEOLOGIC CONDITIONS OF THE COARSE AND FINE DRIFT AQUIFER
SCALE AS SHOWN
DRAWN BY RW
DATE 9-17-84



LEGEND

- SWAMP CREEK DRAINAGE BOUNDARY
- PICKEREL CREEK DRAINAGE BOUNDARY
- SUBWATERSHED BOUNDARIES
- LOWFLOW ESTIMATE LOCATIONS
- LAKEFLOW ESTIMATE LOCATIONS
- SURFACE WATER FLOW DIRECTION

SCALE

0 1000 2000 3000 meters

REFERENCE:
DRAWING NO 050-1-80603
TITLED SURFACE WATERSHEDS AND STUDY LOCATIONS BY GOLDER ASSOCIATES-ATLANTA, GEORGIA, DATED: 5-26-82
SCALE: AS SHOWN

D'APPOLONIA

PROJ. NO 846498 DWG. NO. B8

FIGURE A-17

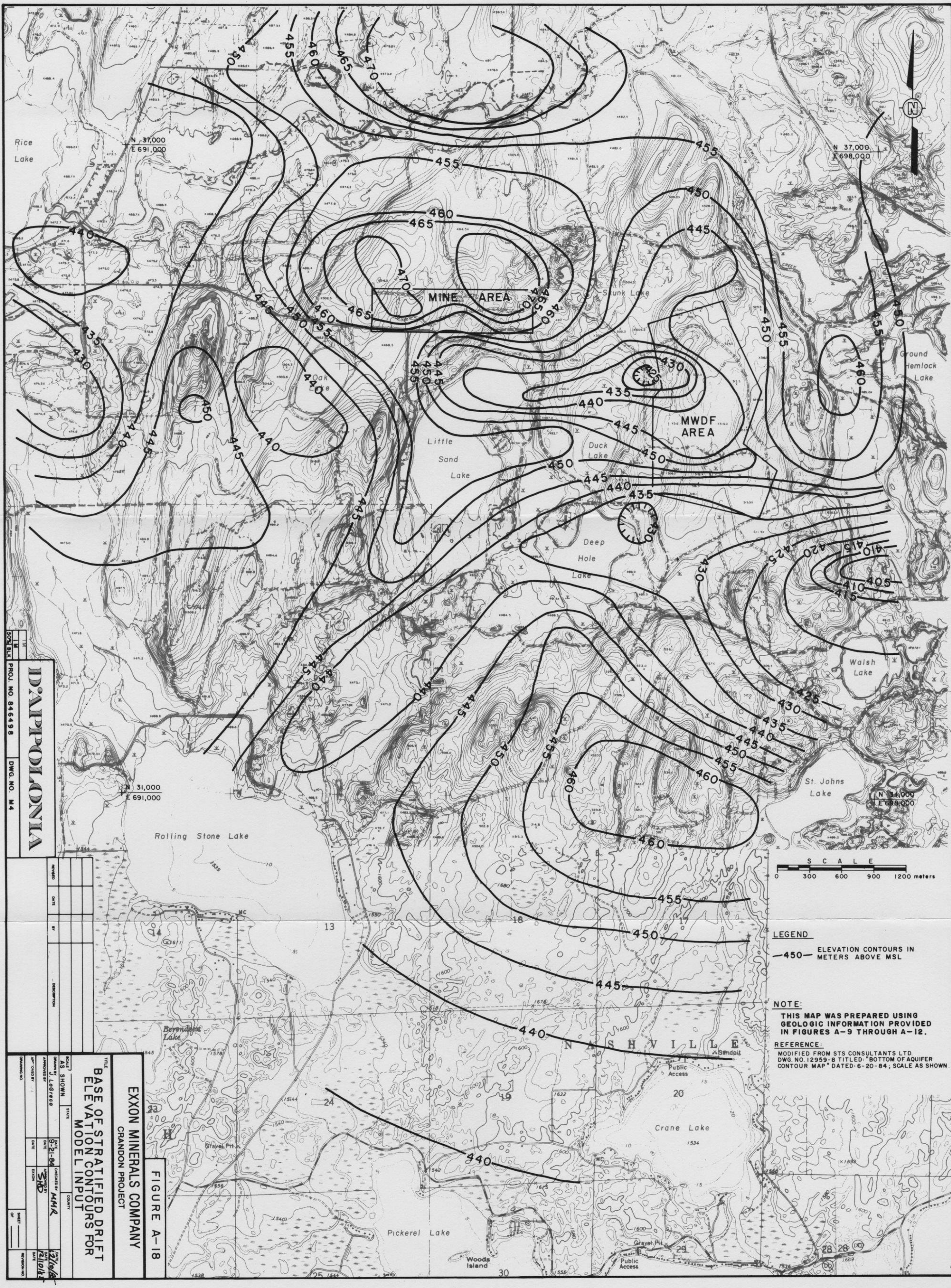
EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
STUDY AREA DRAINAGE BASINS

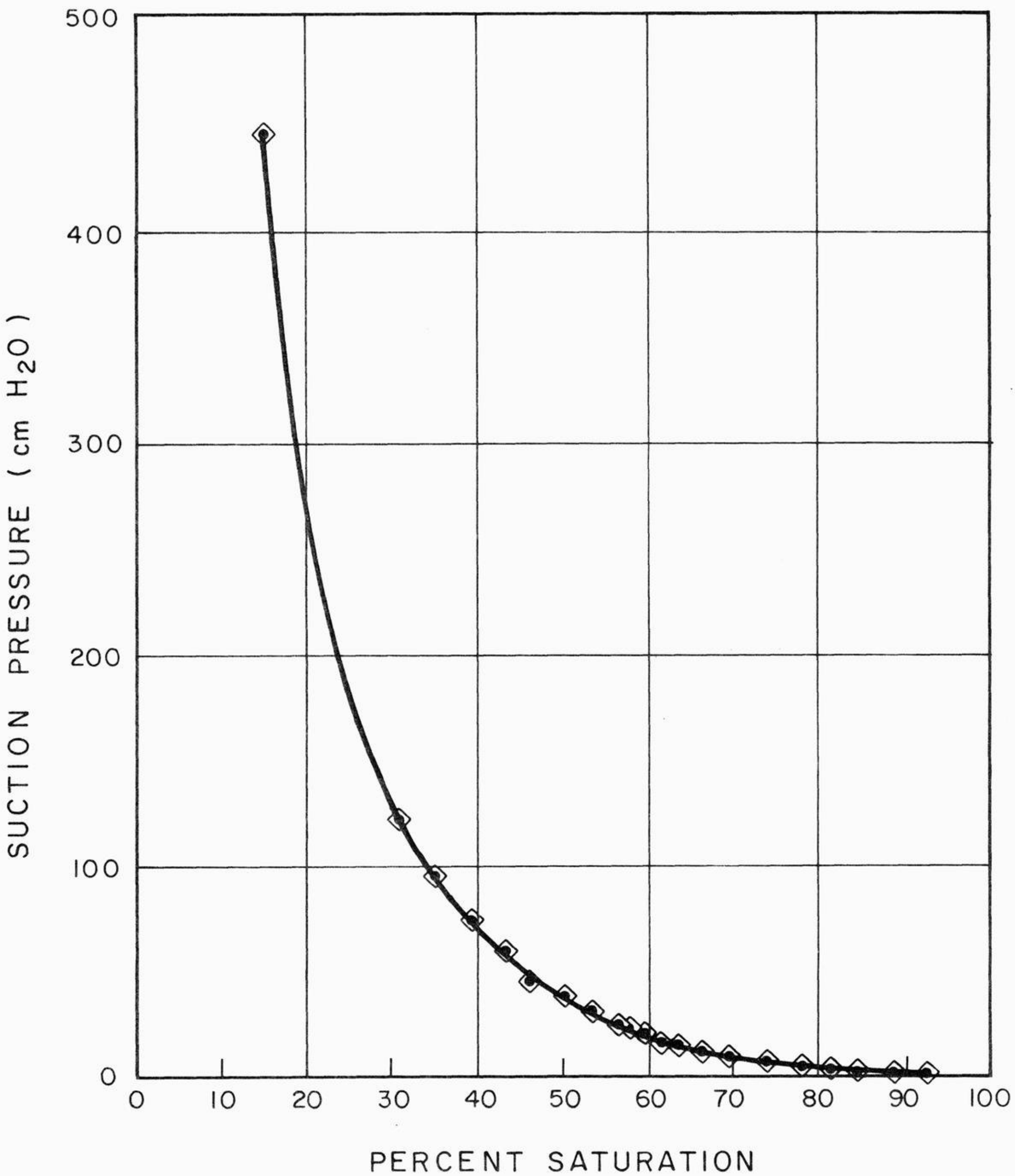
REVISED	DATE	BY	DESCRIPTION

SCALE AS SHOWN
DRAWN BY RW 9-5-84
CHECKED BY MMR 12/10/85
SHD 12/10/85

GBB 5/1961



Rice Lake
N 37,000
E 691,000
N 37,000
E 698,000
MINE AREA
MWDF AREA
Skunk Lake
Ground Hemlock Lake
Oak Lake
Little Sand Lake
Duck Lake
Deep Hole Lake
Walsh Lake
St. Johns Lake
N 31,000
E 691,000
N 31,000
E 698,000
Rolling Stone Lake
Berendsen Lake
NASHVILLE
Sandpit
Public Access
Crane Lake
Gravel Pit
Pickerel Lake
Woods Island
SCALE
0 300 600 900 1200 meters
LEGEND
—450— ELEVATION CONTOURS IN METERS ABOVE MSL
NOTE:
THIS MAP WAS PREPARED USING GEOLOGIC INFORMATION PROVIDED IN FIGURES A-9 THROUGH A-12.
REFERENCE:
MODIFIED FROM STS CONSULTANTS LTD. DWG. NO. 12959-8 TITLED: "BOTTOM OF AQUIFER CONTOUR MAP" DATED: 6-20-84; SCALE AS SHOWN.
D'APPOLONIA
PROJ. NO. 846498
DWG. NO. M4
FIGURE A-18
EXXON MINERALS COMPANY
CRANDON PROJECT
BASE OF STRATIFIED DRIFT
ELEVATION CONTOURS FOR
MODEL INPUT
SCALE AS SHOWN
DRAWN BY J. LoGreco
DATE 9-21-84
CHECKED BY MMR



NOTES:

1. DETERMINED FOR WETTING CYCLE
2. SAMPLE DRY DENSITY = 1.87 g/cm^3
3. 1 ATMOSPHERE = 1033 cm H_2O

FIGURE A-19

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
RELATIONSHIP OF SUCTION PRESSURE TO PERCENT SATURATION FOR THE TILL

SCALE	STATE		COUNTY		
DRAWN BY cjb/	DATE 9-24-84	CHECKED BY MMR	DATE 12/10/85		
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85		
APPROVED BY	DATE	EXXON	DATE		
DRAWING NO		SHEET ____ OF ____	REVISION NO		

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. A4

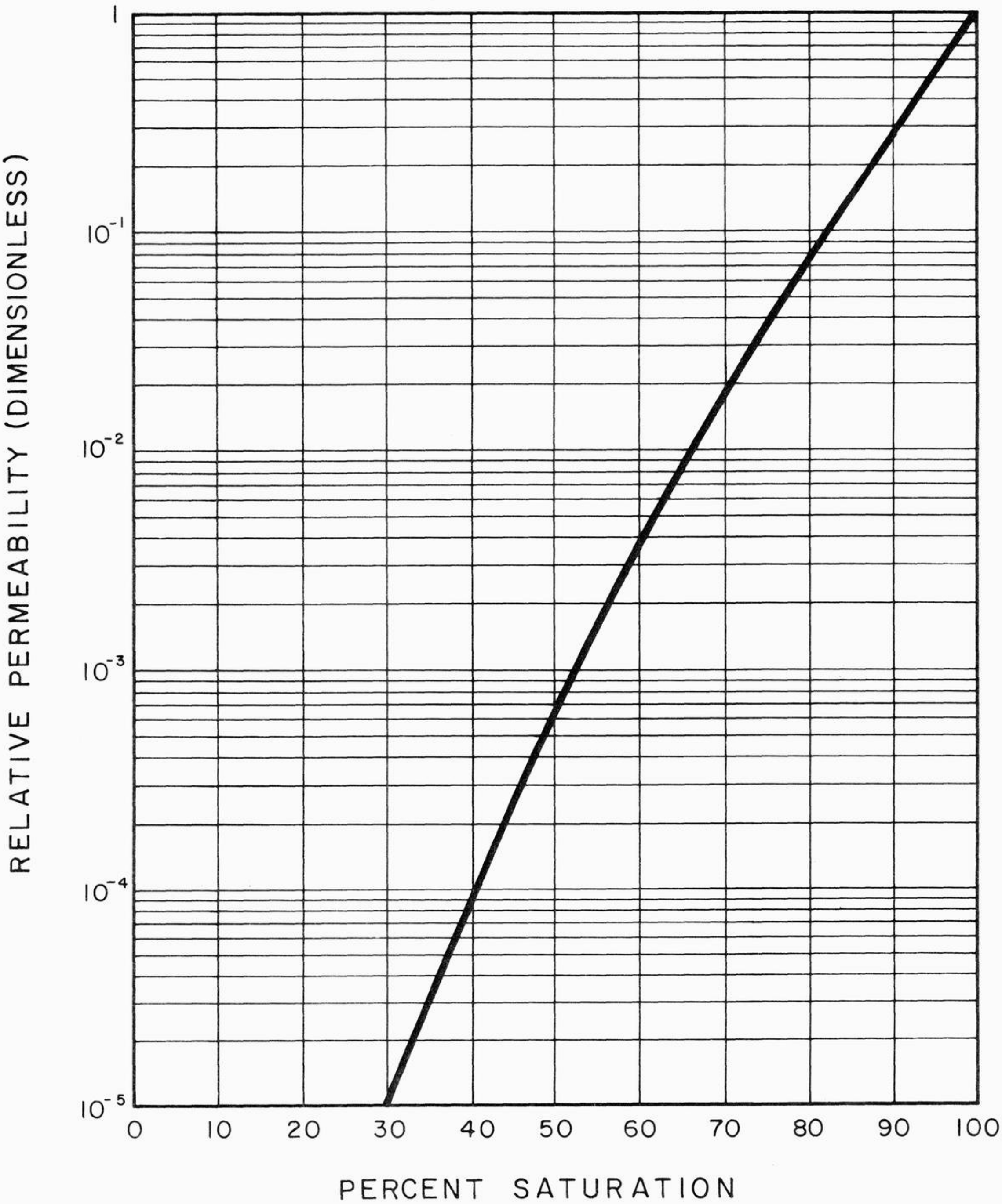


FIGURE A-20

NOTE:

RELATIVE PERMEABILITY EQUALS PARTIALLY SATURATED PERMEABILITY DIVIDED BY SATURATED PERMEABILITY.

EXXON MINERALS COMPANY

CRANDON PROJECT

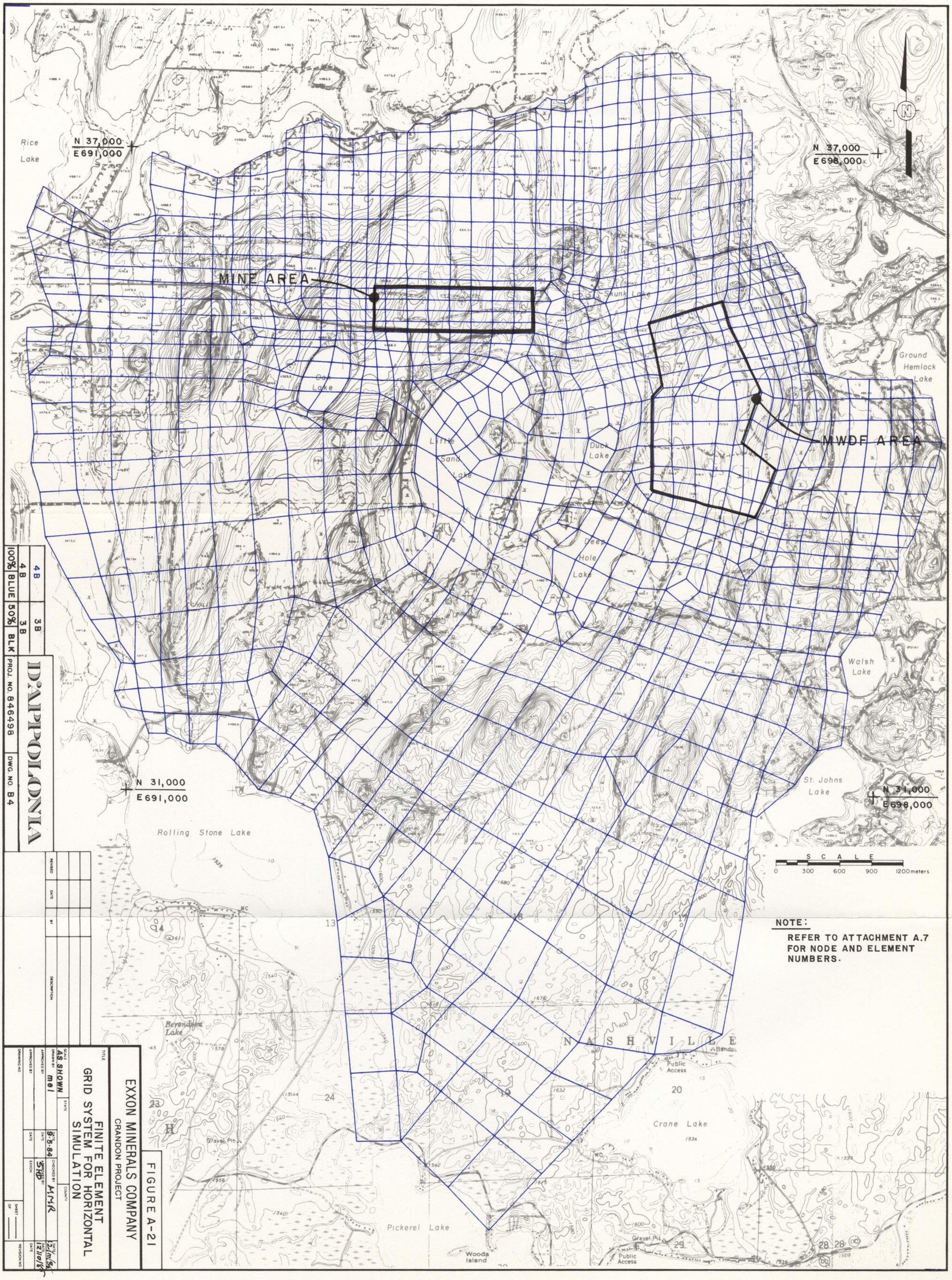
TITLE

RELATIONSHIP BETWEEN PARTIALLY SATURATED TILL PERMEABILITY AND PERCENT SATURATION

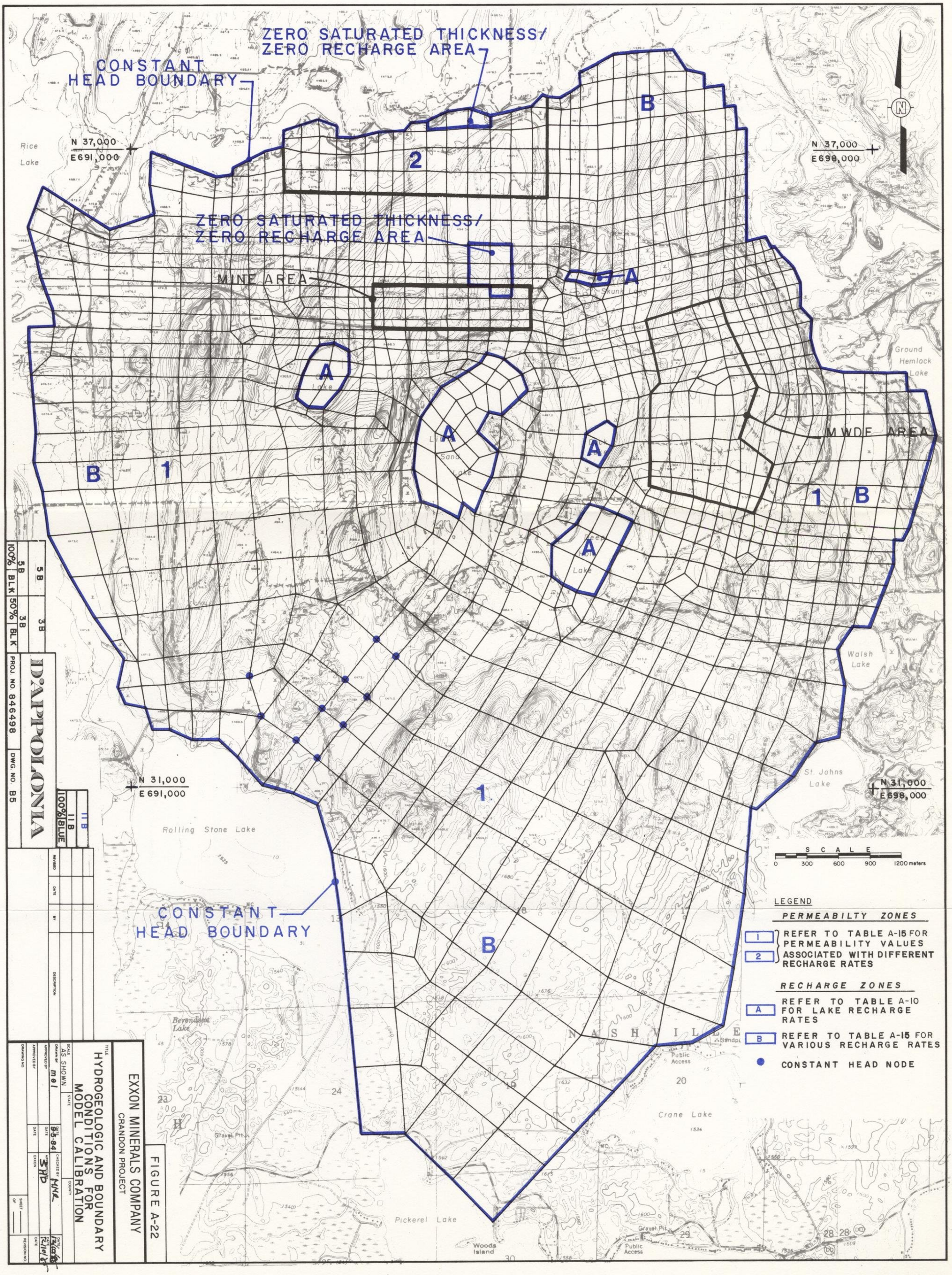
SCALE	STATE	COUNTY	
DRAWN BY cjb/	DATE 9-24-84	CHECKED BY MMR	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO.		SHEET ___ OF ___	REVISION NO.

D'APPOLONIA

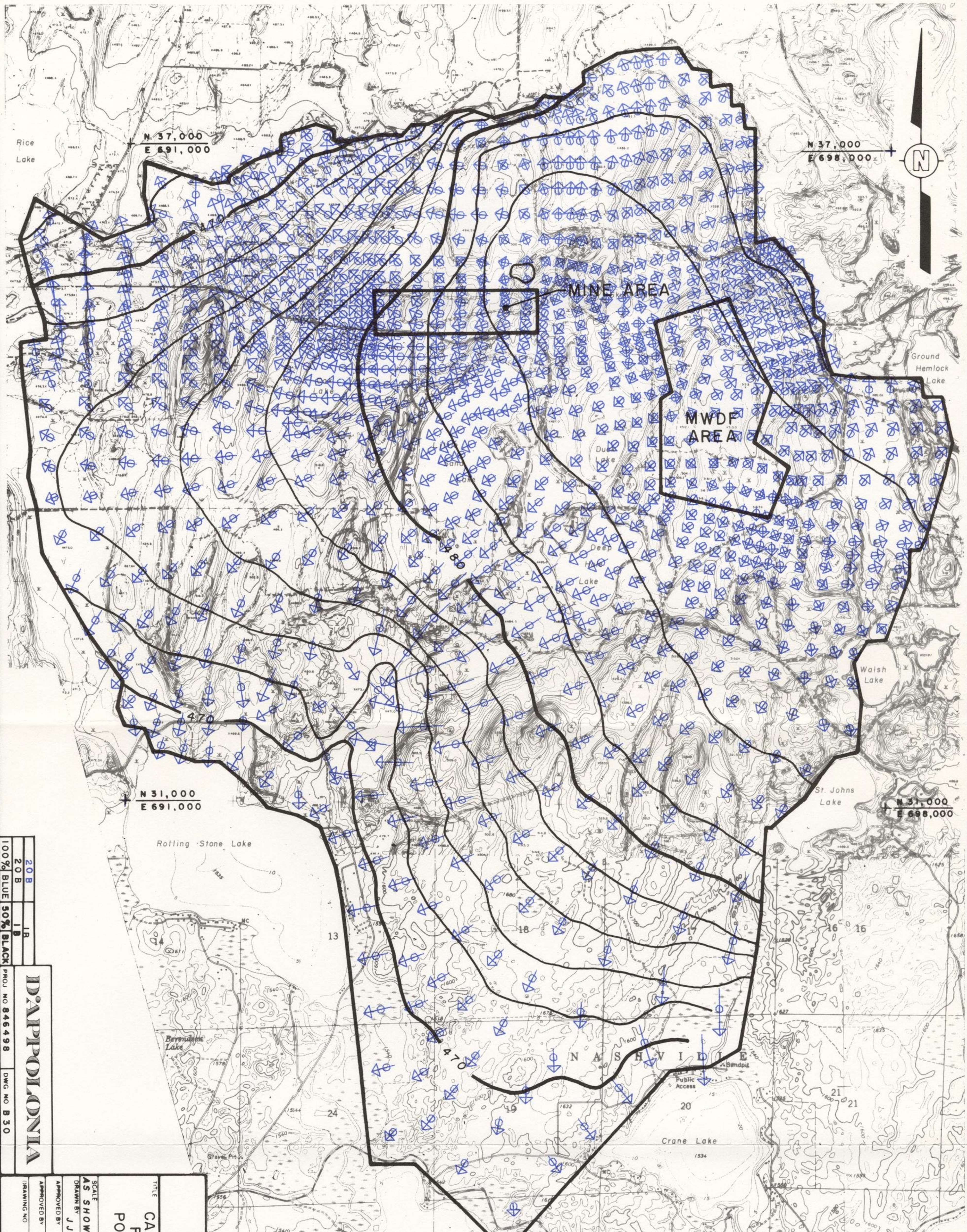
PROJ. NO. 846498 DWG. NO. A6



MINE AREA
MWDF AREA
N 37,000
E691,000
N 37,000
E698,000
N 31,000
E691,000
N 31,000
E698,000
Rice Lake
Skunk Lake
Oak Lake
Little Sand Lake
Duck Lake
Deep Hole Lake
Ground Hemlock Lake
Walsh Lake
St. Johns Lake
Rolling Stone Lake
Crane Lake
Pickerel Lake
Woods Island
NASHVILLE
SCALE
0 300 600 900 1200 meters
NOTE:
REFER TO ATTACHMENT A.7 FOR NODE AND ELEMENT NUMBERS.
FIGURE A-21
EXXON MINERALS COMPANY
CRANDON PROJECT
FINITE ELEMENT GRID SYSTEM FOR HORIZONTAL SIMULATION
D'APPOLONIA
PROJ. NO. 846498
DWG. NO. B4
100% BLUE 50% BLK
4B 3B
AS SHOWN



ZERO SATURATED THICKNESS/ ZERO RECHARGE AREA
CONSTANT HEAD BOUNDARY
N 37,000 E691,000
N 37,000 E698,000
Rice Lake
ZERO SATURATED THICKNESS/ ZERO RECHARGE AREA
MINE AREA
MWDF AREA
Skunk Lake
Ground Hemlock Lake
Walsh Lake
St. Johns Lake
N 31,000 E691,000
N 31,000 E698,000
Rolling Stone Lake
CONSTANT HEAD BOUNDARY
Pickerel Lake
Crane Lake
Woods Island
Public Access
Gravel Pit
NASHVILLE
SCALE
0 300 600 900 1200 meters
LEGEND
PERMEABILTY ZONES
1 2 REFER TO TABLE A-15 FOR PERMEABILITY VALUES ASSOCIATED WITH DIFFERENT RECHARGE RATES
RECHARGE ZONES
A REFER TO TABLE A-10 FOR LAKE RECHARGE RATES
B REFER TO TABLE A-15 FOR VARIOUS RECHARGE RATES
CONSTANT HEAD NODE
D'APPOLONIA
PROJ. NO 846498
DWG. NO. B5
FIGURE A-22
EXXON MINERALS COMPANY
CRANDON PROJECT
HYDROGEOLOGIC AND BOUNDARY CONDITIONS FOR MODEL CALIBRATION
AS SHOWN



NOTE:

LENGTH OF VECTOR IS PROPORTIONAL TO THE MAGNITUDE OF FLOW. EACH cm IS APPROXIMATELY EQUAL TO 787.4 m^3/y PER HORIZONTAL UNIT WIDTH IN METERS.

SCALE

0 1000 2000 meters

LEGEND

470 PREDICTED POTENTIOMETRIC SURFACE IN METERS ABOVE MSL

PREDICTED FLOW VECTOR

FIGURE A-23

EXXON MINERALS COMPANY

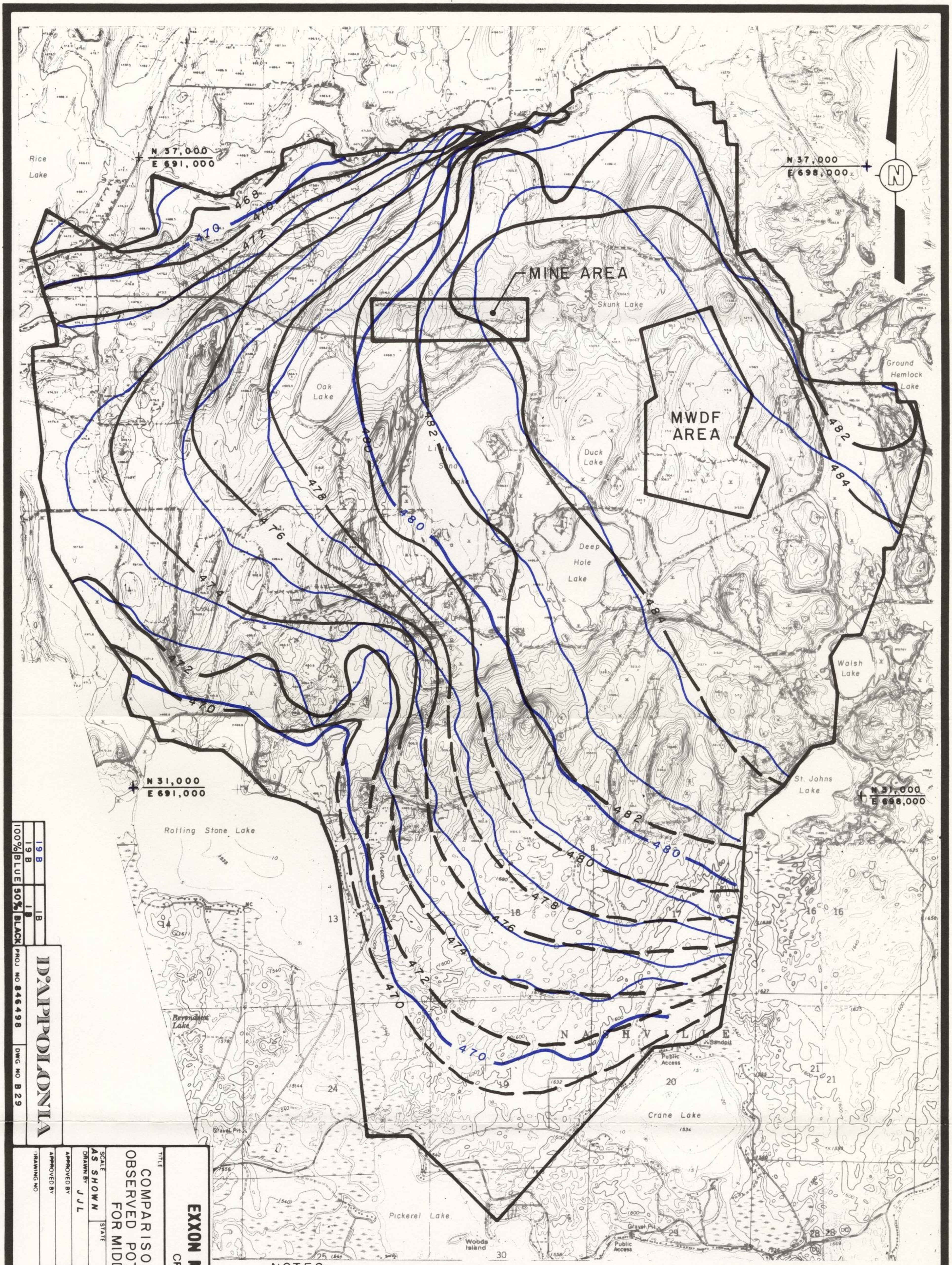
CRANDON PROJECT

CALIBRATED HORIZONTAL MODEL FOR MIDDLE RECHARGE CASE POTENTIOMETRIC SURFACE AND FLOW VECTORS

SCALE AS SHOWN	STATE	COUNTY	
DRAWN BY J J L	DATE 9-26-84	CHECKED BY MMK	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET OF	REVISION NO

D'APPOLONIA PROJ. NO 846498 DWG NO B30

20B		
20B		1B
100% BLUE	50%	BLACK



NOTES:

1. OBSERVED POTENTIOMETRIC SURFACE IS FROM FIGURE A-13
2. CALIBRATED POTENTIOMETRIC SURFACE IS FROM FIGURE A-23

SCALE

0 1000 2000 meters

LEGEND:

476 — OBSERVED POTENTIOMETRIC SURFACE IN METERS ABOVE MSL

480 — CALIBRATED POTENTIOMETRIC SURFACE IN METERS ABOVE MSL

FIGURE A-24

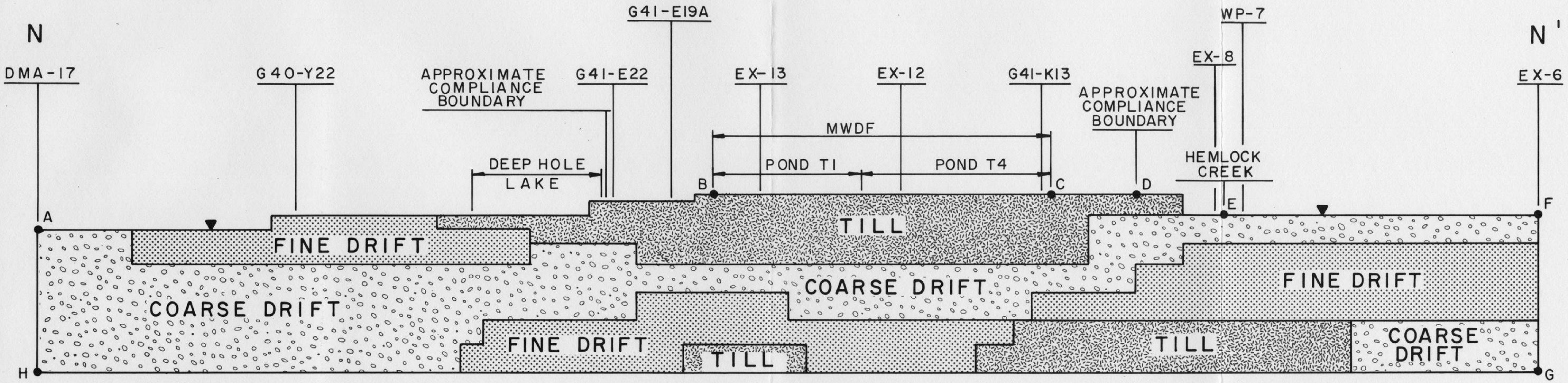
EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: COMPARISON OF CALIBRATED AND OBSERVED POTENTIOMETRIC SURFACES FOR MIDDLE RECHARGE CASE

SCALE AS SHOWN		STATE		COUNTY	
DRAWN BY JJL	DATE 9-26-84	CHECKED BY MMR	DATE 12/10/85		
APPROVED BY	DATE	APPROVED BY SHB	DATE 12/18/85		
APPROVED BY	DATE	EXXON	DATE		
DRAWING NO			SHEET OF		REVISION NO

D'APPOLONIA PROJ. NO 846498 DWG NO B29

19 B | 19 B | 1 B
100% BLUE | 50% BLACK



LEGEND:

- ● A POINTS REFERRED TO IN TEXT
- ▼ WATER TABLE (RECHARGE BOUNDARY)

HORIZONTAL SCALE: 0 300 600 900 meters

VERTICAL SCALE: 0 20 40 60 meters

NOTES:

1. FOR PLAN AND LOCATION OF SECTION N-N' REFER TO FIGURE A-8
2. VERTICAL EXAGGERATION 15X

FIGURE A-25

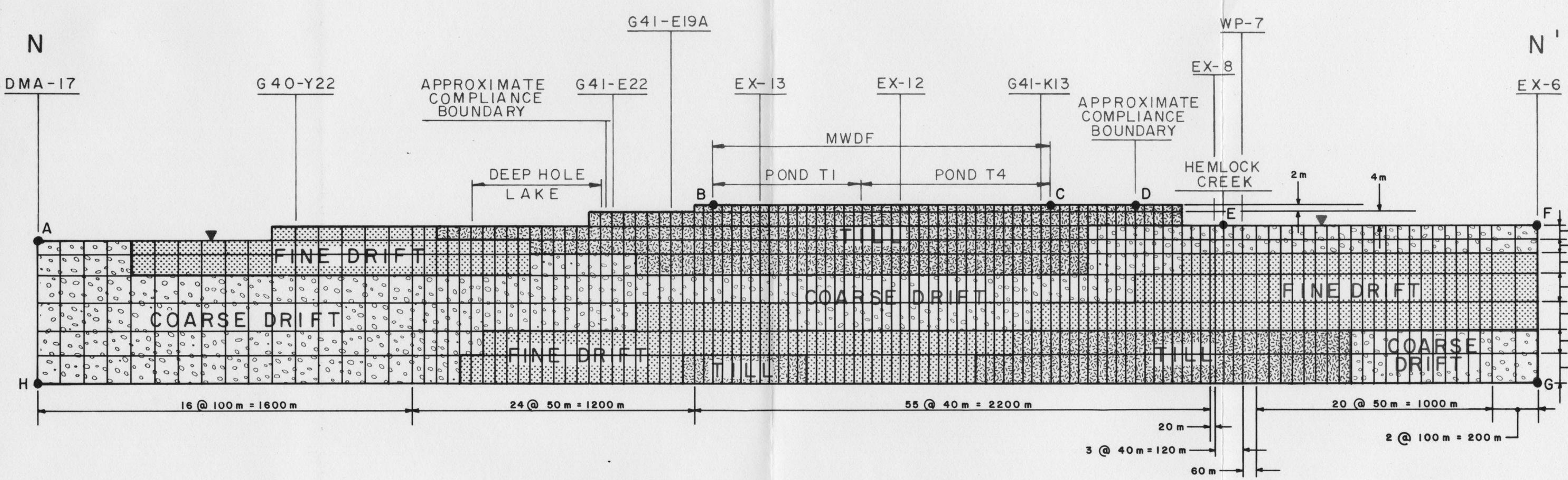
EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
IDEALIZED SATURATED HYDROGEOLOGIC CONDITIONS IN VERTICAL GEOLOGIC SECTION N-N'

SCALE AS SHOWN	STATE		COUNTY
DRAWN BY D. Weick	DATE 10-12-84	CHECKED BY MBS	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET ___ OF ___	REVISION NO.

13B 13B 50% BLK.

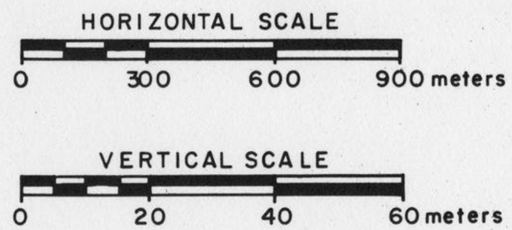
D'APPOLONIA — PROJ. NO. 846498 — DWG. NO. B21



LEGEND:

A ● POINTS REFERRED TO IN TEXT

▼ WATER TABLE (RECHARGE BOUNDARY)



NOTES:

1. FOR PLAN AND LOCATION OF SECTION N-N' REFER TO FIGURE A-8
2. VERTICAL EXAGGERATION 15X
3. THICKNESS OF ALL ELEMENTS IS 1 METER

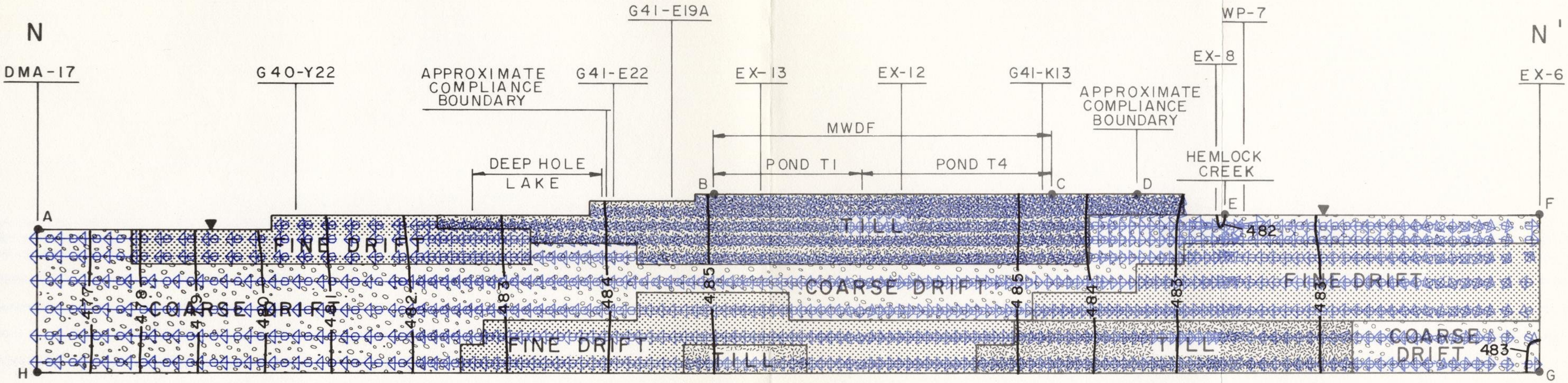
FIGURE A-26

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
GRID SYSTEM FOR VERTICAL SIMULATION OF GEOLOGIC SECTION N-N' SATURATED ZONE

SCALE AS SHOWN	STATE		COUNTY	
DRAWN BY D. Weick	DATE 10-12-84	CHECKED BY MDS		DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD		DATE 12/10/85
APPROVED BY	DATE	EXXON		DATE
DRAWING NO.			SHEET ___ OF ___	REVISION NO.

14 B	D'APPOLONIA	
14 B		
50% BLK.	PROJ. NO. 846498	DWG. NO. B22



LEGEND:

A ● POINTS REFERRED TO IN TEXT

—485— CALIBRATED POTENTIOMETRIC CONTOURS IN METERS ABOVE MSL

▼ WATER TABLE (RECHARGE BOUNDARY)

HORIZONTAL SCALE 0 300 600 900 meters

VERTICAL SCALE 0 20 40 60 meters

NOTES:

1. FOR PLAN AND LOCATION OF SECTION N-N' REFER TO FIGURE A-8.
2. VERTICAL EXAGGERATION 15X
3. LENGTH OF VECTOR IS PROPORTIONAL TO THE MAGNITUDE OF FLOW. EACH cm IS APPROXIMATELY EQUAL TO 0.08 m /day PER VERTICAL UNIT WIDTH IN METERS
4. INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7

FIGURE A-27

EXXON MINERALS COMPANY
CRANDON PROJECT

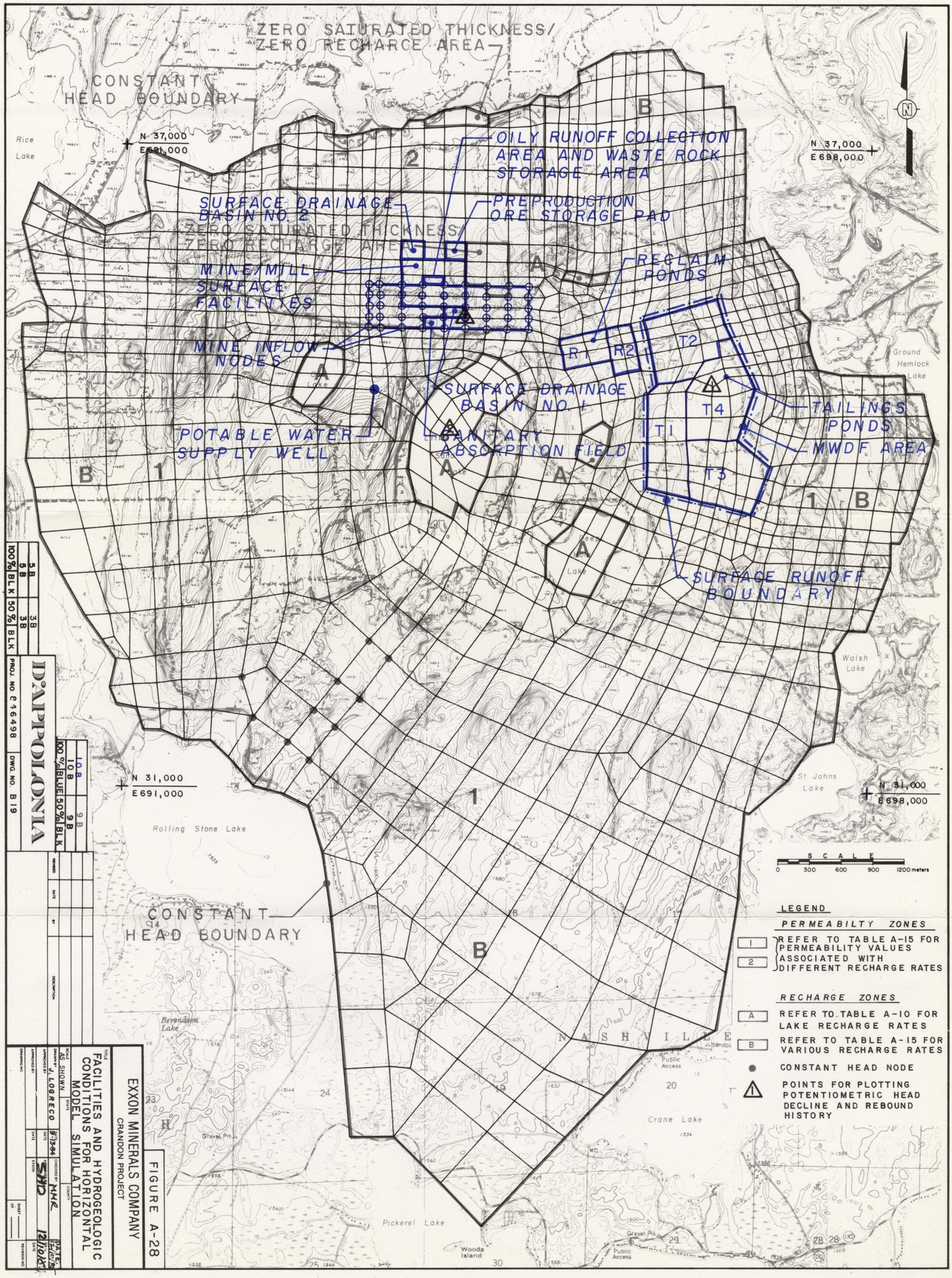
TITLE: CALIBRATED VERTICAL MODEL FOR MIDDLE RECHARGE CASE POTENTIOMETRIC CONTOURS AND FLOW VECTORS

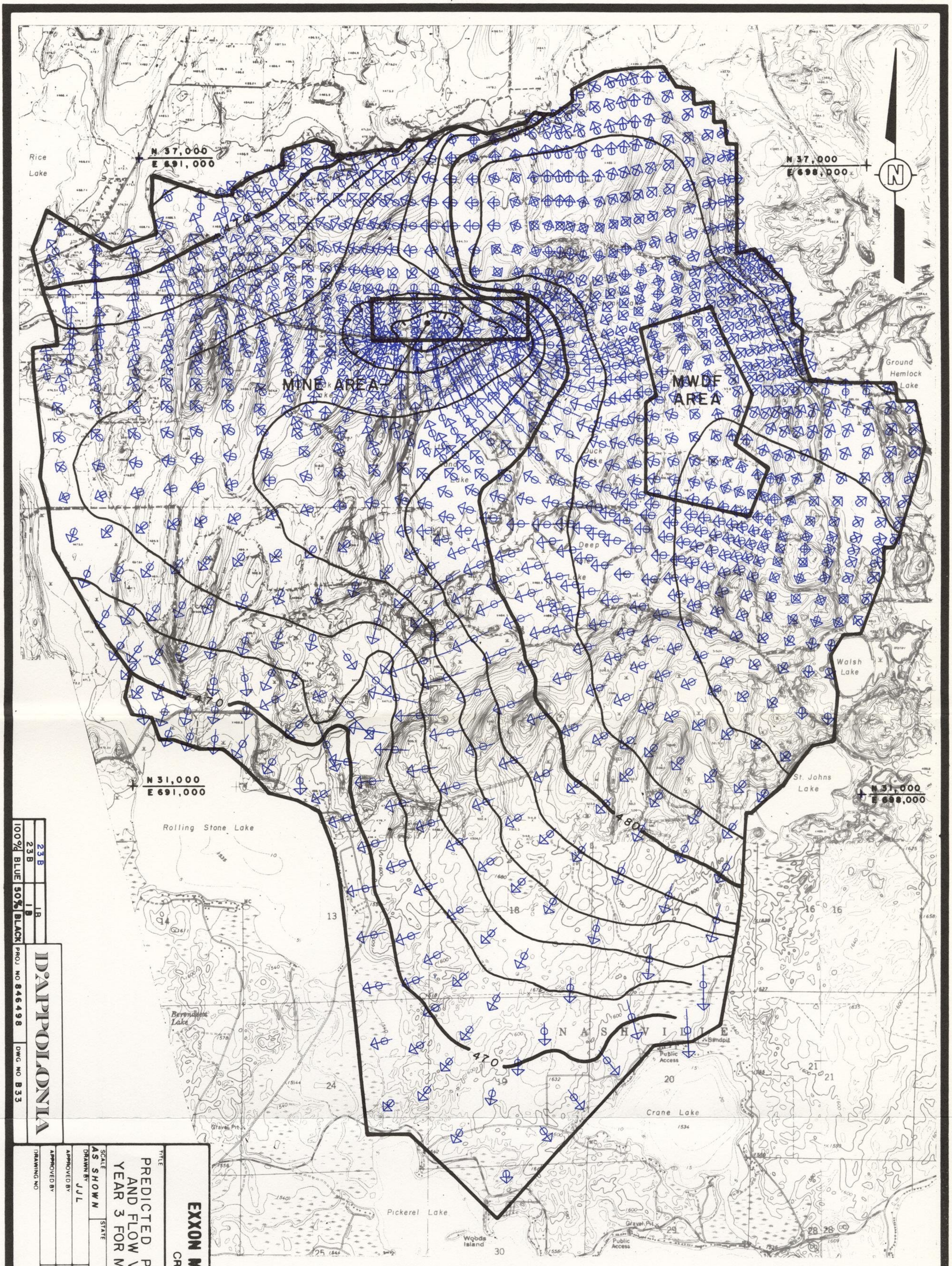
SCALE: AS SHOWN	STATE	COUNTY	
DRAWN BY: D. Weick	DATE: 10-12-84	CHECKED BY: MBL	DATE: 12/10/85
APPROVED BY	DATE	APPROVED BY: SHD	DATE: 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO.		SHEET ___ OF ___	REVISION NO.

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B39

26B	25B
26B	25B
50% BLU.	50% BLK


ZERO SATURATED THICKNESS/
ZERO RECHARGE AREA
CONSTANT HEAD BOUNDARY
N 37,000
E691,000
N 37,000
E698,000
Rice Lake
OILY RUNOFF COLLECTION AREA AND WASTE ROCK STORAGE AREA
SURFACE DRAINAGE BASIN NO. 2
PREPRODUCTION ORE STORAGE PAD
ZERO SATURATED THICKNESS/
ZERO RECHARGE AREA
MINE/MILL SURFACE FACILITIES
RECLAIM PONDS
MINE INFLOW NODES
R1
R2
T1
T2
T3
T4
SURFACE DRAINAGE BASIN NO. 1
Ground Hemlock Lake
TAILINGS PONDS
MWDF AREA
POTABLE WATER SUPPLY WELL
SANITARY ABSORPTION FIELD
SURFACE RUNOFF BOUNDARY
Walsh Lake
St. Johns Lake
N 31,000
E691,000
N 31,000
E698,000
Rolling Stone Lake
CONSTANT HEAD BOUNDARY
SCALE
0 300 600 900 1200 meters
LEGEND
PERMEABILTY ZONES
1
2
REFER TO TABLE A-15 FOR PERMEABILITY VALUES ASSOCIATED WITH DIFFERENT RECHARGE RATES
RECHARGE ZONES
A
REFER TO TABLE A-10 FOR LAKE RECHARGE RATES
B
REFER TO TABLE A-15 FOR VARIOUS RECHARGE RATES
CONSTANT HEAD NODE
POINTS FOR PLOTTING POTENTIOMETRIC HEAD DECLINE AND REBOUND HISTORY
NASHVILLE
Crane Lake
Pickerel Lake
Woods Island
D'APPOLONIA
PROJ. NO. 8 16498
DWG. NO. B19
FIGURE A-28
EXXON MINERALS COMPANY
CRANDON PROJECT
FACILITIES AND HYDROGEOLOGIC CONDITIONS FOR HORIZONTAL MODEL SIMULATION
AS SHOWN
J. LOGRECO



NOTE:

LENGTH OF VECTOR IS PROPORTIONAL TO THE MAGNITUDE OF FLOW. EACH cm IS APPROXIMATELY EQUAL TO 787.4 m^3/y PER HORIZONTAL UNIT WIDTH IN METERS.

SCALE

0 1000 2000 meters

LEGEND

470 PREDICTED POTENTIOMETRIC SURFACE IN METERS ABOVE MSL

PREDICTED FLOW VECTOR

FIGURE A-29

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE

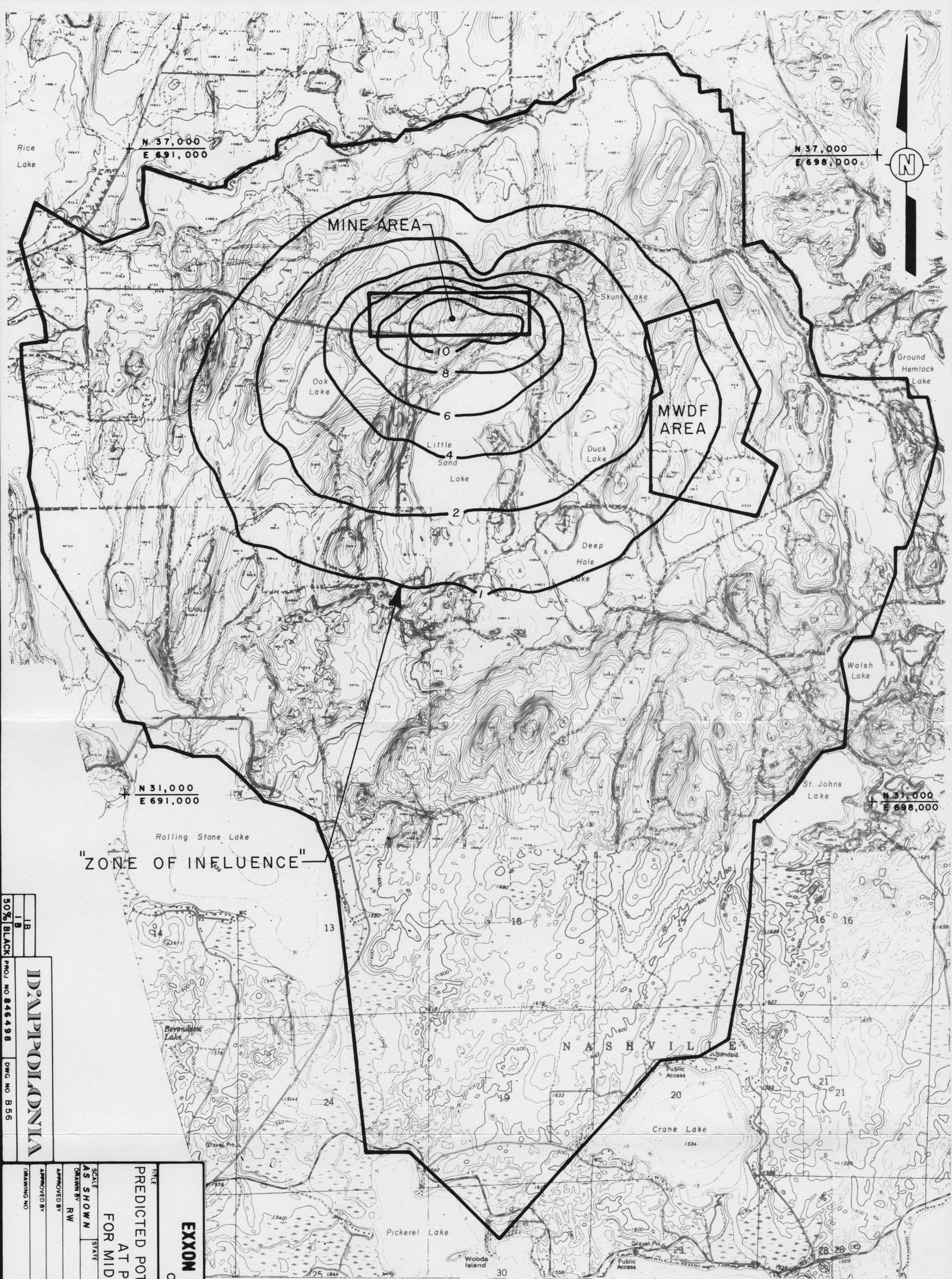
PREDICTED POTENTIOMETRIC SURFACE AND FLOW VECTORS AT PROJECT YEAR 3 FOR MIDDLE RECHARGE CASE

SCALE AS SHOWN	STATE		COUNTY
DRAWN BY J.J.L.	DATE 9-26-84	CHECKED BY MMK	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET OF	REVISION NO

D'APPOLONIA

PROJ. NO 846498 DWG NO B33

23B	
23B	1B
100% BLUE	50% BLACK



NOTE:

LIMIT OF ZONE OF INFLUENCE IS SET AT A MAXIMUM DRAWDOWN OF 1.0m (3.3 FEET)

LEGEND

—2— PREDICTED POTENTIOMETRIC DRAWDOWN IN METERS

SCALE

0 1000 2000 meters

FIGURE A-30

EXXON MINERALS COMPANY

CRANDON PROJECT

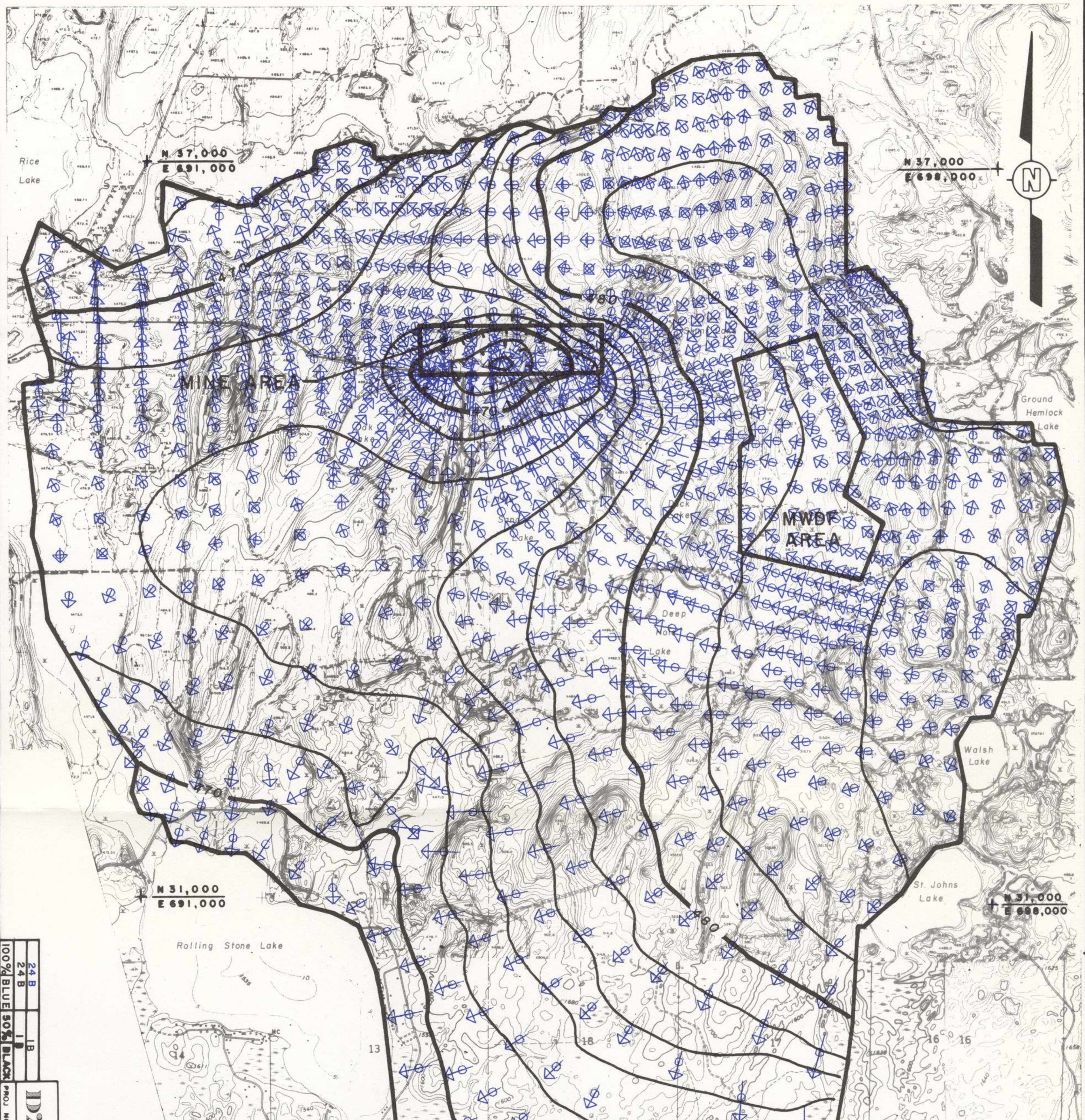
TITLE: PREDICTED POTENTIOMETRIC DRAWDOWN AT PROJECT YEAR 3 FOR MIDDLE RECHARGE CASE

SCALE AS SHOWN	STATE		COUNTY
DRAWN BY RW	DATE 9-26-84	CHECKED BY MMR	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	
DRAWING NO		SHEET OF	REVISION NO

D'APPOLONIA

PROJ NO 846498 DWG NO B56

50% BLACK 1B 1B



NOTE:

LENGTH OF VECTOR IS PROPORTIONAL TO THE MAGNITUDE OF FLOW. EACH cm IS APPROXIMATELY EQUAL TO 787.4 m^3/y PER HORIZONTAL UNIT WIDTH IN METERS.

SCALE

0 1000 2000 meters

LEGEND

470 — PREDICTED POTENTIOMETRIC SURFACE IN METERS ABOVE MSL

PREDICTED FLOW VECTOR

FIGURE A-31

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE: PREDICTED POTENTIOMETRIC SURFACE AND FLOW VECTORS AT PROJECT YEAR 28 FOR MIDDLE RECHARGE CASE

SCALE: AS SHOWN	STATE	COUNTY	
DRAWN BY: JJL	DATE: 9-26-84	CHECKED BY: MMR	DATE: 12/10/85
APPROVED BY	DATE	APPROVED BY: SHD	DATE: 12/10/85
EXXON	DATE		DATE
DRAWING NO		SHEET OF	REVISION NO

D'APPOLONIA PROJ. NO 846498 DWG NO B35

24B	24 B	1B
100% BLUE	50% BLACK	

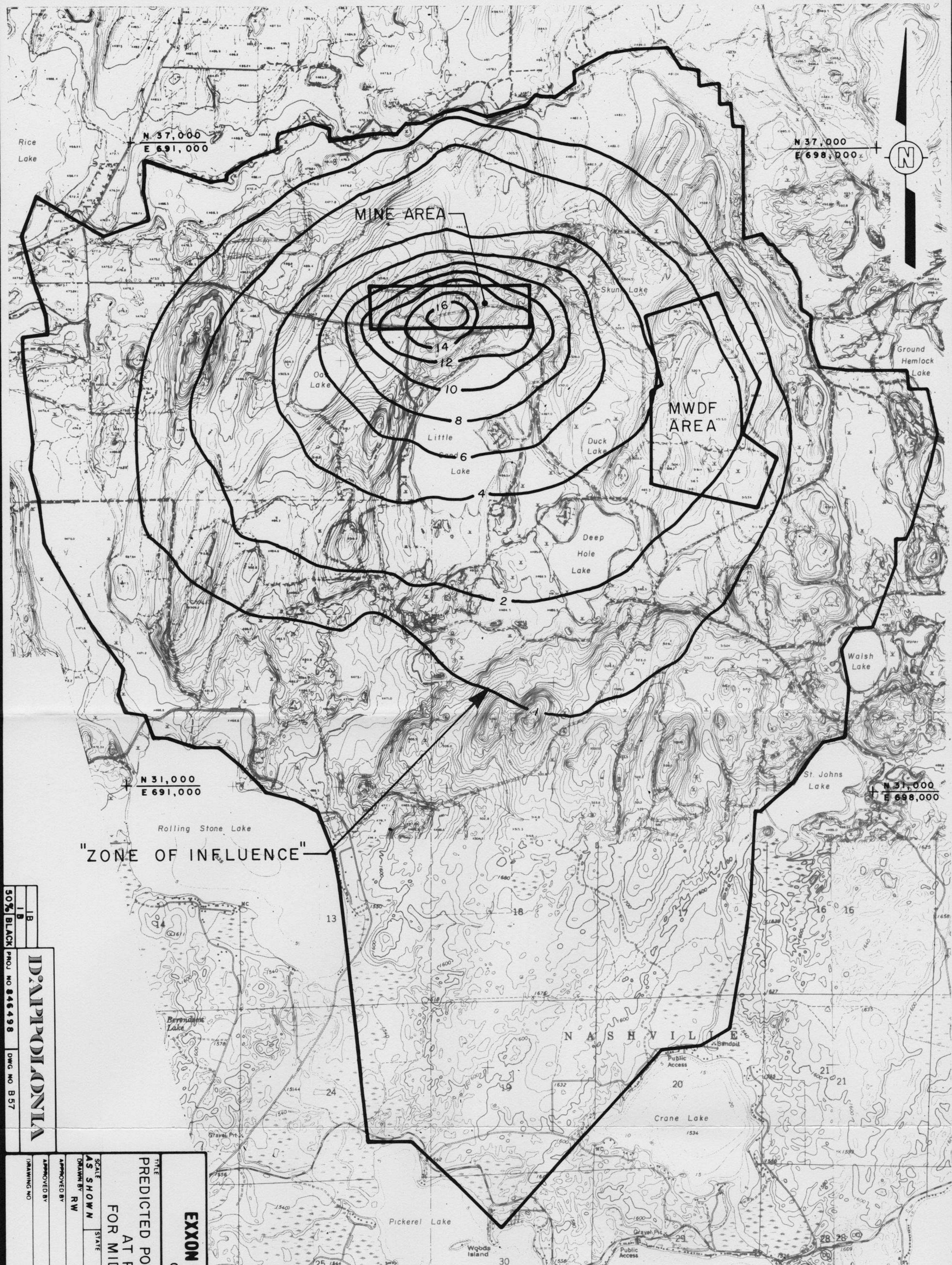


FIGURE A-32

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE: PREDICTED POTENTIOMETRIC DRAWDOWN AT PROJECT YEAR 28 FOR MIDDLE RECHARGE CASE

SCALE: AS SHOWN	STATE	COUNTY	
DRAWN BY: RW	DATE: 9-26-84	CHECKED BY: MMR	DATE: 12/10/85
APPROVED BY:	DATE	APPROVED BY: SMD	DATE: 12/10/85
APPROVED BY:	DATE	EXXON	DATE
DRAWING NO		SHEET __ OF __	REVISION NO

D'APPOLONIA — PROJ NO 846498 — DWG NO B57

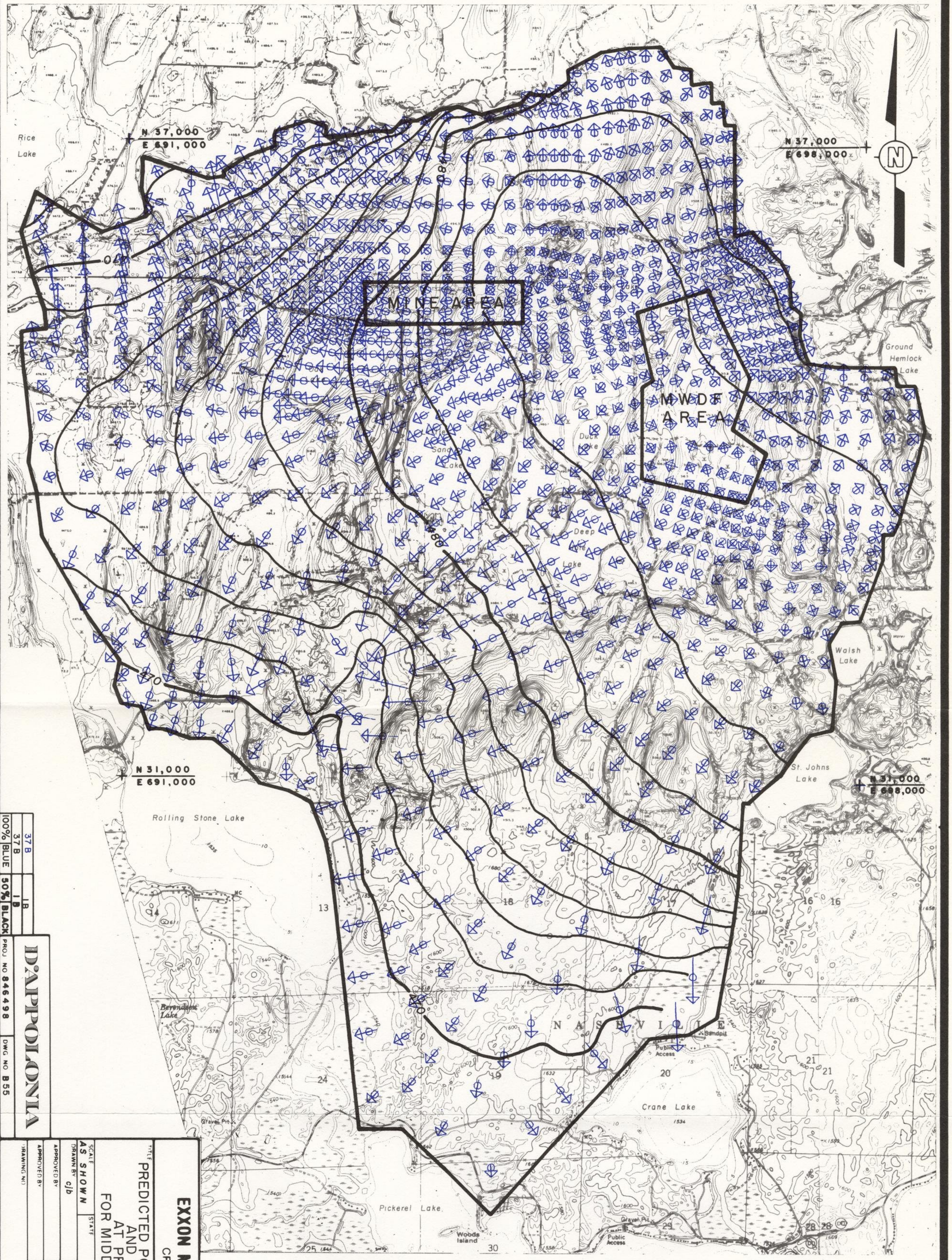
1B / 1B / 50% BLACK

NOTE:

LIMIT OF ZONE OF INFLUENCE IS SET AT A MAXIMUM DRAWDOWN OF 1.0m (3.3 FEET)

LEGEND

—2— PREDICTED POTENTIOMETRIC DRAWDOWN IN METERS



NOTE:

LENGTH OF VECTOR IS PROPORTIONAL TO THE MAGNITUDE OF FLOW. EACH cm IS APPROXIMATELY EQUAL TO 787.4 m^3/y PER HORIZONTAL UNIT WIDTH IN METERS.

SCALE

0 1000 2000 meters

LEGEND

470 PREDICTED POTENTIOMETRIC SURFACE IN METERS ABOVE MSL

PREDICTED FLOW VECTOR

FIGURE A-33

EXXON MINERALS COMPANY

CRANDON PROJECT

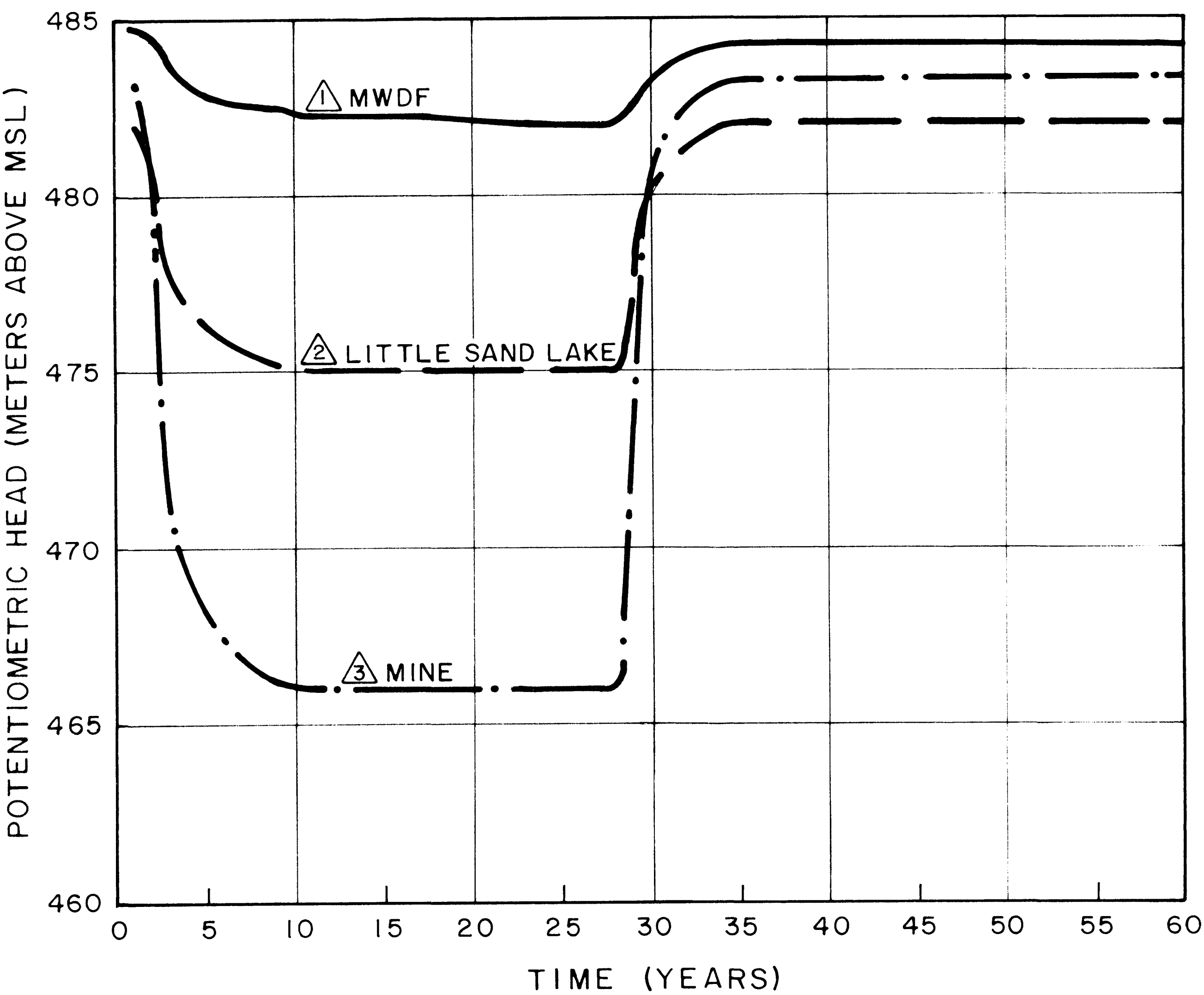
PREDICTED POTENTIOMETRIC SURFACE AND FLOW VECTORS AT PROJECT YEAR 60 FOR MIDDLE RECHARGE CASE

SCALE AS SHOWN	STATE		COUNTY
DRAWN BY cjb	DATE 10-10-84	CHECKED BY MMK	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHB	DATE 12/10/85
DRAWING NO.			REVISION NO.

D'APPOLONIA

PROJ NO 846498 DWG NO B55

37 B		
37 B	1 B	
100% BLUE	50% BLACK	



NOTE:

REFER TO FIGURE A-28 FOR LOCATION OF POINTS FOR PLOTTING POTENTIOMETRIC DECLINE AND REBOUND HISTORY.

FIGURE A-34

EXXON MINERALS COMPANY

CRANDON PROJECT

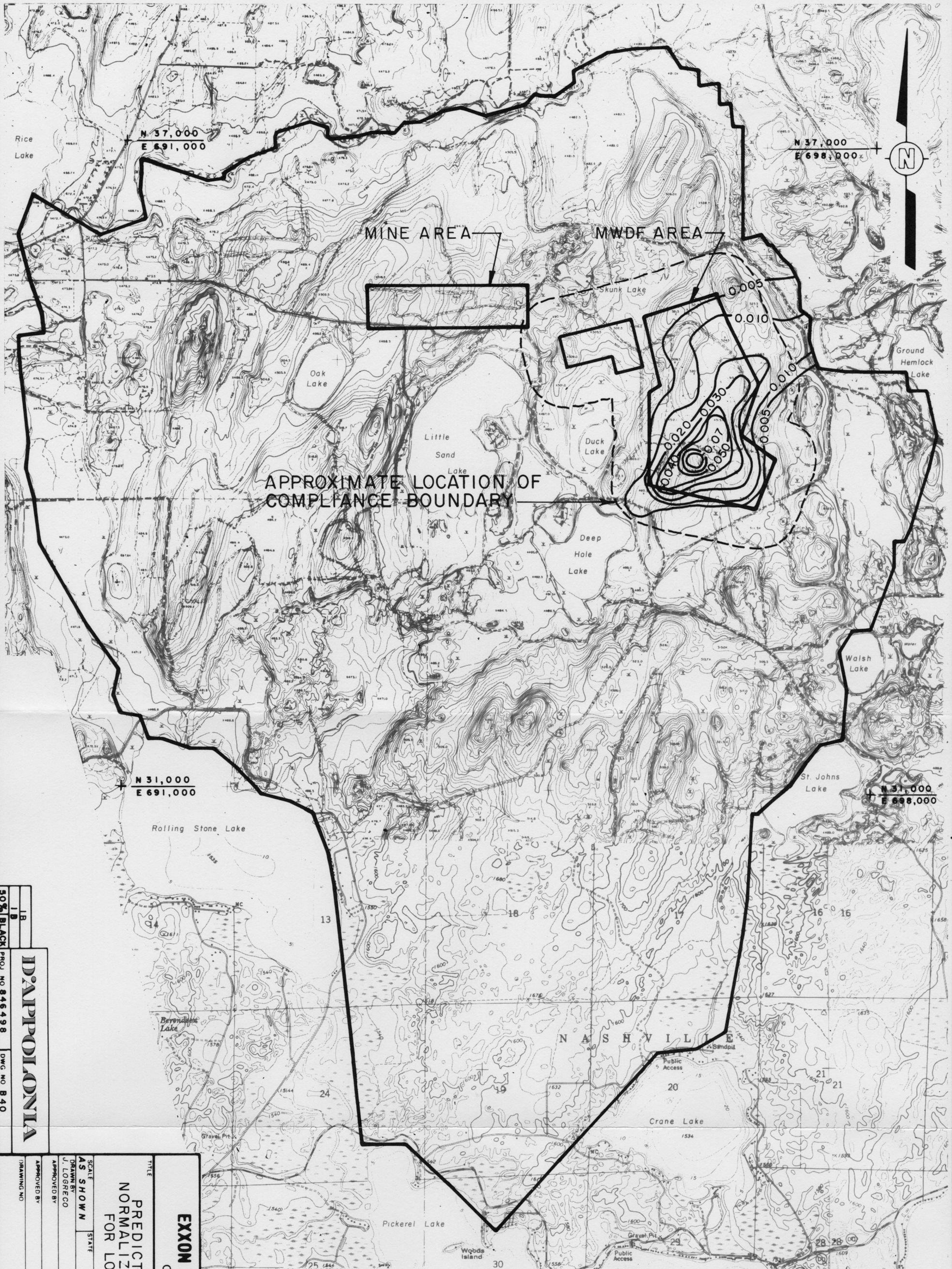
TITLE

POTENTIOMETRIC DECLINE AND REBOUND HISTORY FOR MIDDLE RECHARGE CASE

SCALE AS SHOWN	DATE		
DRAWN BY mel	DATE 10·11·84	CHECKED BY MMR	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET OF	REVISION NO

D'APPOLONIA

PROJ. NO. 846498 | DWG. NO. A-11



NOTES:

1. THE ANALYSIS ASSUMES A CONSTANT MASS FLUX AND A RETARDATION FACTOR OF 1.0
2. LONGITUDINAL DISPERSIVITY EQUALS 60 m (197 FEET) TRANSVERSE DISPERSIVITY EQUALS 15m (49 FEET)
3. OTHER INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7

LEGEND:

—0.010— NORMALIZED CONCENTRATION CONTOUR

FIGURE A-35

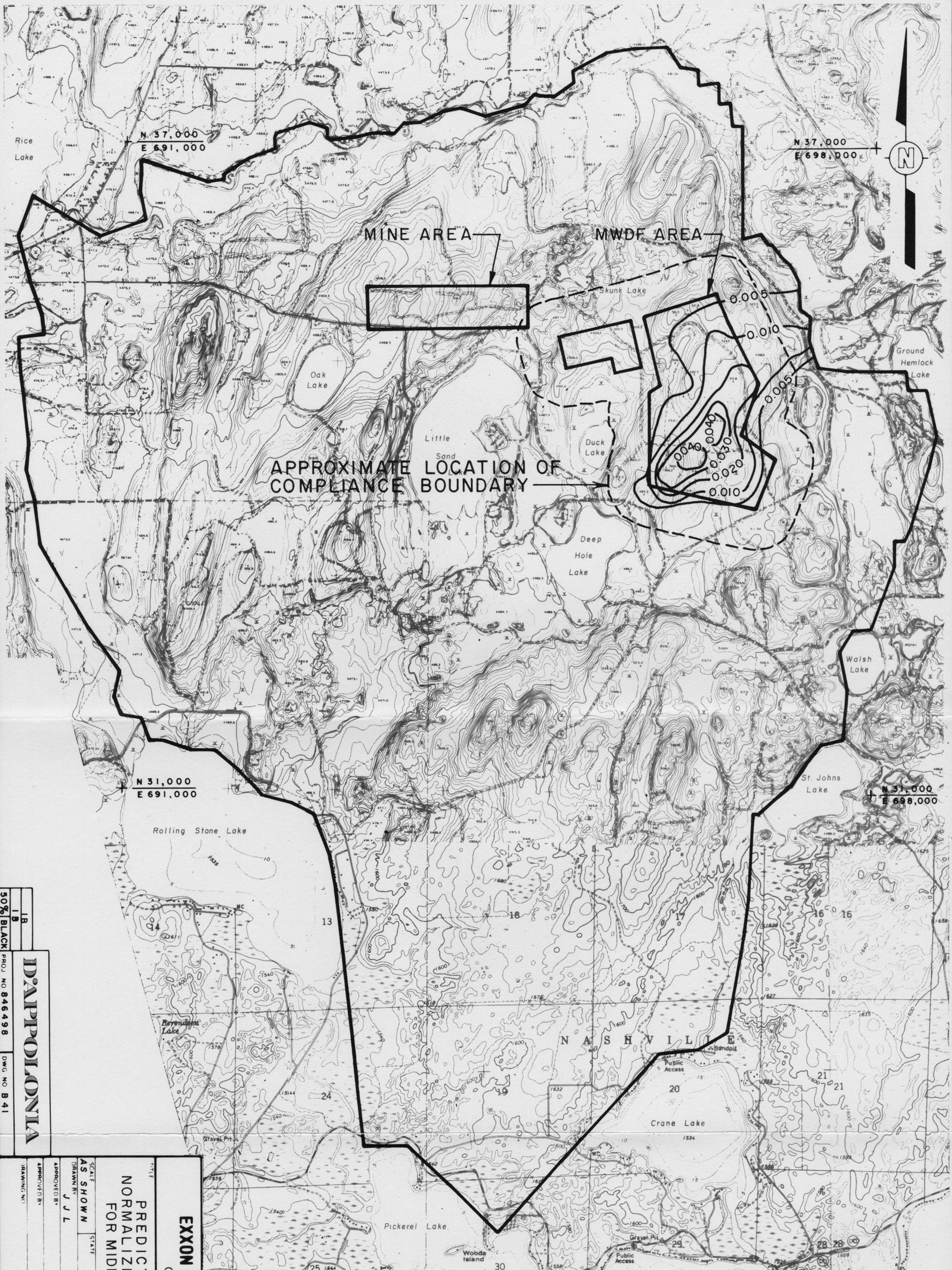
EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: PREDICTED STEADY STATE NORMALIZED CONCENTRATIONS FOR LOW RECHARGE CASE

SCALE: AS SHOWN	STATE	COUNTY	
DRAWN BY: J. LOGRECO	DATE: 9-21-84	CHECKED BY: MMK	DATE: 12/16/85
APPROVED BY:	DATE	APPROVED BY: SMD	DATE: 12/16/85
APPROVED BY:	DATE	EXXON	DATE
DRAWING NO		SHEET OF	REVISION NO

D'APPOLONIA
PROJ NO 846498 DWG NO B40

50% BLACK 1B 1B



NOTES:

1. THE ANALYSIS ASSUMES A CONSTANT MASS FLUX AND A RETARDATION FACTOR OF 1.0
2. LONGITUDINAL DISPERSIVITY EQUALS 60m (197 FEET) TRANSVERSE DISPERSIVITY EQUALS 15m (49FEET)
3. OTHER INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7

LEGEND:

—0.010— NORMALIZED CONCENTRATION CONTOURS

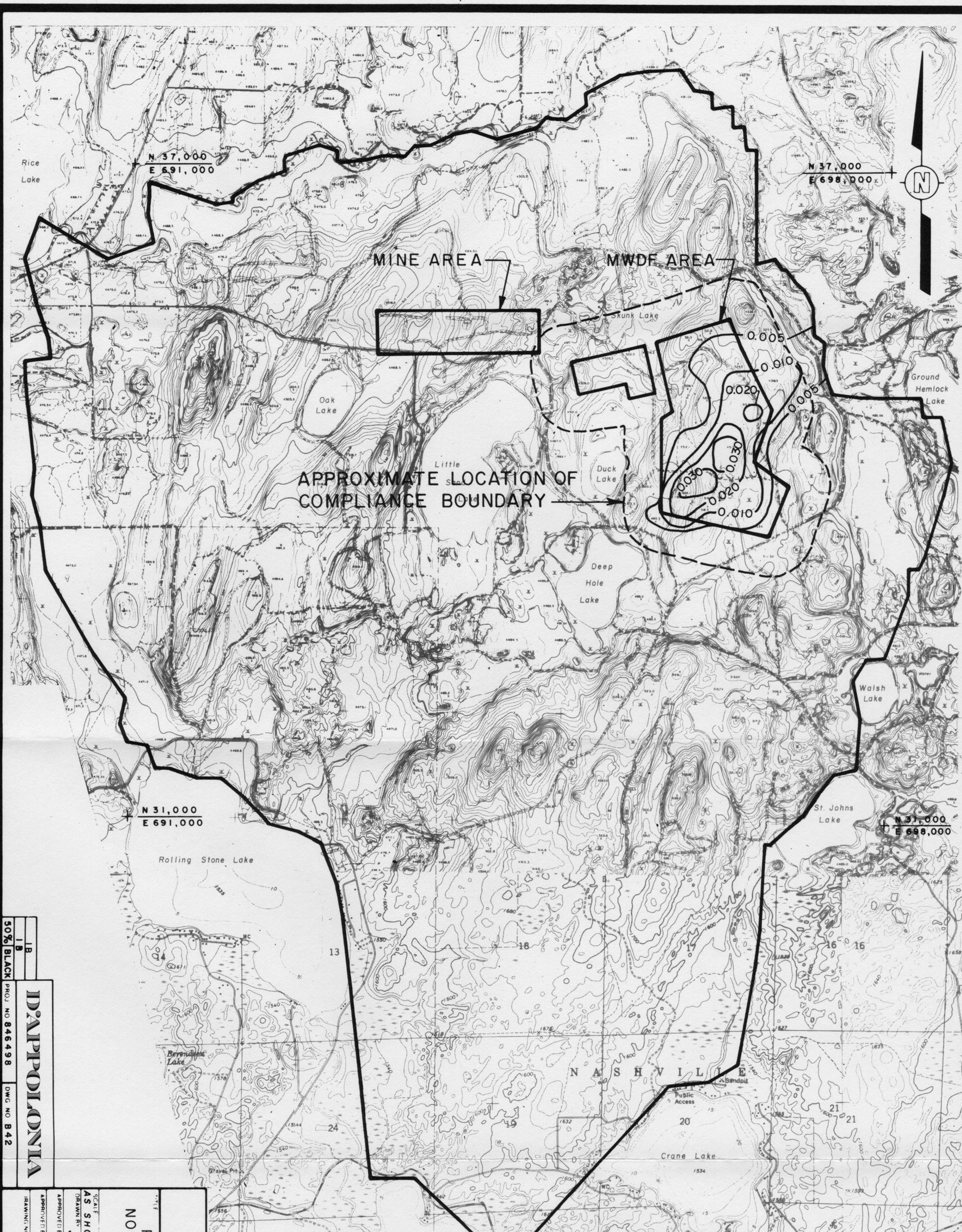
FIGURE A-36

EXXON MINERALS COMPANY
CRANDON PROJECT

PREDICTED STEADY STATE NORMALIZED CONCENTRATIONS FOR MIDDLE RECHARGE CASE

SCALE AS SHOWN	STATE	COUNTY	
DRAWN BY J J L	DATE 9-28-84	CHECKED BY MMK	DATE 12/11/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/11/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO.		SHEET	REVISION NO.

D'APPOLONIA
PROJ NO 846498 DWG NO B41
1B
50% BLACK



EXXON MINERALS COMPANY
CRANDON PROJECT

PREDICTED STEADY STATE NORMALIZED CONCENTRATIONS FOR HIGH RECHARGE CASE

FIGURE A-37

SCALE AS SHOWN	STATE	COUNTY
DRAWN BY J J L	DATE 9-28-84	
CHECKED BY MMK	DATE 12/10/85	
APPROVED BY SHD	DATE 12/10/85	
DRAWING NO.		REVISION NO.

D'APPOLONIA PROJ NO 846498 DWG NO B42

1B
1B
50% BLACK

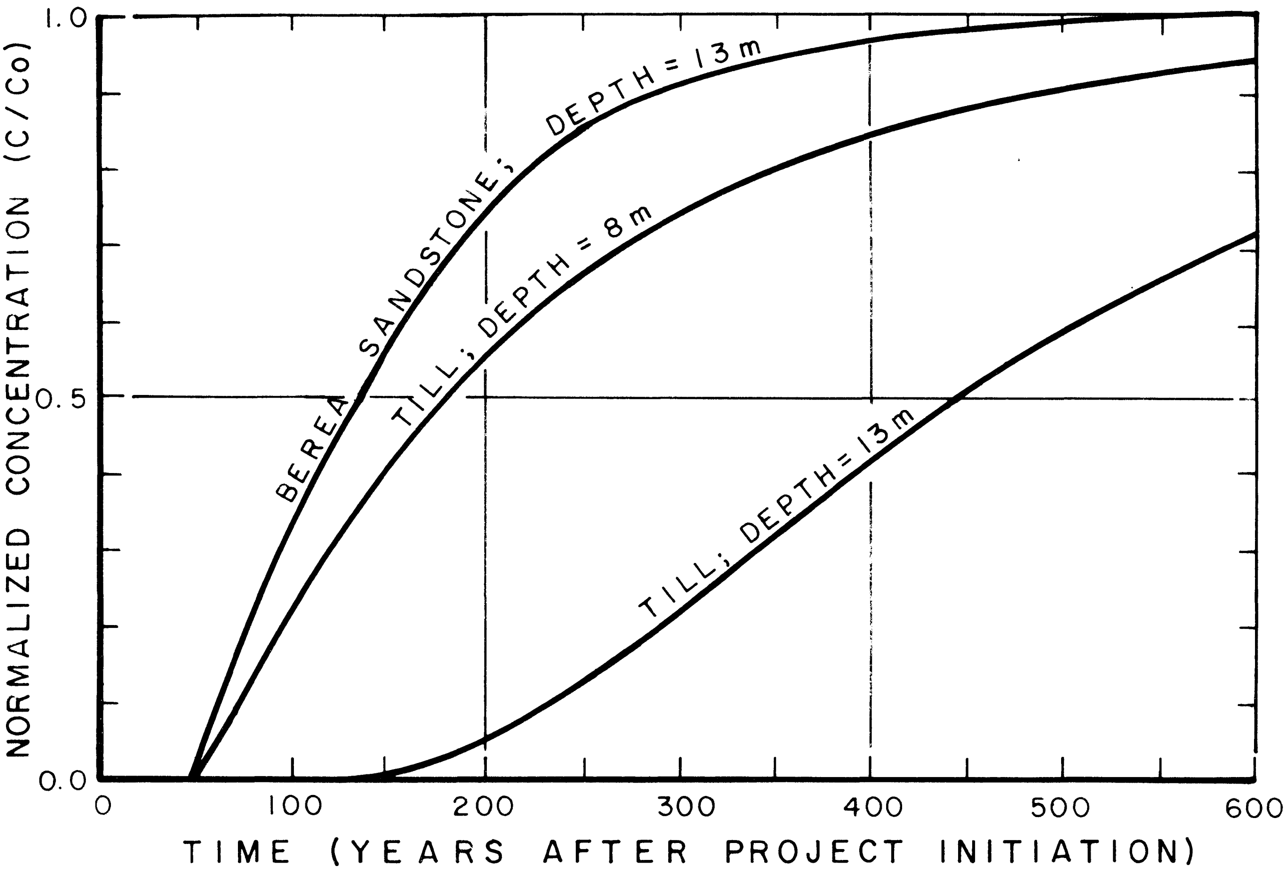
NOTES:

1. THE ANALYSIS ASSUMES A CONSTANT MASS FLUX AND A RETARDATION FACTOR OF 1.0
2. LONGITUDINAL DISPERSIVITY EQUALS 60 m (197 FEET) TRANSVERSE DISPERSIVITY EQUALS 15m (49 FEET)
3. OTHER INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7

SCALE
0 1000 2000 meters

LEGEND

—0.010— NORMALIZED CONCENTRATION CONTOUR



NOTES:

1. ANALYSIS ASSUMES A CONSTANT CONCENTRATION SOURCE AND A RETARDATION FACTOR OF 1.0
2. MODEL INCORPORATES TAILINGS POND T4 SEEPAGE RATE SCHEDULE AS SHOWN IN FIGURE A-3b
3. OTHER INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7

FIGURE A-38

EXXON MINERALS COMPANY

CRANDON PROJECT

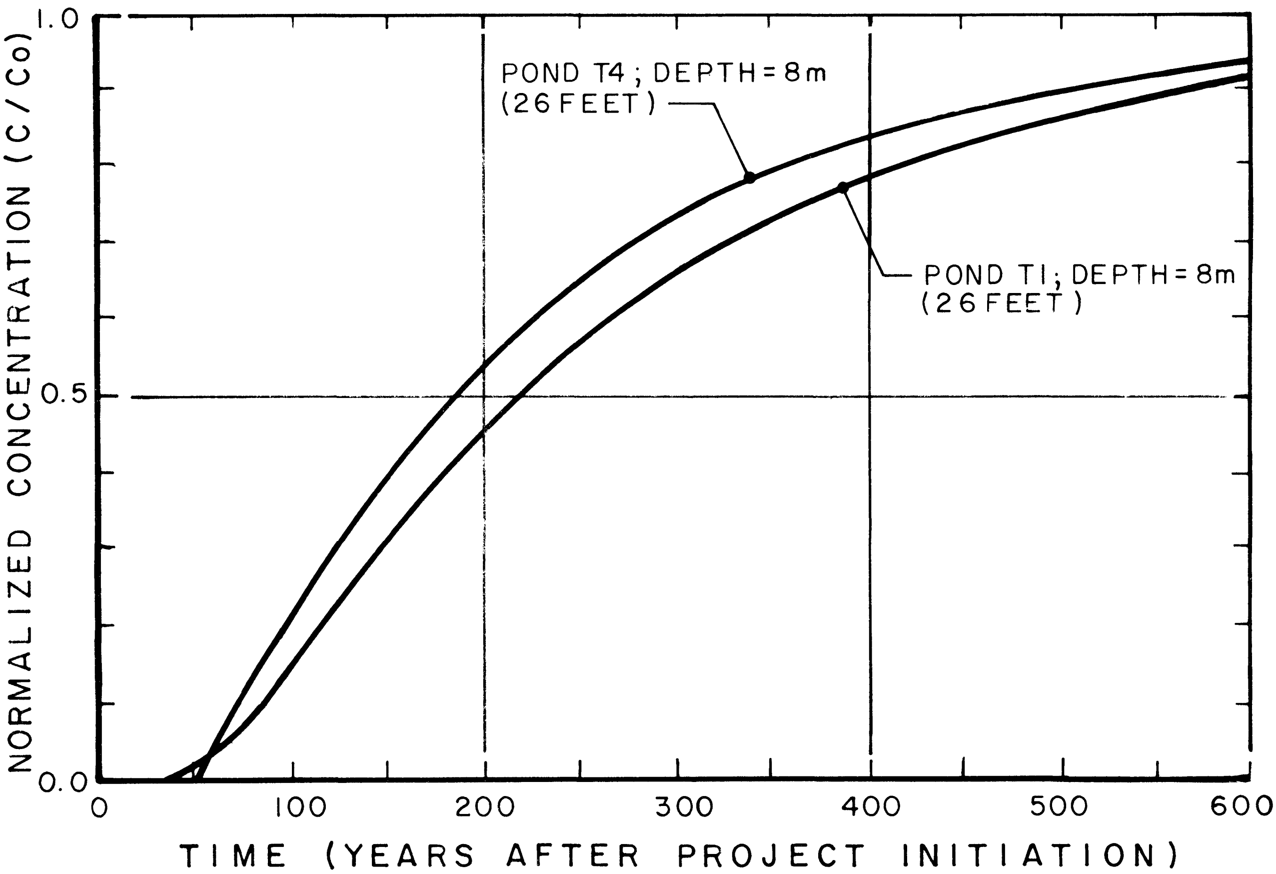
TITLE

COMPUTED NORMALIZED CONCENTRATIONS FOR PARTIALLY SATURATED TILL AND BEREA SANDSTONE

SCALE AS SHOWN	STATE	COUNTY	
DRAWN BY J J L	DATE 9·26·84	CHECKED BY MMR	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET ___ OF ___	REVISION NO

D'APPOLONIA

PROJ NO 846498 | DWG NO A8



NOTES:

1. ANALYSIS ASSUMES A CONSTANT CONCENTRATION SOURCE AND A RETARDATION FACTOR OF 1.0
2. MODEL INCORPORATES TAILINGS PONDS T1 AND T4 SEEPAGE RATE SCHEDULES AS SHOWN IN FIGURE A-3b
3. OTHER INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7

FIGURE A-39

EXXON MINERALS COMPANY

CRANDON PROJECT

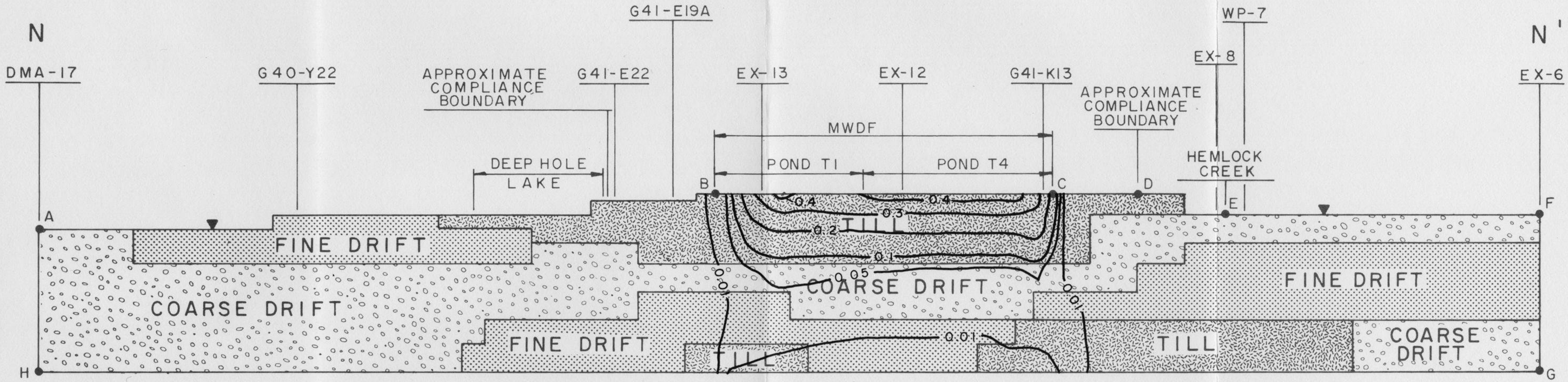
TITLE

COMPUTED NORMALIZED CONCENTRATIONS IN PARTIALLY SATURATED TILL BENEATH MWDF

SCALE AS SHOWN	DATE		
DRAWN BY J J L	DATE 9-26-84	CHECKED BY MMR	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE		DATE
DRAWING NO.		SHEET OF	REVISION NO.

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. A9



NOTES:

1. FOR PLAN AND LOCATION OF SECTION N-N' REFER TO FIGURE A-8
2. VERTICAL EXAGGERATION 15X
3. THE ANALYSIS ASSUMES A CONSTANT MASS FLUX AND A RETARDATION FACTOR OF 1.0
4. A RECHARGE RATE OF 216 mm/y (8.5 inch/y) IS USED
5. VERTICAL TO HORIZONTAL PERMEABILITY RATIO, TILL = 1/1, DRIFT = 1/50.
6. LONGITUDINAL DISPERSIVITY = 60 m (197 feet)
7. LONGITUDINAL TO TRANSVERSE DISPERSIVITY RATIO = 50
8. OTHER MODEL INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7.

LEGEND:

A ● POINTS REFERRED TO IN TEXT

—0.1— NORMALIZED CONCENTRATION CONTOUR

▼ WATER TABLE (RECHARGE BOUNDARY)

HORIZONTAL SCALE

0 300 600 900 meters

VERTICAL SCALE

0 20 40 60 meters

FIGURE A-40

EXXON MINERALS COMPANY
CRANDON PROJECT

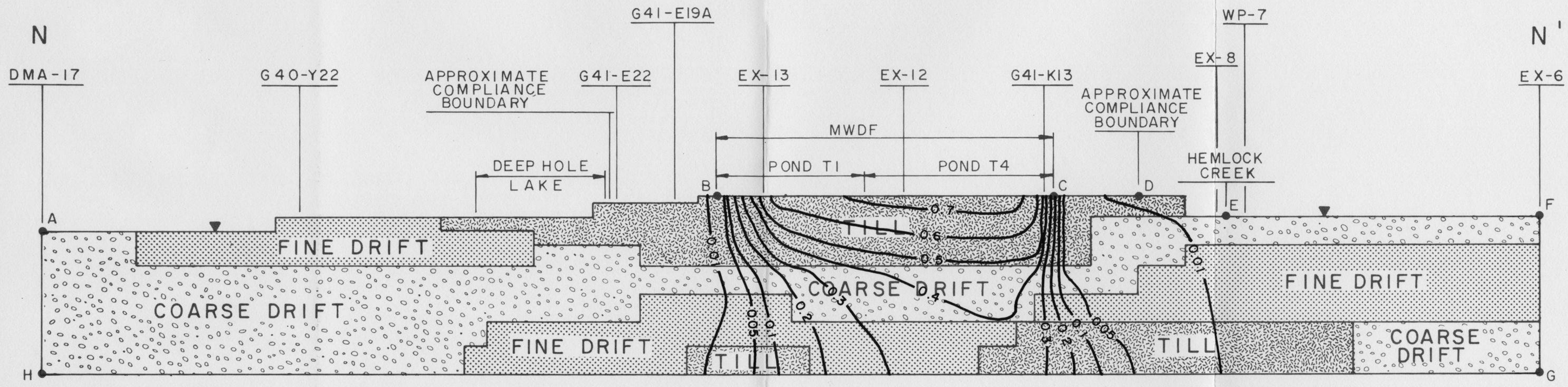
TITLE
PREDICTED NORMALIZED CONCENTRATIONS AT YEAR 800 FOR SECTION N-N' FOR MIDDLE RECHARGE CASE

SCALE AS SHOWN	STATE		COUNTY
DRAWN BY D. Weick	DATE 10-12-84	CHECKED BY MDS	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET ___ OF ___	REVISION NO

28B
28B
50% BLK.

D'APPOLONIA

PROJ NO 846498 DWG NO B44



NOTES:

1. FOR PLAN AND LOCATION OF SECTION N-N' REFER TO FIGURE A-8
2. VERTICAL EXAGGERATION 15X
3. THE ANALYSIS ASSUMES A CONSTANT MASS FLUX AND A RETARDATION FACTOR OF 1.0
4. A RECHARGE RATE OF 216 mm/y (8.5 inch/y) IS USED
5. VERTICAL TO HORIZONTAL PERMEABILITY RATIO, TILL = 1/1, DRIFT = 1/50.
6. LONGITUDINAL DISPERSIVITY = 60 m (197 feet)
7. LONGITUDINAL TO TRANSVERSE DISPERSIVITY RATIO = 50
8. OTHER MODEL INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7.

LEGEND:

A ● POINTS REFERRED TO IN TEXT

—0.1— NORMALIZED CONCENTRATION CONTOUR

▼ . WATER TABLE (RECHARGE BOUNDARY)

HORIZONTAL SCALE

0 300 600 900 meters

VERTICAL SCALE

0 20 40 60 meters

FIGURE A-41

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE

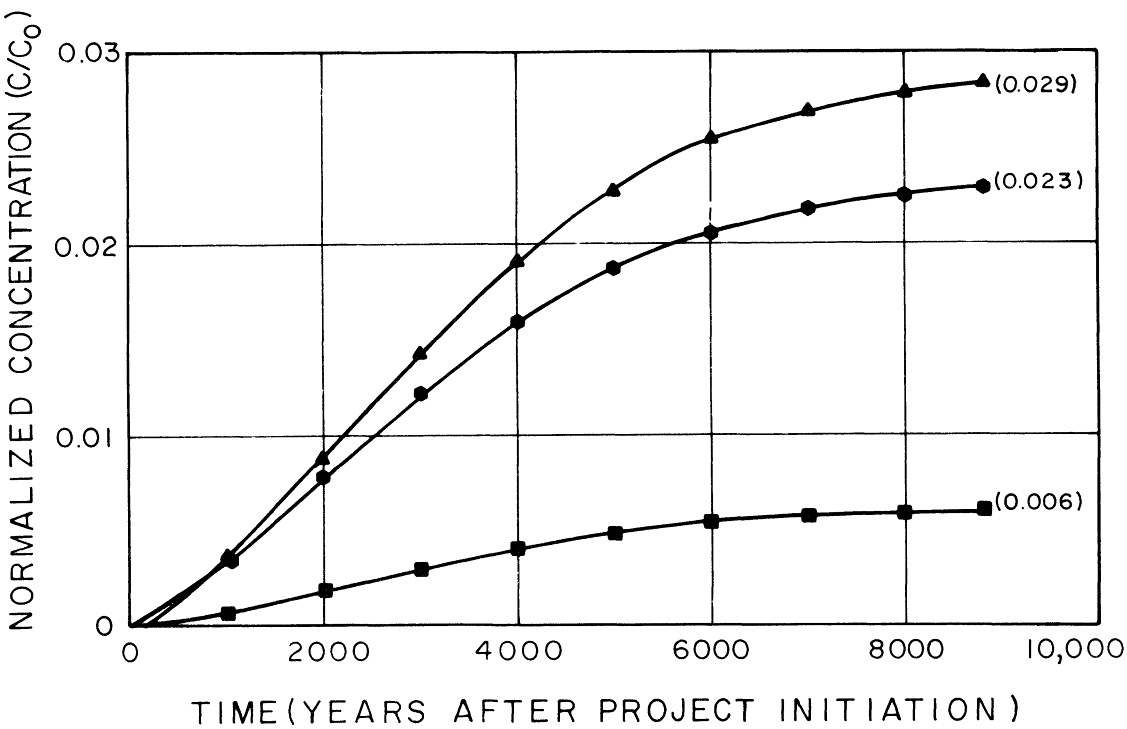
PREDICTED NORMALIZED CONCENTRATIONS AT YEAR 4800 FOR SECTION N-N' FOR MIDDLE RECHARGE CASE

SCALE	STATE	COUNTY	
AS SHOWN			
DRAWN BY D. Weick	DATE 10.12.84	CHECKED BY MBA	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO.		SHEET ___ OF ___	REVISION NO.

28B
28B
50% BLK.

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B43



LEGEND:

NORMALIZED CONCENTRATIONS PRESENTED FOR THE FOLLOWING LOCATIONS:

- ▲ COMPLIANCE BOUNDARY, 36 m (118 FEET) BELOW WATER TABLE (BOTTOM OF FINE DRIFT)
- ● EASTERN EDGE OF MWDF EMBANKMENT, 6 m (20 FEET) BELOW WATER TABLE
- ■ HEMLOCK CREEK AT WATER TABLE

(0.029) PREDICTED STEADY-STATE CONCENTRATION

NOTES:

1. FOR SECTION N-N' LOCATION REFER TO FIGURE A-8
2. VERTICAL TO HORIZONTAL PERMEABILITY RATIO, TILL = 1/1, DRIFT = 1/50
3. LONGITUDINAL DISPERSIVITY = 60m (197 feet)
4. LONGITUDINAL TO TRANSVERSE DISPERSIVITY RATIO = 50
5. OTHER MODEL INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7.

FIGURE A-42

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE: PREDICTED NORMALIZED CONCENTRATION VERSUS TIME SECTION N-N' FOR MIDDLE RECHARGE CASE

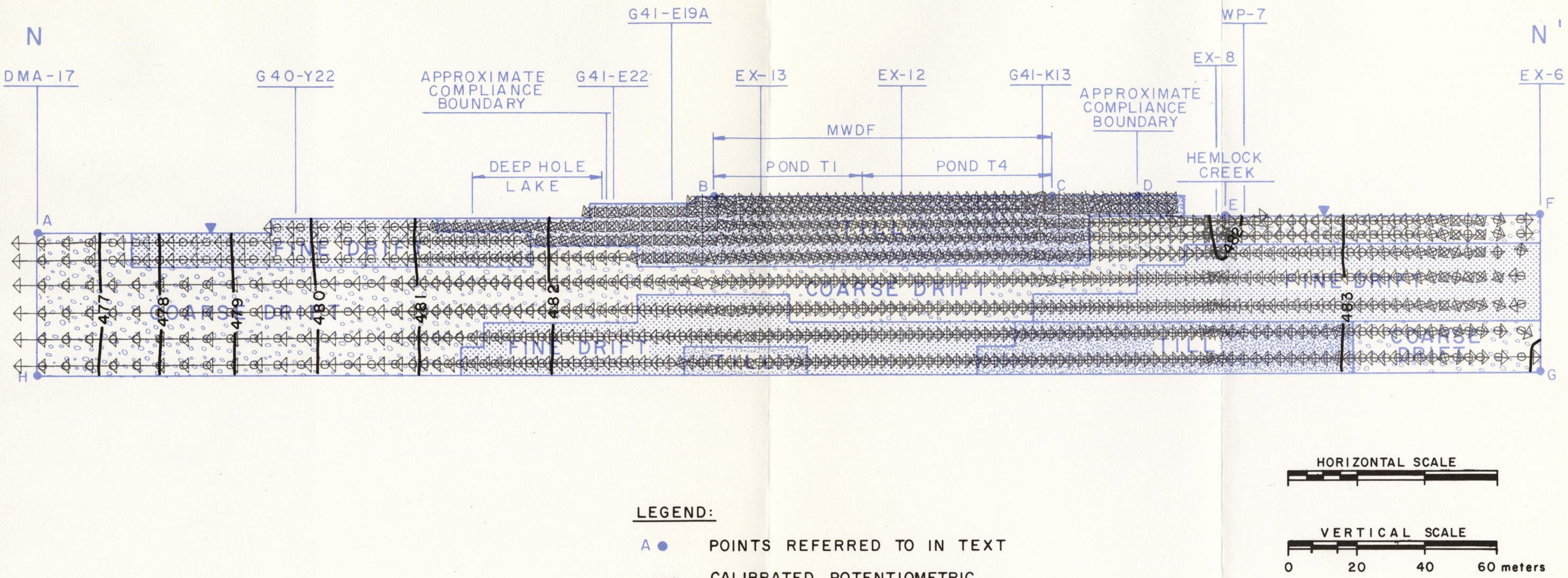
SCALE: AS SHOWN

DRAWN BY: D. Weick DATE: 9-26-84 CHECKED BY: MDA 12/10/85

APPROVED BY: SHD 12/10/85

D'APPOLONIA

PROJ NO 846498 DWG NO A10



LEGEND:

A ● POINTS REFERRED TO IN TEXT

—481— CALIBRATED POTENTIOMETRIC CONTOURS IN METERS ABOVE MSL

▼ WATER TABLE (RECHARGE BOUNDARY)

NOTES:

1. FOR PLAN AND LOCATION OF SECTION N-N' REFER TO FIGURE A-8
2. VERTICAL EXAGGERATION 15X
3. LENGTH OF VECTOR IS PROPORTIONAL TO THE MAGNITUDE OF FLOW. EACH cm IS APPROXIMATELY EQUAL TO 0.04 m/day PER VERTICAL UNIT WIDTH IN METERS
4. INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7

FIGURE A-43

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: CALIBRATED VERTICAL MODEL PREDICTED POTENTIOMETRIC CONTOURS AND FLOW VECTORS FOR TRANSIENT CHEMICAL CONSTITUENT TRANSPORT MODELING

SCALE: As Shown	STATE		COUNTY		
DRAWN BY: J. LoGreco	DATE: 8-22-85	CHECKED BY: MDS		DATE: 12/10/85	
APPROVED BY	DATE	APPROVED BY: SHD		DATE: 12/10/85	
APPROVED BY	DATE	EXXON		DATE	
DRAWING NO			SHEET ___ OF ___	REVISION NO.	

45 B	44 B
45 B	44 B
50% BLU.	50% BLK

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B72

ATTACHMENT A.1

PARTIALLY SATURATED TILL PERMEABILITY CALCULATION

ATTACHMENT A.1

TABLE OF CONTENTS

ATTACHMENT A.1

LIST OF FIGURES

FIGURE NO.	TITLE

ATTACHMENT A.1

PARTIALLY SATURATED TILL PERMEABILITY CALCULATION

A.1.1 INTRODUCTION

Moisture flow through soils is controlled by a number of factors including the porosity and particle size distribution of the soil, the chemical composition of both the soil and fluid, and the percent saturation (ratio of the fluid volume to the total void volume) of the soil. The percent saturation is especially important for partially saturated materials having low permeability which are well below 100 percent saturated; this can result in substantially reduced effective permeabilities from those for the completely saturated condition. A number of procedures are available for determining, by direct measurement, the partially saturated permeability of soils (Olson and Daniel, 1981). In many instances, however, the determination of partially saturated flow characteristics through soils can be simplified by developing a relationship between suction pressure (p_c) and percent saturation (S_r) in the laboratory and by using the empirical relationships between partially saturated permeability (K_u) and p_c versus S_r as described by Corey (1977). These results can then be used in relatively simple or numerically complex models to estimate the time, rate and quantity of moisture flow for a variety of field applications.

The relationship between p_c and S_r is nonlinear and hysteretic depending on the moisture flow path (i.e., wetting or drying cycle). In general, suction decreases with increasing saturation until a limiting condition of $p_c = 0$ at $S_r = 100$ percent is achieved.

A number of laboratory procedures are available to develop p_c versus S_r relationships for particular soils. These include:

1. Direct water column measurement
2. Tensiometers
3. Pressure plates
4. Thermocouple psycrometers

Because each of these procedures can be used within a limited suction range, a particular approach must be selected based on the particle size distribution and the percent saturation of the soil. Accordingly, direct measurement is suitable for predominantly sandy soils which can maintain limited suction (<3/4 atmosphere) within the voids, while each of the others can be effectively used with decreasing particle size. As an example, thermocouple psycrometers can be used for a range of fine-grained soils with an effective suction pressure ranging from 2 to 80 atmospheres.

A.1.2 TEST METHODOLOGY FOR SUCTION HEADS

A split fraction from a composite till sample (Composite No. 1, D'Appolonia, 1982) was sent to Dr. David B. McWhorter at the Colorado State University for testing. Suction pressure-percent saturation relationships were developed using a direct measurement technique with a wetting cycle for the soil. The till sample was compacted to and tested at a dry density of 1,870 kg/m^3 (116.7 pounds per cubic foot), which yielded a porosity of 0.307.

The apparatus used consisted of a saturated porous plate inserted into a lucite cup. A high-air entry porous plate is attached to a sensitive direct reading electronic digital balance. The test is conducted by compacting a test specimen in the lucite cup to the required dry density and moisture content, placing a thin paraffin sheet over the sample to prevent moisture evaporation, allowing the system to equilibrate, and measuring the initial sample weight and suction. The moisture content of the sample is then increased by removing the seal, adding a few drops of water, replacing the seal, and recording changes in the sample weight and suction following equilibration. This step is repeated until the suction is reduced to zero. The balance and pressure transducer are calibrated prior to each test and checked at the completion of each test.

A.1.3 TEST RESULTS AND DISCUSSION

The test results are presented in Figure A.1-1. This curve reveals a nonlinear relationship between suction pressure and percent saturation which is typical for the composite soil type that was tested.

A.1.4 DETERMINATION OF PARTIALLY SATURATED PERMEABILITY

The relationship between K_u and S_r for the till was approximated using the empirical method developed by Brooks and Corey (Corey, 1977). Brooks and Corey suggest that the partially saturated permeability K_u can be approximated by the following equation:

$$K_u = KC^{\varepsilon} \qquad \text{(A.1.1)}$$

where K is the fully saturated permeability of soil, and ε and C are defined by Equations A.1.2, A.1.3a, and A.1.3b.

$$\text{as} \quad \varepsilon = \frac{2 + 3\lambda}{\lambda} \qquad \text{(A.1.2)}$$

$$\text{and} \quad C = \frac{P_d}{P_c}^{\lambda} \qquad \text{(A.1.3a)}$$

$$\text{or} \quad C = \frac{S_r - S_o}{1 - S_o} \qquad \text{(A.1.3b)}$$

where

P_d = displacement pressure

S_o = the residual saturation

λ = a curve fitting parameter

The values of the unknown parameters P_d, S_o, and λ are obtained from a P_c versus S_r curve (Figure A.1-1) by a trial-and-error method using both Equations A.1.3a and A.1.3b.

In this procedure, a value for S_o is assumed and the value of C from Equation A.1.3b is calculated. Then C is plotted against p_c on semi-logarithmic paper with p_c on the logarithmic axis. If the selected S_o is appropriate, most calculated points will fall in a nearly straight line. The parameter λ equals the slope of this nearly straight line, and P_d equals p_c intercepted by the line. The trial-and-error procedure continues until the proper line is obtained.

After P_d and λ are determined, Equations A.1.1 and A.1.3a are used to determine the relationship between permeability and suction pressure. Equations A.1.1 and A.1.3b are utilized to obtain the relationship between permeability and percent saturation.

Using the technique outlined, the following values were obtained for partially saturated till:

$$P_d = 1.75 \text{ cm}$$

$$S_o = -0.36^{(1)}$$

$$\lambda = 0.153$$

$$\varepsilon = 16.072$$

and hence,

$$K_u = K\, C^{16.072}$$

where $$C = \frac{S_r + 0.36}{1.36}$$

Using this relationship, the relationship between relative permeability and S_r was calculated and the results are presented in Figure A.1-2. Relative permeability equals partially saturated permeability (K_u) divided by saturated permeability (K).

---

(1) The physical meaning of a negative S_o is uncertain and is used as a parameter for curve-fitting purposes (Corey, 1977).

ATTACHMENT A.1

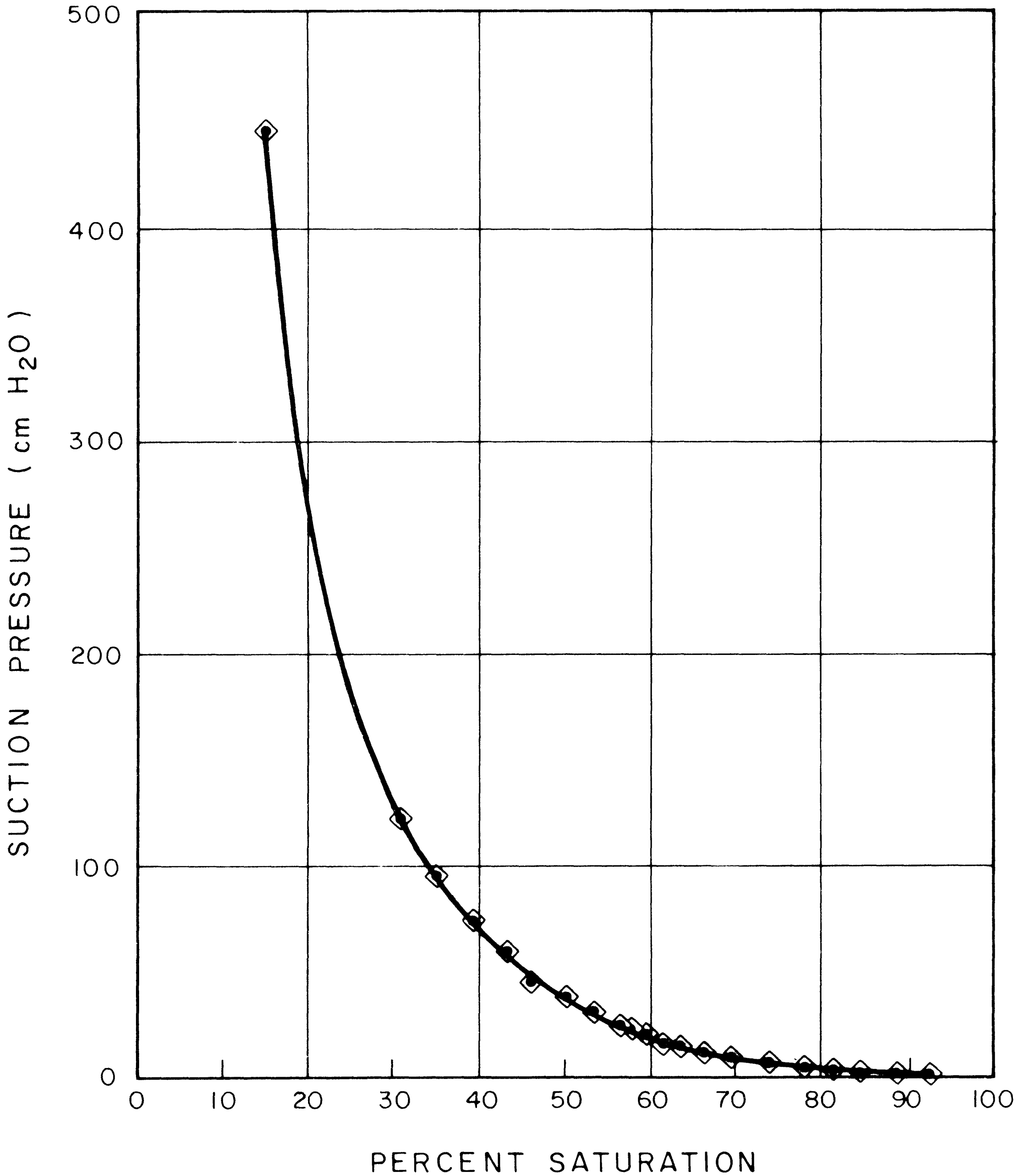
REFERENCES

Corey, A. T., 1977, "Mechanics of Heterogeneous Fluids in Porous Media," Fort Collins, Colorado, Water Resources Publications.

D'Appolonia Consulting Engineers, Inc., 1982, "Ground Water/Soil Attenuation Study," Vol. 1 of 2, Exxon Minerals Company, Crandon Project, D'Appolonia, Pittsburgh, Pennsylvania.

Olson, R. E. and D. E. Daniel, 1981, "Measurement of the Hydraulic Conductivity of Fined-Grained Soils in Permeability and Groundwater Contaminant Transport," American Society for Testing and Materials, STP 746, p. 18-64.

FIGURES



NOTES:

1. DETERMINED FOR WETTING CYCLE
2. SAMPLE DRY DENSITY = 1.87 g/cm^3
3. 1 ATMOSPHERE = 1033 cm H_2O

FIGURE A.1-1

EXXON MINERALS COMPANY

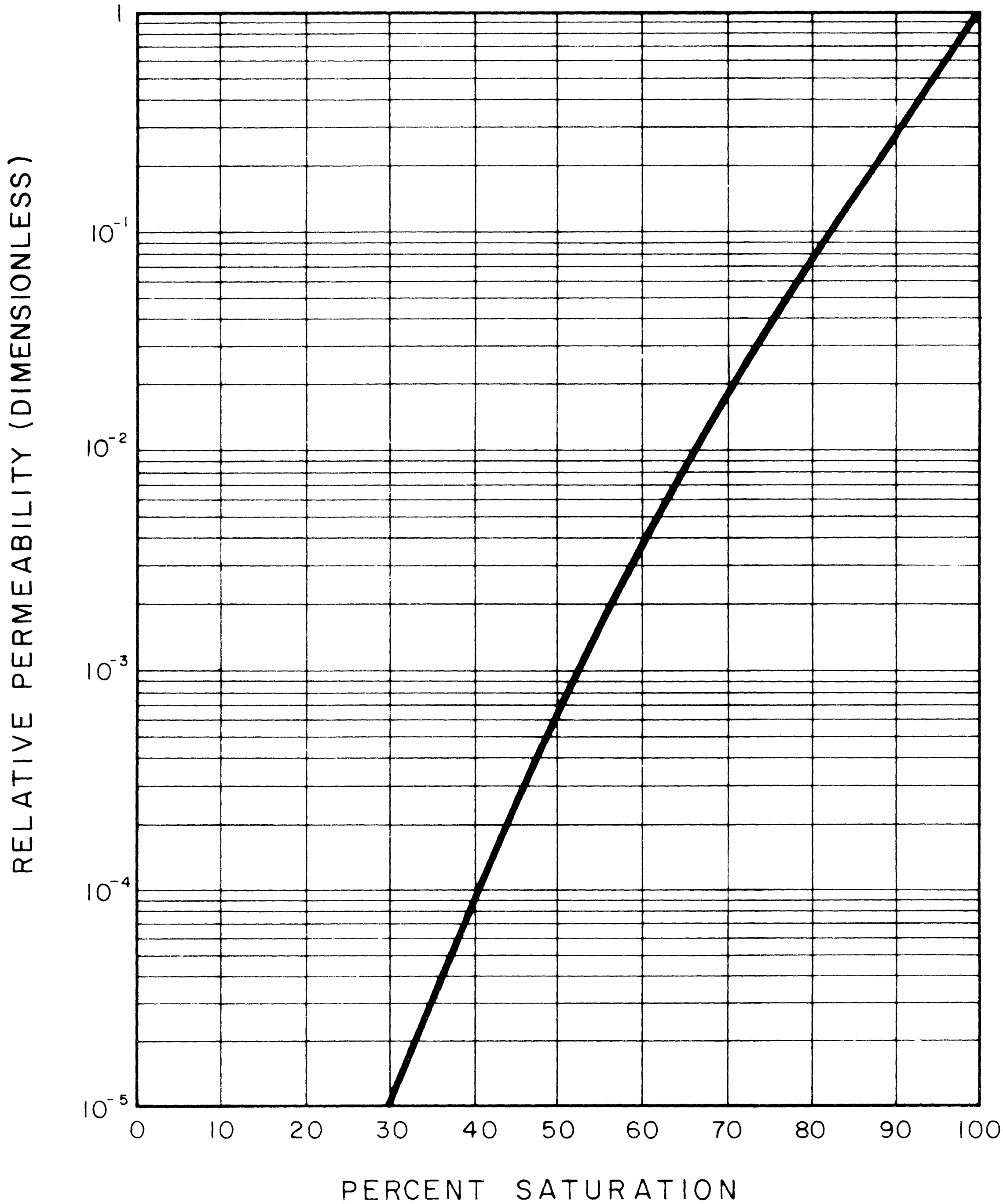
CRANDON PROJECT

TITLE: RELATIONSHIP OF SUCTION PRESSURE TO PERCENT SATURATION FOR THE TILL

DRAWN BY cjb/	DATE 9-24-84	CHECKED BY MDA	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85

D'APPOLONIA

PROJ NO 846498 DWG NO A5



NOTE:
RELATIVE PERMEABILITY EQUALS PARTIALLY SATURATED PERMEABILITY DIVIDED BY SATURATED PERMEABILITY.

FIGURE A.1-2

EXXON MINERALS COMPANY

CRANDON PROJECT

RELATIONSHIP BETWEEN PARTIALLY SATURATED TILL PERMEABILITY AND PERCENT SATURATION

DRAWN BY cjb/	DATE 9-24-84	CHECKED BY MJD	12/10/85
APPROVED BY	DATE	APPROVED BY SHD	12/10/85
APPROVED BY	DATE		
DRAWING No			

D'APPOLONIA

PROJ NO 846498 DWG NO A7

ATTACHMENT A.2

CALCULATION OF GROUND WATER RECHARGE IN SITE AREA

ATTACHMENT A.2

TABLE OF CONTENTS

ATTACHMENT A.2

LIST OF TABLES

LIST OF FIGURES

ATTACHMENT A.2

CALCULATION OF GROUND WATER RECHARGE IN SITE AREA

A water balance analysis was performed to estimate the ground water recharge rate in the site area. The purpose of the analysis was to determine the range of potential recharge rates that could be expected based on base flow measurements from streams bordering the site area. The results were used to determine the range of precipitation recharge. Sections A.2.1 and A.2.2 of this attachment discuss the computation methodology and analysis results, respectively. For comparison purposes, Q7,2 and Q7,10 base flow estimates are provided in Section A.2.3 (USGS, 1984).

A.2.1 COMPUTATION METHODOLOGY

As discussed in Section 3.2, base flow measurements were obtained for several streams in the study area. Two of these streams--Swamp Creek and Pickerel Creek--form a major portion of the site area boundary (Figure A.2-1), and therefore receive ground water discharge (base flow) from the site area. Since the ground water discharge from an area is an indicator of the net ground water recharge, base flow measurements in bordering streams can be used to estimate ground water recharge rates. Assuming all site area ground water flows into streams bordering the area, the following water balance equation illustrates this concept:

$$R = fB + \Delta S + U \qquad (A.2.1)$$

where

- R = Ground water recharge rate in the site area.
- B = Summation of base flow rates in streams bordering the site area.
- f = Fraction of stream base flow that is due to ground water discharge from the site area.
- ΔS = Change in ground water storage with time.
- U = Underflow rate; i.e., total ground water discharge which flows beneath the bordering streams and does not contribute to base flow.

With this method, the evapotranspiration from the site area does not need to be calculated separately because it is not required for the determination of net ground water recharge. It was assumed that annual ground water level fluctuations were negligible so that the change in storage (ΔS) was zero.

In order to evaluate the factor "f," the total areas contributing base flow to Swamp Creek and Pickerel Creek were separated into (1) the area inside the site area boundary (A_i) and (2) the area outside the site area boundary (A_o). The factor "f" was determined separately for the USGS gaging stations at Highway 55 and County Road M and for the SG 22 gaging station by the equation $f = A_i/A_o$. To determine the individual factors, the total area contributing base flow to a gaging station was divided into basins which were either inside or outside the site area boundary (Figure A.2-1). The boundaries of these areas were determined based on ground water flow directions in the hydrologic study area (Golder, 1981). Where insufficient ground water data existed, it was assumed that ground water divides generally followed surface watershed boundaries. This has been shown (Golder, 1982) to be a reasonable approximation, especially for the Swamp Creek basin.

The underflow component, "U", was assumed to be negligible. As shown in Figure A.2-1, ground water inflow to Swamp Creek (Basins 1, 2, 3, and 4) generally occurs on both sides of the stream. This assumption is also supported by field investigation (STS Consultants, Ltd., 1984). Due to this convergence of flow, the magnitude of underflow should be small. In the portion of Pickerel Creek upstream from Rolling Stone Lake, available ground water data indicate that both sides of the stream receive discharge; therefore, only a small amount of underflow is expected.

The parameter "B", summation of base flows in bordering streams, was determined from the streamflow hydrographs presented by Dames and Moore (1981) in which the base flow component of the total streamflow hydrograph was separated from the surface runoff portion. Two different time periods for the water years 1978, 1979, and 1980 were used: (1) February-March (low base flow conditions) and (2) May-June (high base flow conditions). From an evaluation of precipitation records and gaging station records for Wolf River, the water years 1978, 1979, and 1980 were found to reflect average base flow conditions in the study area. Table A.2-1 shows the gaging stations that were used and the base flows that were taken from the hydrographs.

A.2.2 ANALYSIS RESULTS

The results of the base flow computations for each ground water basin in Figure A.2-1 are shown in Table A.2-2. The ground water recharge rate in the site area, which equals the site area ground water discharge rate, was computed as the summation of base flows from areas within the site area boundary (Basins 1, 3, 5, and 7). The results indicate that the total base flow discharging from the site area could vary from 0.249 m^3/s (8.7 cubic feet per second) to 0.415 m^3/s (14.6 cubic feet per second) during dry (February-March) and wet (May-June) periods of the year, respectively. In terms of area recharge, the rate varies from 137 mm/y (5.39 inches per year) to 228 mm/y (8.98 inches per year).

A.2.3 Q7,2 AND Q7,10 BASE FLOW ESTIMATES

Measurements of the flows in streams adjacent to the Crandon Project Area were performed by the USGS in the winter of 1984. Based upon correlation of these measurements with concurrent discharge from the Wolf River at Langlade, the USGS has provided preliminary estimates of base flows at gaging stations near the Crandon Project. Base flows consist of the base flows Q7,2 and Q7,10 which are defined as average flow rates over a 7-day period and having a 2- and 10-year recurrence period, respectively. For comparison to the average base flows reported previously, these extreme flows at stations adjacent to the site are presented in Table A.2-3.

ATTACHMENT A.2

REFERENCES

Dames and Moore, 1981, "Surface Water Study and Study Methods (Draft 3)," Exxon Minerals Company, Crandon Project: Dames and Moore, Park Ridge, Illinois.

Golder Associates, 1981, "Groundwater Base Map," Project Report No. 7, Exxon Minerals Company, Crandon Project: Golder Associates, Atlanta, Georgia.

Golder Associates, 1982, "Geohydrologic Characterization," Exxon Minerals Company, Crandon Project: Golder Associates, Atlanta, Georgia.

STS Consultants, Ltd., 1984, "Hydrologic Study Update for the Crandon Project," STS Consultants, Ltd., Green Bay, Wisconsin.

USGS (United States Geological Survey), 1984, Letter from William Krug, Madison, Wisconsin to Dale Simon of WDNR, Madison, Wisconsin, December 13, 1984.

TABLES

TABLE A.2-1

BASE FLOW RATES IN STREAMS
BORDERING SITE AREA

STREAM	BASIN NO.[a]	GAGING STATION USED TO ESTIMATE BASE FLOW[a]	BASE FLOW RATE[b] 1978 FEB.-MAR. m³/s	1978 FEB.-MAR. cfs	1978 MAY-JUNE m³/s	1978 MAY-JUNE cfs	1979 FEB.-MAR. m³/s	1979 FEB.-MAR. cfs	1979 MAY-JUNE m³/s	1979 MAY-JUNE cfs	1980 FEB.-MAR. m³/s	1980 FEB.-MAR. cfs	1980 MAY-JUNE m³/s	1980 MAY-JUNE cfs	AVERAGE[c] FEB.-MAR. m³/s	AVERAGE[c] FEB.-MAR. cfs	AVERAGE[c] MAY-JUNE m³/s	AVERAGE[c] MAY-JUNE cfs
Swamp Creek	1,2	USGS at Highway 55	0.42	15	0.57	20	0.48	17	0.88	31	0.42	15	0.57	20	0.44	16	0.67	24
Swamp Creek	3,4	USGS at County Road M	0.76	27	0.85	30	0.82	29	1.27	45	NA	NA	NA	NA	0.79	28	1.06	38
Pickerel Creek	5,6	SG 22	0.11	3.9	0.28	10	NA	NA	0.14	4.9	NA	NA	NA	NA	0.11	3.9	0.21	7.4

[a] Refer to Figure A.2-1 for basin and gaging station locations. Basin numbers correspond to areas which contribute base flow to a particular gaging location.

[b] SOURCE: Stream flow hydrographs presented in Dames and Moore (1981). The hydrographs were separated into surface runoff and base flow components. "NA" indicates that stream flow measurements were not available for a particular period.

[c] Average of 1978, 1979, and 1980 base flow rates.

TABLE A.2-2

COMPUTATION OF GROUND WATER RECHARGE RATE IN SITE AREA

GAGING STATION	BASIN NO.[a]	GAGING STATION BASE FLOW[b]				BASIN AREA		TOTAL GAGING STATION AREA		BASIN BASE FLOW[c]			
		FEB.-MAR.		MAY-JUNE						FEB.-MAR.		MAY-JUNE	
		m^3/s	cfs	m^3/s	cfs	ha	acres	ha	acres	m^3/s	cfs	m^3/s	cfs
USGS at Highway 55	1	0.44	16	0.67	24	1,756	4,340	11,373	28,103	0.068	2.4	0.103	3.6
	2	0.44	16	0.67	24	9,617	23,763	11,373	28,103	0.372	13.1	0.567	20.0
USGS at County Road M	3	0.35[d]	12	0.39[d]	14	322	795	2,776	6,858	0.041	1.4	0.045	1.6
	4	0.35[d]	12	0.39[d]	14	2,454	6,063	2,776	6,858	0.309	11.0	0.345	12.3
SG 22	5	0.11	3.9	0.21	7.4	2,720	6,721	2,938	7,260	0.102	3.6	0.194	6.9
	6	0.11	3.9	0.21	7.4	218	539	2,938	7,260	0.008	0.4	0.016	0.6
-	7	-	-	-	-	1,020	2,519	-	-	0.038[e]	1.3	0.073[e]	2.5
Total Site Area	-	-	-	-	-	-	-	-	-	0.249[f]	8.7	0.415[f]	14.6

[a] Refer to Figure A.2-1 for basin locations.

[b] Refer to average values in Table A.2-1 for base flows. Based on measured data, the February-March period represents low base flow conditions and the May-June period represents high base flow conditions.

[c] Basin Base Flow = (Basin Area/Total Gaging Station Area) x (Gaging Station Base Flow).

[d] Base Flow Contributed by Basin Nos. 3 and 4 = (Base Flow Measured at County Road M) - (Base Flow Measured at Highway 55).

[e] Base flow from Basin No. 7 flows toward Pickerel Lake. Since discharge measurements from Pickerel Lake were not available, it was assumed that the Basin No. 7 base flow was a fraction of the Basin No. 5 base flow, i.e., Base Flow from Basin 7 = (Base Flow from Basin No. 5) x (Basin Area No. 7/Basin Area No. 5).

[f] Base flow discharge from site area is the summation of base flows from Basin Nos. 1, 3, 5, and 7.

TABLE A.2-3

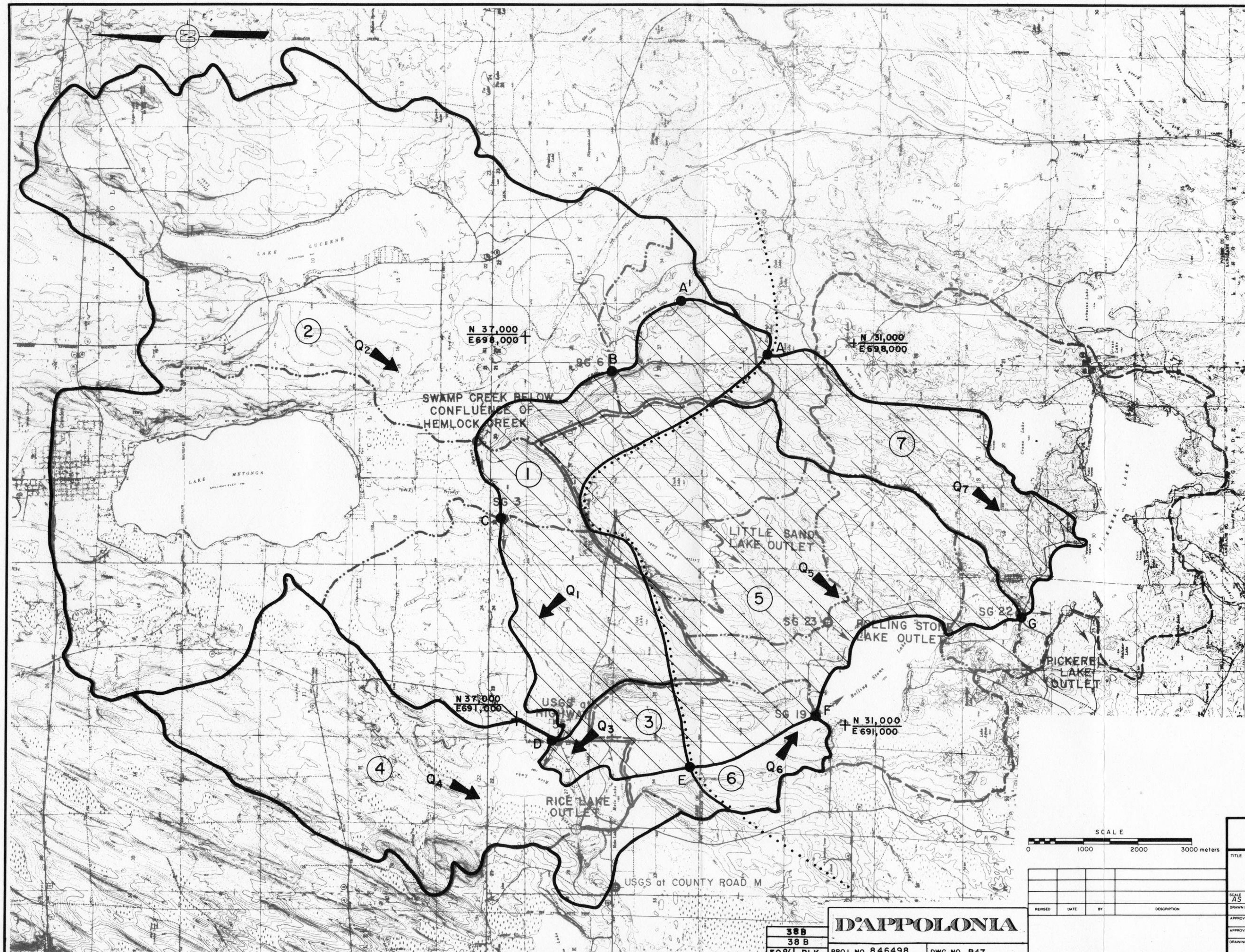
BASE FLOW RATES
IN STREAMS BORDERING SITE AREA

GAGING STATION[a]	BASE FLOW[b] Q7,2 m^3/sec	cfs	Q7,10 m^3/sec	cfs
SG6	0.057	2.0	0.040	1.4
SG3	0.190	6.7	0.133	4.7
USGS at Highway 55	0.311	11.0	0.226	8.0
SG19	0.017	0.6	0.011	0.4
SG22	0.184	6.5	0.133	4.7

[a]See Figure A.2-1 for gaging station locations.

[b]Q7,2 and Q7,10 are the average low flows over a 7-day period and having recurrence periods of 2- and 10-years, respectively (USGS, 1984).

FIGURES



LEGEND:

- SWAMP CREEK DRAINAGE BOUNDARY
- PICKEREL CREEK DRAINAGE BOUNDARY
- SUBWATERSHED BOUNDARIES
- LOWFLOW ESTIMATE LOCATIONS
- LAKEFLOW ESTIMATE LOCATIONS
- SURFACE WATER FLOW DIRECTION
- (5) BASIN NUMBER
- Q_5 GENERAL DIRECTION OF GROUND WATER DISCHARGE FROM BASIN No. 5
- REGIONAL GROUND WATER DIVIDE
- SITE AREA
- BASIN BOUNDARY
- A—B SITE AREA BOUNDARY SEGMENT WHERE GROUND WATER DISCHARGE IS CALCULATED

REFERENCE:
DRAWING NO. 050-1-80603
TITLED: SURFACE WATERSHEDS AND STUDY LOCATIONS BY GOLDER ASSOCIATES- ATLANTA GEORGIA; DATED: 5-26-82
SCALE: AS SHOWN.

NOTES:

1. REFER TO TABLE A.2-2 FOR BASE FLOW RATES AND SITE AREA WATERSHEDS.
2. WHERE INSUFFICIENT GROUND WATER DATA EXISTED, IT WAS ASSUMED THAT GROUND WATER DIVIDES GENERALLY FOLLOW SURFACE WATERSHED BOUNDARIES.

FIGURE A.2-1

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
DRAINAGE BASINS FOR DETERMINATION OF GROUND WATER RECHARGE IN SITE AREA

REVISED	DATE	BY	DESCRIPTION

SCALE AS SHOWN	STATE		COUNTY		
DRAWN BY D. Weick	DATE 9-17-82	CHECKED BY M.D.S	DATE 12/10/85		
APPROVED BY	DATE	SHD	12/10/85		
APPROVED BY	DATE	EXXON	DATE		
DRAWING NO.			SHEET ___ OF ___	REVISION NO.	

D'APPOLONIA

38B
38 B
50% BLK.

PROJ. NO. 846498
DWG. NO. B47

GBS 5/1961

ATTACHMENT A.3

SIMPLIFICATION OF DISPERSION EQUATION FOR PARTIALLY SATURATED SOIL

ATTACHMENT A.3

TABLE OF CONTENTS

ATTACHMENT A.3

SIMPLIFICATION OF DISPERSION EQUATION FOR PARTIALLY SATURATED SOIL

The one-dimensional partially saturated soil dispersion equation in the vertical direction can be written as (Warrick, et al., 1972):

$$D \frac{\partial^2 C}{\partial x^2} - \frac{V}{\theta} - \frac{D}{\theta} \frac{\partial \theta}{\partial x} \frac{\partial C}{\partial x} = \frac{\partial C}{\partial t} \qquad \text{(A.3.1)}$$

where

- C is concentration of the chemical constituent
- D is time-dependent dispersion coefficient
- V is time-dependent Darcian velocity of the fluid
- θ is moisture content
- x is distance
- t is time

In partially saturated soil, if the fluid seepage rate (flux) is less than the saturated permeability, the soil will remain partially saturated. If such a flux continues for a sufficient time, the soil will reach a uniform moisture content (Rubin and Steinhardt, 1963). This moisture content is termed the limiting moisture content and its value is a function of soil characteristics, primarily soil permeability, and the flux. For this condition, the moisture content and velocity and dispersion coefficient will be time independent. Therefore, Equation A.3.1 can be simplified to the following form:

$$D \frac{\partial^2 C}{\partial x^2} - \frac{V}{\theta_L} \frac{\partial C}{\partial x} = \frac{\partial C}{\partial t} \qquad \text{(A.3.2)}$$

Equation A.3.2 is identical to the saturated soil dispersion equation except that the dispersion coefficient for partially saturated soil should be used in this analysis and the flux should be divided by limiting moisture content, (θ_L).

The application of this method for the Crandon Project is discussed in Section 6.4.1.

ATTACHMENT A.3

REFERENCES

Rubin, J. and R. Steinhardt, 1963, "Soil Water Relations During Rain Infiltration," Soil Sci. Soc. Amer. Proc., Vol. 27, pp. 246-251.

Warrick, A. W., J. H. Kichen, and J. L. Thames, 1972, "Solutions for Miscible Displacement of Soil Water," Soil Sci. Soc. Amer. Proc., Vol. 36, pp. 863-867.

ATTACHMENT A.4

PARAMETER SENSITIVITY ANALYSIS FOR VERTICAL TWO-DIMENSIONAL MODEL

ATTACHMENT A.4

TABLE OF CONTENTS

ATTACHMENT A.4

LIST OF TABLES

LIST OF FIGURES

ATTACHMENT A.4

PARAMETER SENSITIVITY ANALYSIS FOR VERTICAL TWO-DIMENSIONAL MODEL

The sensitivity of the vertical two-dimensional dispersion model for determining chemical constituent transport from the MWDF was evaluated for various parameters. Normalized steady-state concentrations were computed using the calibrated vertical flow model for Section N-N'. Figure A.4-1 presents the generalized configuration of the vertical model; input parameters, and conditions are described in Attachment A.7.

A.4.1 VARIABLE PARAMETERS

The sensitivity analysis tested model response to various values of the following parameters:

- Ratio of vertical to horizontal permeability (K_V/K_H)
- Longitudinal dispersivity (a_L)
- Ratio of longitudinal to transverse dispersivity (a_L/a_T)
- MWDF seepage rate
- Ground water recharge rate

The parameter values used in each sensitivity analysis are summarized in Table A.4-1.

A.4.2 RESULTS

The results of the sensitivity analyses are presented in Figures A.4-2 to A.4-6.

Figure A.4-2 indicates that different values for the permeability ratio affect the vertical distribution of chemical constituents under the MWDF, but have little effect on horizontal migration of chemical constituents from the MWDF.

Figure A.4-3 presents results for various values of longitudinal dispersivity with a constant dispersivity ratio (a_L/a_T) of 30. The horizontal migration of chemical constituents is greatest for a longitudinal dispersivity of 5 m (16 feet), and least for a value of 60 m (197 feet). This results from the effect of a constant dispersivity ratio of 30: for a a_L of 5 m (16 feet), a_T is 0.17 m (0.55 feet); for a a_L of 60 m (197 feet), a_T is 2 m (6.6 feet).

The results of varying dispersivity ratios with a constant longitudinal dispersivity of 60 m (197 feet) are shown in Figure A.4-4. The greatest horizontal migration of chemical constituents corresponds to a a_L/a_T of 1000, where a_T is 0.06 m (0.20 feet); the least migration corresponds to a a_L/a_T of 5, where a_T is 12 m (39 feet).

Figure A.4-5 presents the difference between predicted normalized concentrations for the predicted steady-state seepage rate for the MWDF with a synthetic membrane and predicted normalized concentrations for the steady-state seepage rate for the MWDF without a synthetic membrane. The higher seepage rate for the MWDF without a synthetic membrane results in greater vertical and horizontal chemical constituent migration.

The predicted distributions of chemical constituent concentrations for the three different recharge rates are shown in Figure A.4-6. The high recharge rate, 279 mm/y (11 inches per year), results in lower normalized concentrations for chemical constituent transport toward Hemlock Creek than the other rates because of dilution from recharge. The middle recharge rate, 216 mm/y (8.5 inches per year), and the low recharge rate, 152 mm/y (6 inches per year), show similar normalized concentrations for chemical constituent transport toward Hemlock Creek.

A.4.3 CONCLUSIONS

Figures A.4-2 to A.4-6 indicate that (1) the vertical two-dimensional dispersion model is relatively insensitive to ratios of vertical to horizontal permeability; (2) the model is sensitive to transverse dispersivity values; (3) the model is sensitive to the steady-state seepage rates for the MWDF; and (4) the model is moderately sensitive to recharge values.

TABLES

TABLE A.4-1

PARAMETERS FOR SENSITIVITY ANALYSIS
STEADY-STATE VERTICAL TWO-DIMENSIONAL MODEL

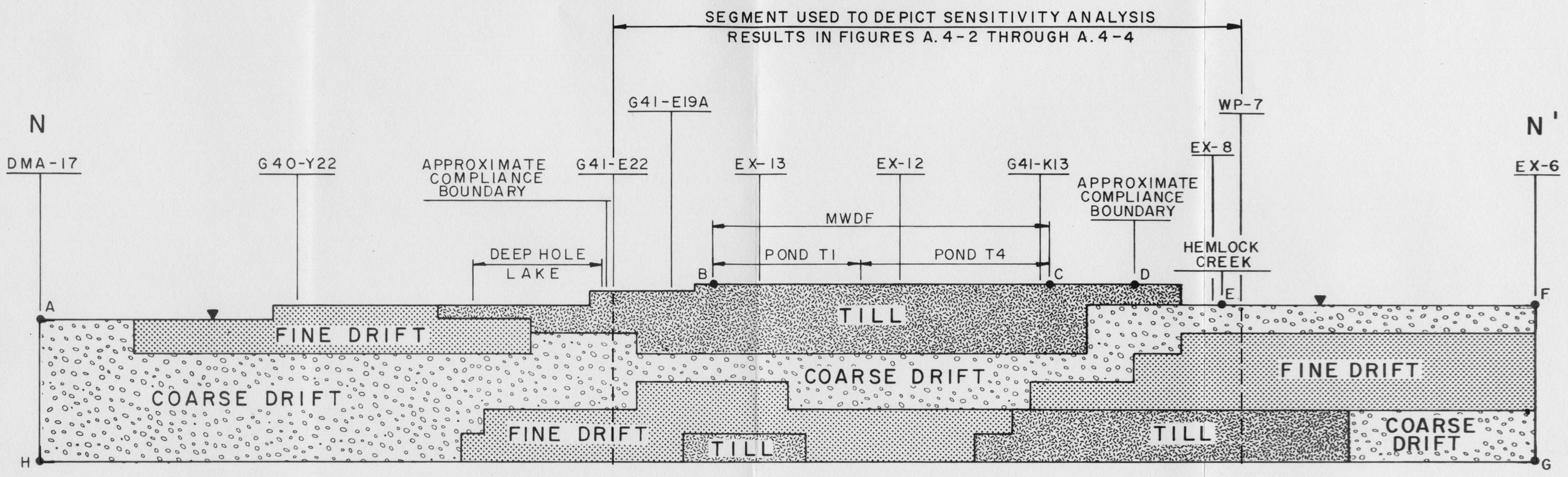
VARIABLE PARAMETER	K_V/K_H[a] TILL	K_V/K_H[a] DRIFT	a_L[b] m	a_L[b] ft	a_L/a_T[c]	RECHARGE	MWDF SEEPAGE mm/y	MWDF SEEPAGE in/y	FIGURE NUMBER
Permeability Ratio	1/1	1/10	20	66	30	Middle	1.68	0.066	A.4-2
	1/1	1/20							
	1/1	1/50							
	1/3	1/50							
Longitudinal Dispersivity	1/1	1/50	5	16	30	Middle	1.68	0.066	A.4-3
			20	66					
			30	98					
			60	197					
Dispersivity Ratio	1/1	1/50	60	197	5	Middle	1.68	0.066	A.4-4
					20				
					50				
					1000				
MWDF Seepage Rate	1/1	1/50	60	197	50	Middle	1.68	0.066	A.4-5
							16.8	0.66	
Recharge Rate	1/1	1/50	60	197	50	Low	1.68	0.066	A.4-6
						Middle			
						High			

[a] K_V/K_H is defined as the ratio of vertical to horizontal permeability.

[b] a_L is defined as longitudinal dispersivity.

[c] a_L/a_T is defined as the ratio of longitudinal to transverse dispersivity.

FIGURES



NOTES:

1. FOR PLAN AND LOCATION OF SECTION N-N' REFER TO FIGURE A-8
2. VERTICAL EXAGGERATION 15X
3. THE ANALYSIS ASSUMES A CONSTANT MASS FLUX AND A RETARDATION FACTOR OF 1.0
4. A RECHARGE RATE OF 216 mm/y (8.5 inch/y) IS USED UNLESS OTHERWISE NOTED.
5. MODEL INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7

LEGEND:

A● POINTS REFERRED TO IN TEXT

▼ WATER TABLE (RECHARGE BOUNDARY)

HORIZONTAL SCALE
0 300 600 900 meters

VERTICAL SCALE
0 20 40 60 meters

FIGURE A.4-1

EXXON MINERALS COMPANY
CRANDON PROJECT

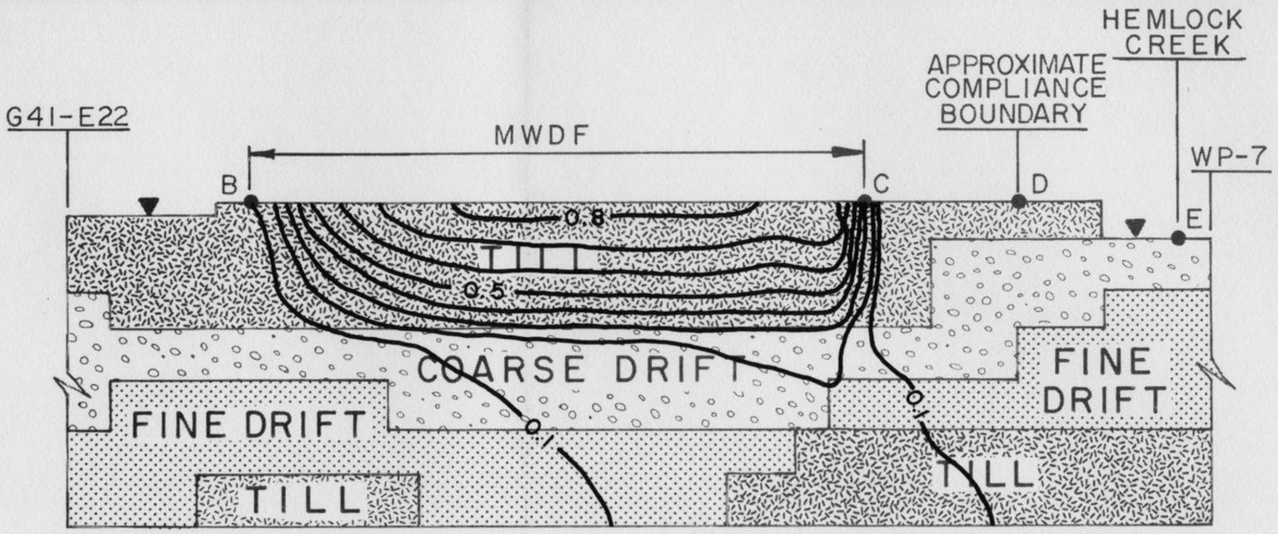
TITLE
TWO-DIMENSIONAL VERTICAL MODEL FOR SENSITIVITY ANALYSIS

SCALE AS SHOWN	STATE		COUNTY	
DRAWN BY D. Weick	DATE 10-12-84	CHECKED BY MBS		DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD		12/10/85
APPROVED BY	DATE	EXXON		DATE
DRAWING NO.			SHEET ___ OF ___	REVISION NO.

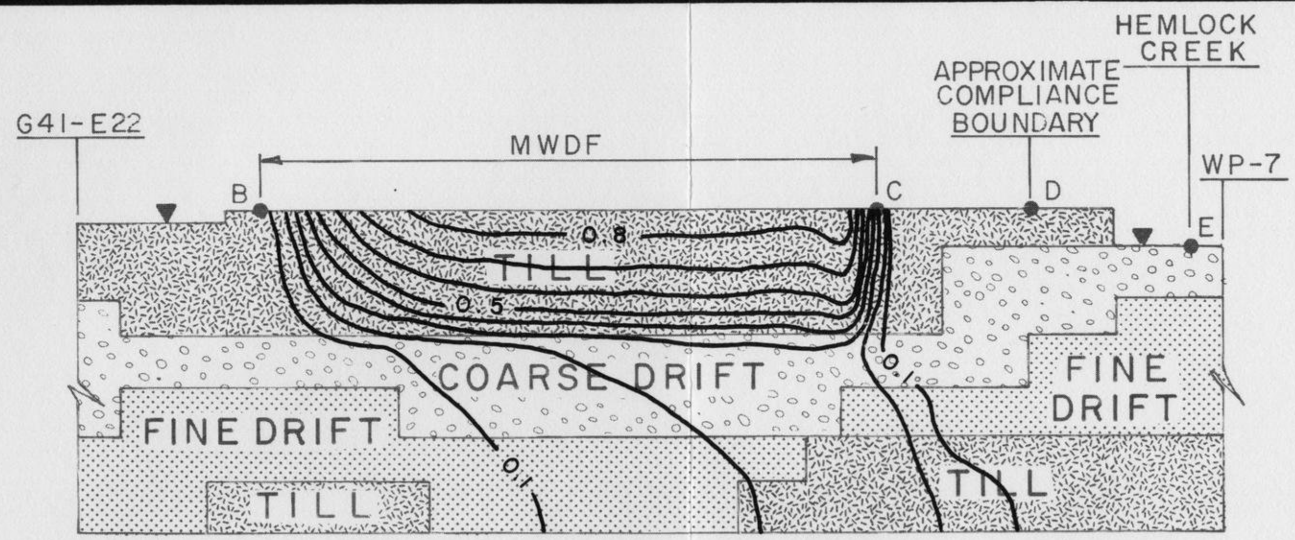
15B
15B
50% BLK.

D'APPOLONIA

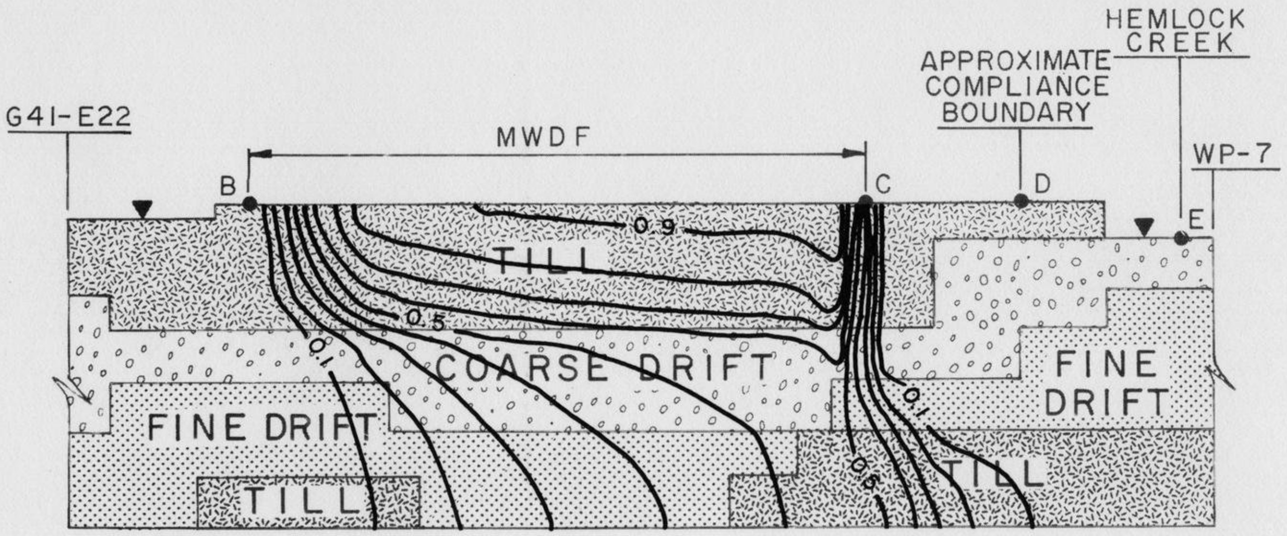
PROJ. NO. 846498 DWG. NO. B23



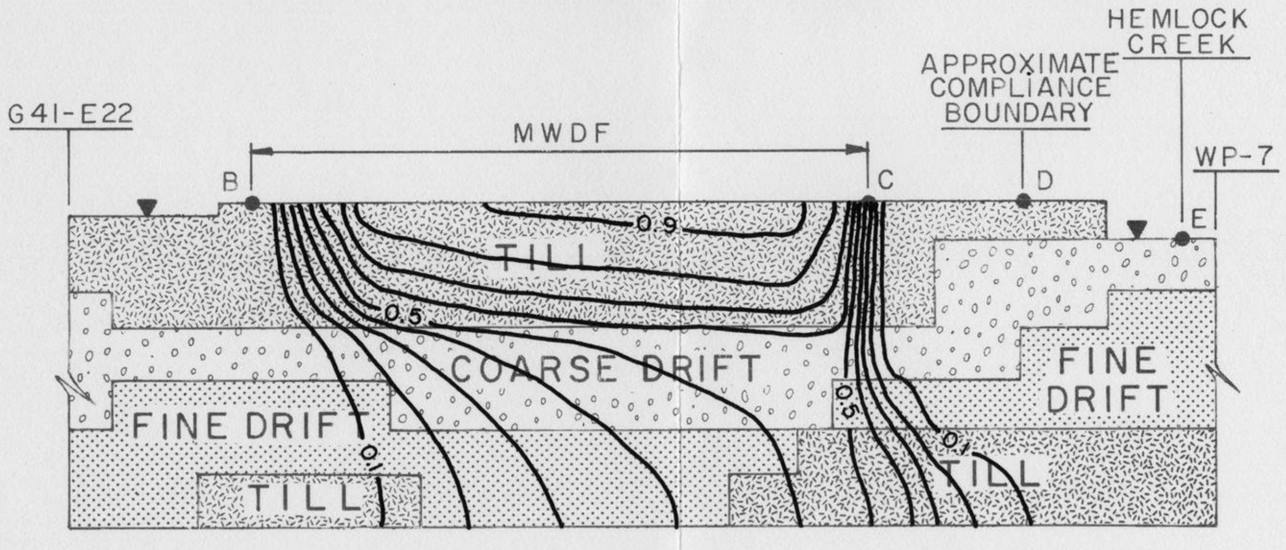
TILL K_V/K_H = 1/1 , DRIFT K_V/K_H = 1/10



TILL K_V/K_H = 1/1 , DRIFT K_V/K_H = 1/20



TILL K_V/K_H = 1/1 , DRIFT K_V/K_H = 1/50



TILL K_V/K_H = 1/3 , DRIFT K_V/K_H = 1/50

NOTES:

1. FOR SEGMENT LOCATION REFER TO FIGURE A.4-1
2. K_V = VERTICAL PERMEABILITY
   K_H = HORIZONTAL PERMEABILITY
3. a_L = LONGITUDINAL DISPERSIVITY = 20m (66 feet)
   a_T = TRANSVERSE DISPERSIVITY = 0.67m (2.2 feet)
4. a_L/a_T = LONGITUDINAL TO TRANSVERSE DISPERSIVITY RATIO = 30
5. MDWF SEEPAGE RATE = 1.68 mm/y. (0.066 inch/y.)
6. OTHER MODEL INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7

LEGEND:

B ● POINTS REFERRED TO IN TEXT

—0.1— NORMALIZED CONCENTRATION CONTOURS

▼ WATER TABLE (RECHARGE BOUNDARY)

HORIZONTAL SCALE

0 300 600 900 meters

VERTICAL SCALE

0 20 40 60 meters

FIGURE A.4-2

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE

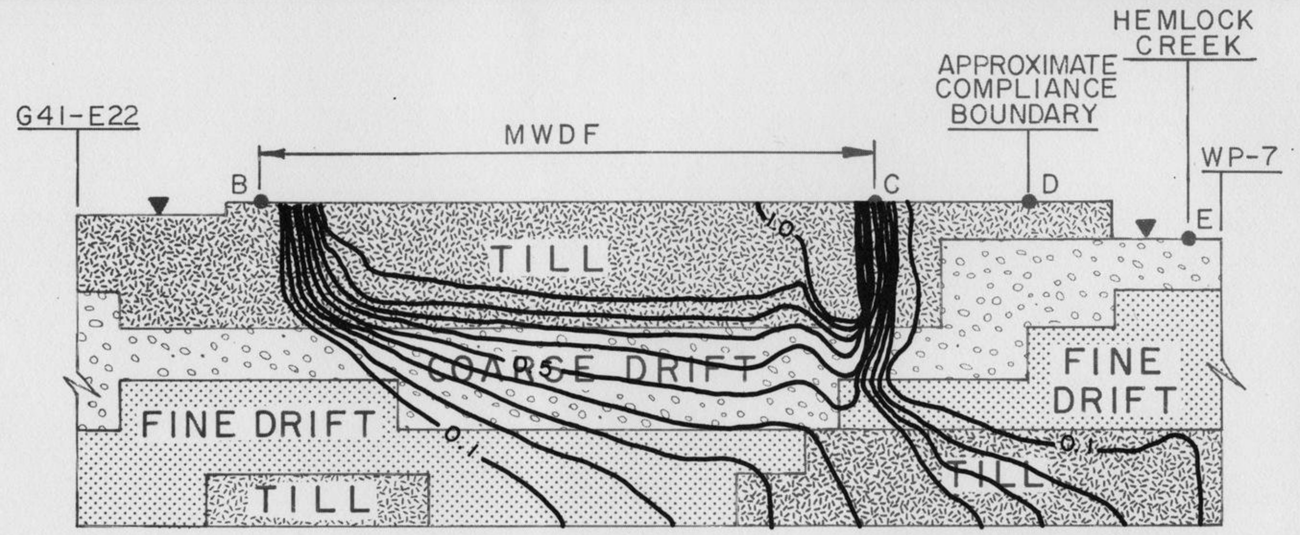
PREDICTED STEADY STATE NORMALIZED CONCENTRATIONS WITH DIFFERENT PERMEABILITY RATIOS

SCALE AS SHOWN	STATE	COUNTY	
DRAWN BY D. Weick	DATE 10-12-84	CHECKED BY [illegible]	DATE [illegible]
APPROVED BY	DATE	APPROVED BY SHD	DATE [illegible]
APPROVED BY	DATE	EXXON	DATE
DRAWING NO.		SHEET ___ OF ___	REVISION NO.

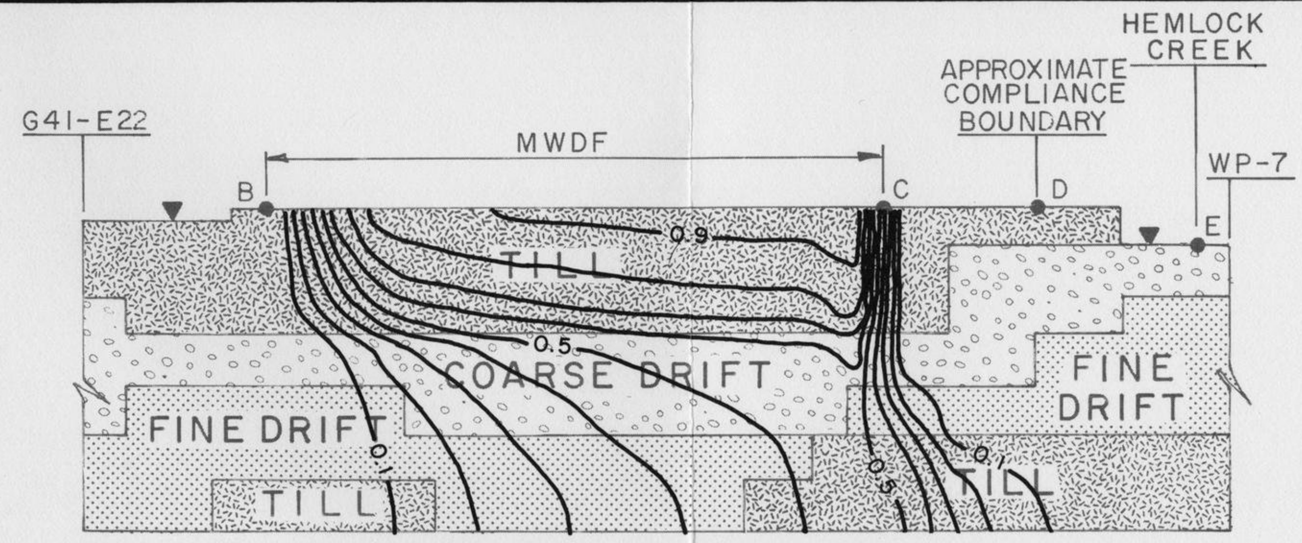
D'APPOLONIA

16B
16B
50% BLK.

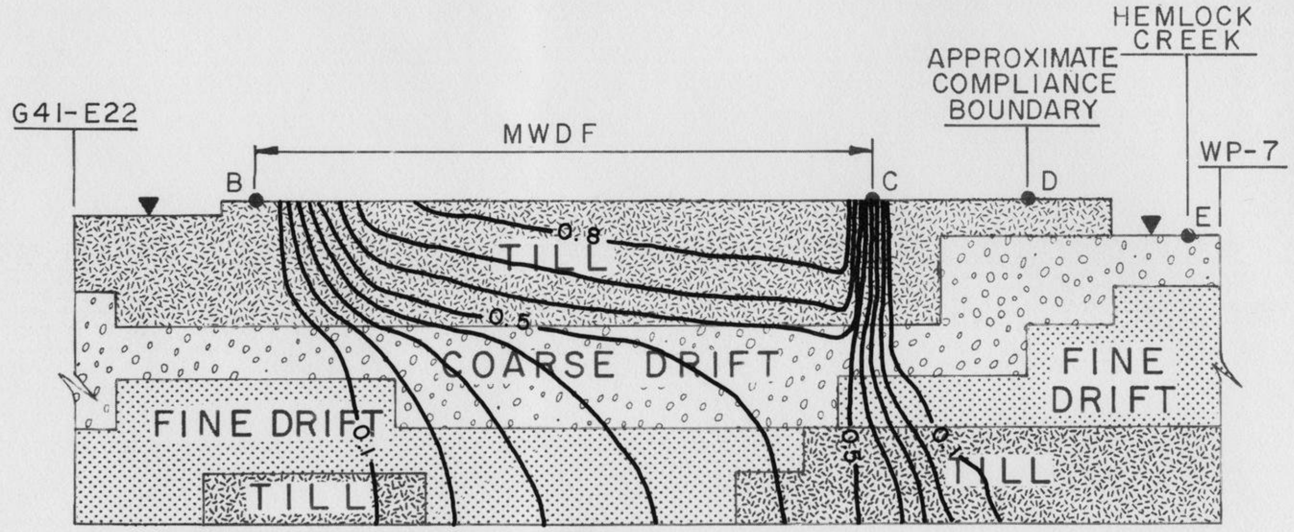
PROJ. NO. 846498 DWG. NO. B24



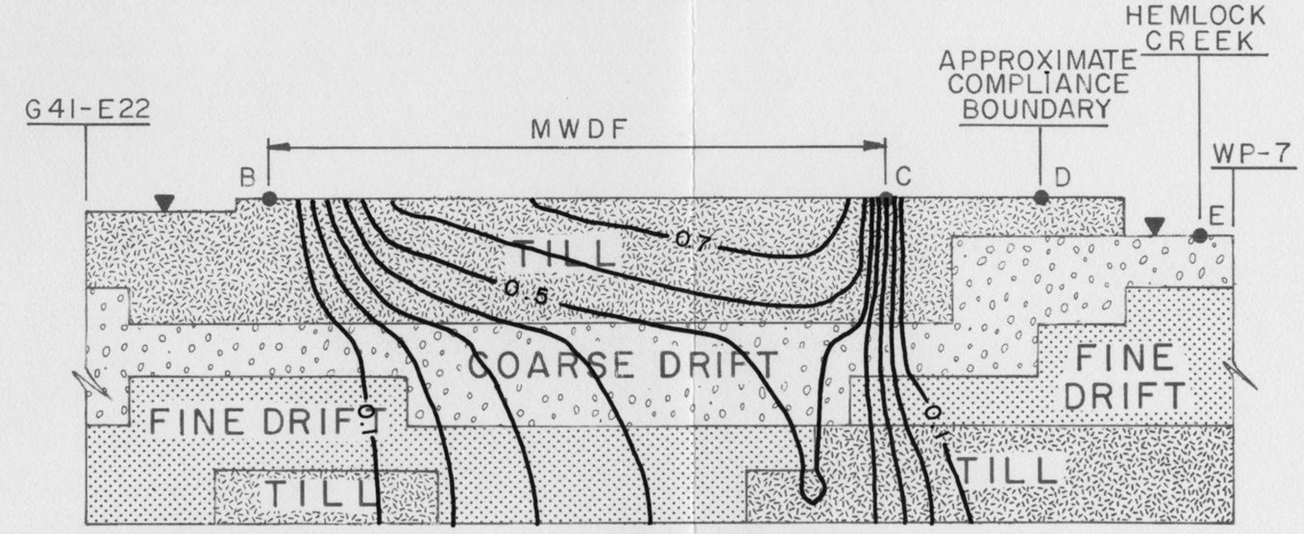
$a_L = 5m$ (16 FEET)



$a_L = 20m$ (66 FEET)



$a_L = 30m$ (98 FEET)



$a_L = 60m$ (197 FEET)

NOTES:

1. FOR SEGMENT LOCATION REFER TO FIGURE A.4-1
2. a_L = LONGITUDINAL DISPERSIVITY
3. a_L/a_T = LONGITUDINAL TO TRANVERSE DISPERSIVITY RATIO = 30.
4. K_V/K_H = VERTICAL TO HORIZONTAL PERMEABILITY RATIO, TILL = 1/1, DRIFT = 1/50.
5. MDWF SEEPAGE RATE = 1.68 mm/y (0.066 inch/y)
6. OTHER MODEL INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7

LEGEND:

B ● POINTS REFERRED TO IN TEXT

—0.1— NORMALIZED CONCENTRATION CONTOURS

▼ WATER TABLE (RECHARGE BOUNDARY)

HORIZONTAL SCALE
0 300 600 900 meters

VERTICAL SCALE
0 20 40 60 meters

FIGURE A.4-3

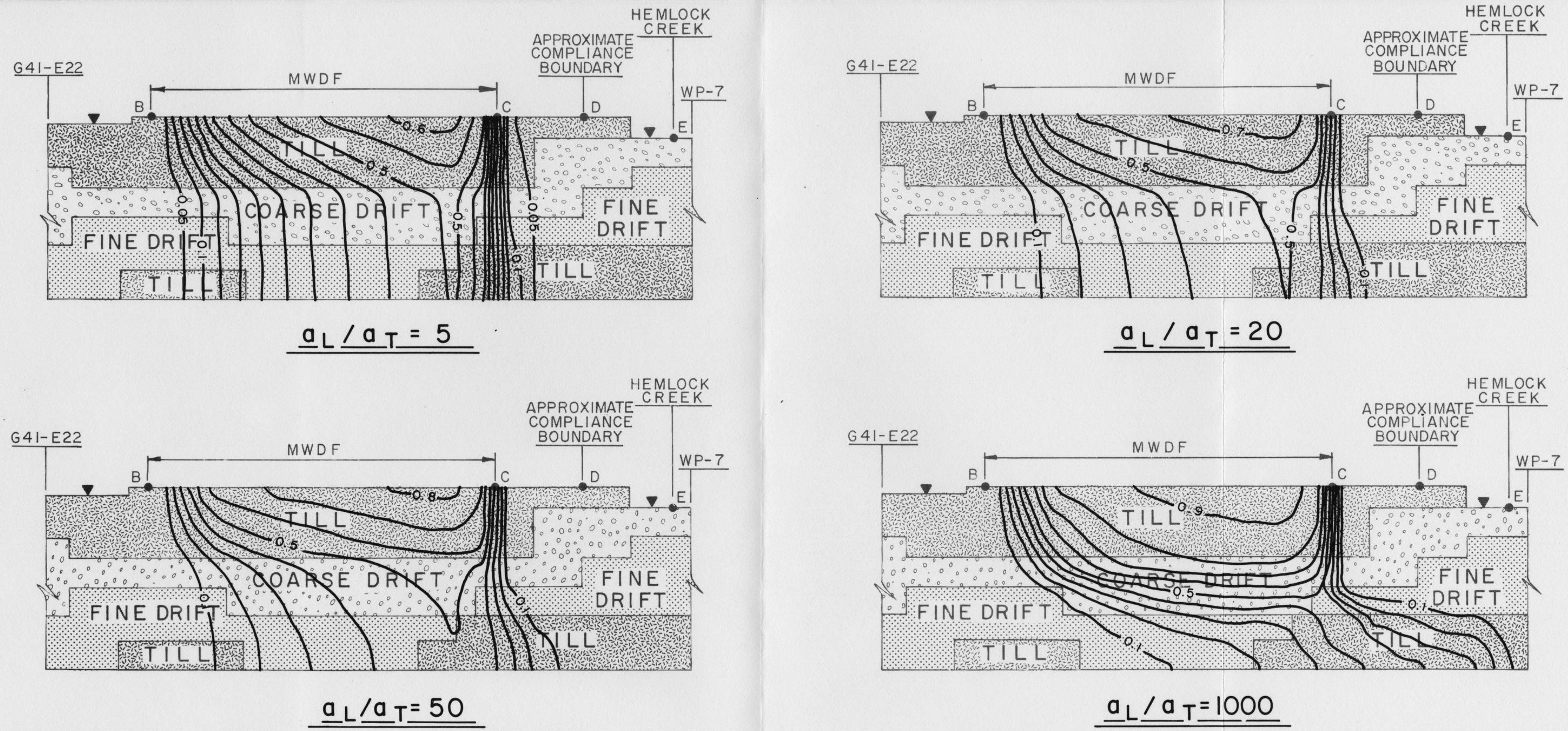
EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
PREDICTED STEADY STATE NORMALIZED CONCENTRATIONS WITH DIFFERENT LONGITUDINAL DISPERSIVITY

SCALE AS SHOWN	STATE		COUNTY
DRAWN BY D. Weick	DATE 10-2-84	CHECKED BY MBL	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET ___ OF ___	REVISION NO.

16B
16B
50% BLK.

D'APPOLONIA
PROJ. NO. 846498 DWG. NO. B25



NOTES:

1. FOR SEGMENT LOCATION REFER TO FIGURE A.4-1
2. a_L = LONGITUDINAL DISPERSIVITY = 60m (197 feet)
3. a_L/a_T = LONGITUDINAL TO TRANSVERSE DISPERSIVITY RATIO.
4. K_V/K_H = VERTICAL TO HORIZONTAL PERMEABILITY RATIO, TILL = 1/1, DRIFT = 1/50.
5. MDWF SEEPAGE RATE = 1.68 mm/y (0.066 inch/y)
6. OTHER MODEL INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7

LEGEND:

B ● POINTS REFERRED TO IN TEXT

—0.1— NORMALIZED CONCENTRATION CONTOURS

▼ WATER TABLE (RECHARGE BOUNDARY)

HORIZONTAL SCALE: 0 300 600 900 meters

VERTICAL SCALE: 0 20 40 60 meters

FIGURE A.4-4

EXXON MINERALS COMPANY

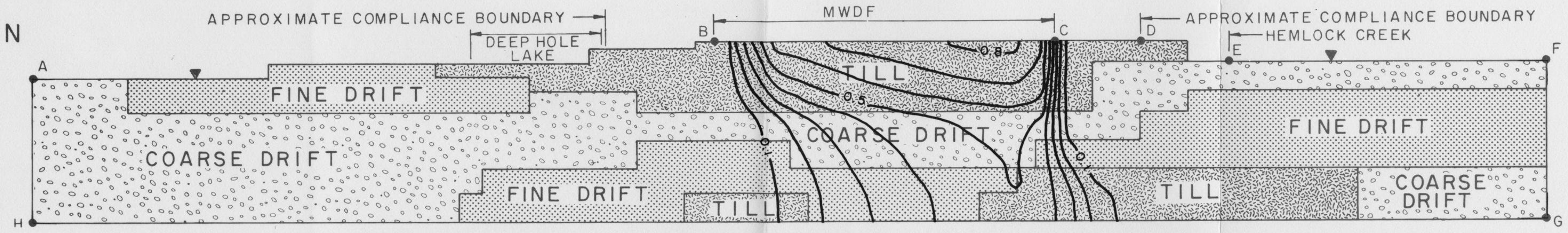
CRANDON PROJECT

TITLE: PREDICTED STEADY STATE NORMALIZED CONCENTRATIONS WITH DIFFERENT DISPERSIVITY RATIOS

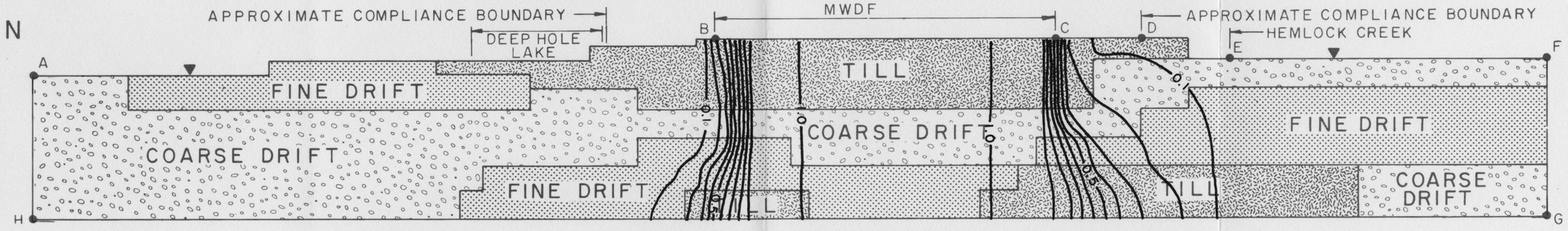
SCALE AS SHOWN	STATE		COUNTY	
DRAWN BY D. Weick	DATE 10-12-84	CHECKED BY MDA	DATE 1/10/85	
APPROVED BY	DATE	APPROVED BY SHD	DATE 1/10/85	
APPROVED BY	DATE	EXXON	DATE	
DRAWING NO			SHEET ___ OF ___	REVISION NO.

D'APPOLONIA

16B 16B 50% BLK. PROJ NO 846498 DWG NO B26



SEEPAGE RATE WITH MEMBRANE = 1.68 mm/y (0.066 inch/y)



SEEPAGE RATE WITHOUT MEMBRANE = 16.8 mm/y (0.66 inch/y)

NOTES:

1. FOR SECTION N-N' LOCATION REFER TO FIGURE A-8
2. VERTICAL TO HORIZONTAL PERMEABILITY RATIO, TILL = 1/1, DRIFT = 1/50.
3. LONGITUDINAL DISPERSIVITY = 60 m (197 feet)
4. LONGITUDINAL TO TRANSVERSE DISPERSIVITY RATIO = 50
5. OTHER MODEL INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7

LEGEND:

- A ● POINTS REFERRED TO IN TEXT
- —0.1— NORMALIZED CONCENTRATION CONTOURS
- ▼ WATER TABLE (RECHARGE BOUNDARY)

HORIZONTAL SCALE: 0 300 600 900 meters

VERTICAL SCALE: 0 20 40 60 meters

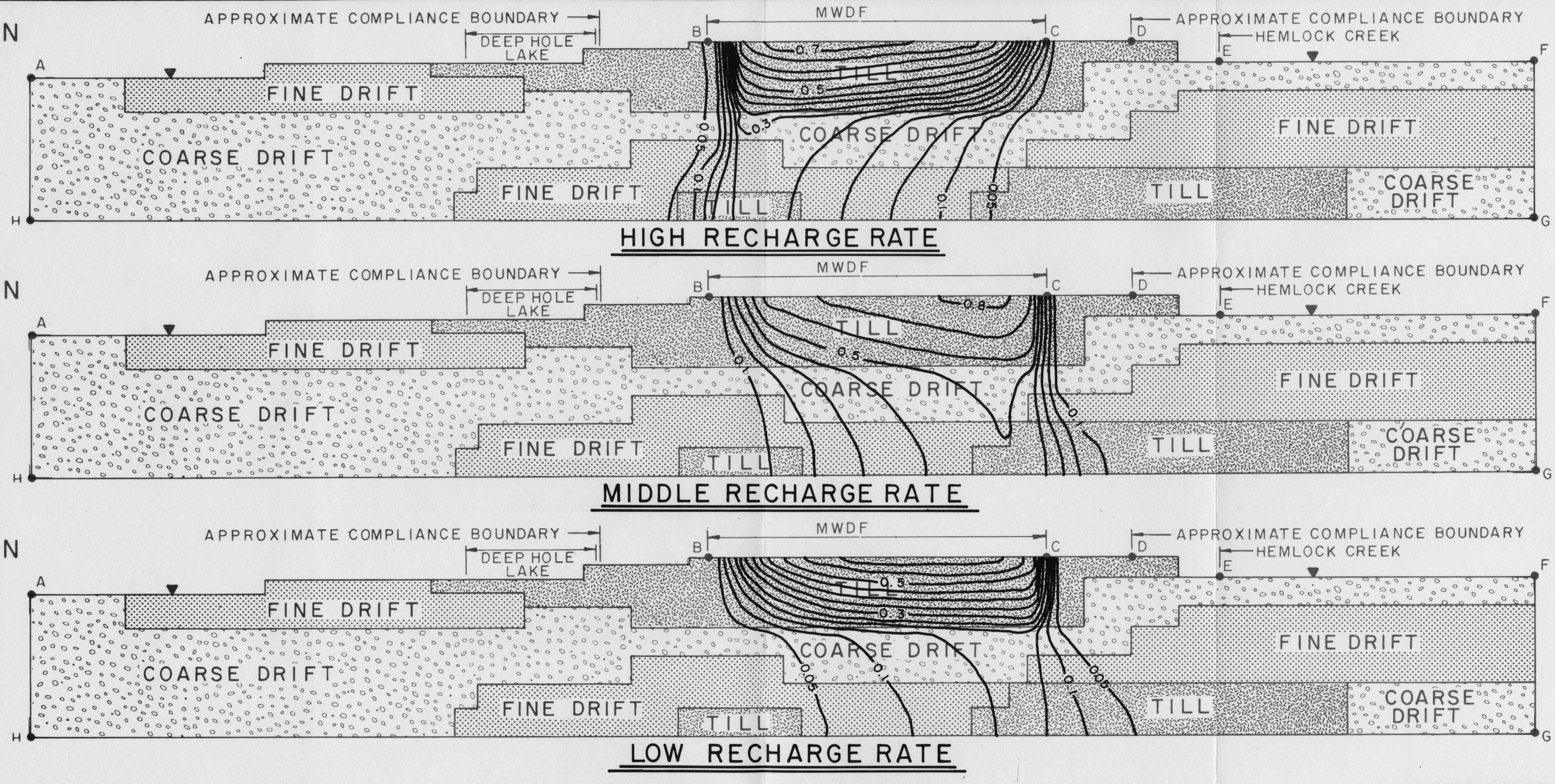
FIGURE A.4-5

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: PREDICTED STEADY STATE NORMALIZED CONCENTRATIONS WITH DIFFERENT MWDF SEEPAGE RATES

SCALE	STATE	COUNTY	
AS SHOWN			
DRAWN BY D. Weick	DATE 10-12-84	CHECKED BY MDA	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/8[illegible]
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET ___ OF ___	REVISION NO.

17B 17B 50% BLK. D'APPOLONIA PROJ. NO. 846498 DWG. NO. B27



NOTES:

1. FOR PLAN AND LOCATION OF SECTION N-N' REFER TO FIGURE A-8.
2. VERTICAL TO HORIZONTAL PERMEABILITY RATIO, TILL = 1/1, DRIFT = 1/50.
3. LONGITUDINAL DISPERSIVITY = 60 m (197 feet).
4. LONGITUDINAL TO TRANSVERSE DISPERSIVITY RATIO = 50.
5. MWDF SEEPAGE RATE = 1.68 mm/y (0.066 inch/y)
6. OTHER MODEL INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7.

LEGEND:

A ● POINTS REFERRED TO IN TEXT

—0.1— NORMALIZED CONCENTRATION CONTOURS

▼ WATER TABLE (RECHARGE BOUNDARY)

HORIZONTAL SCALE

0 300 600 900 meters

VERTICAL SCALE

0 20 40 60 meters

18B
18B
50% BLK.

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B28

FIGURE A.4-6

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE

PREDICTED STEADY STATE NORMALIZED CONCENTRATIONS WITH DIFFERENT RECHARGE RATES

SCALE	STATE	COUNTY	
AS SHOWN			
DRAWN BY D. Weick	DATE 10-12-84	CHECKED BY MDA	DATE 8/1/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET ___ OF ___	REVISION NO.

ATTACHMENT A.5

LONG-TERM GROUND WATER QUALITY ANALYSIS ADJACENT TO MWDF

ATTACHMENT A.5

TABLE OF CONTENTS

ATTACHMENT A.5

LIST OF TABLES

ATTACHMENT A.5

LONG-TERM GROUND WATER QUALITY ANALYSIS ADJACENT TO MWDF

Accurate long-term prediction of ground water quality adjacent to the MWDF is limited by difficulties of evaluating time-dependent changes in hydrologic and geochemical parameters. However, the analyses presented herein indicate that the long-term impact of the MWDF on ground water quality will be negligible. These analyses include calculation of dilution by recharge and steady-state dispersion simulation.

A.5.1 DILUTION BY RECHARGE

The ground water recharge resulting from precipitation within the compliance boundary for the middle recharge rate of 216 mm/y (8.5 inches per year) is 0.0242 m^3/s (384 gallons per minute). Comparison of this rate with the 0.000083 m^3/s (1.33 gallons per minute) post-operation phase steady-state seepage rate from the MWDF indicates that seepage will be diluted 290 times. With this dilution ratio, the average normalized concentration of a chemical constituent within the compliance boundary area would be about 0.003. Table A.5-1 shows the precipitation recharge within the compliance boundary, and the dilution ratios for the range of precipitation recharge rates evaluated in this study.

This simplified dilution calculation assumes that complete mixing will occur in the aquifer and the chemical constituents are uniformly distributed in the compliance boundary area. However, chemical constituent migration may follow a preferred path and there will be variation of vertical concentrations, resulting in areas of higher and lower concentrations along the compliance boundary (Figure A-41). Therefore, the model results have been used to develop the conclusions of the impact of the MWDF on the ground water quality. The simplified dilution calculation is used to provide an average normalized concentration assuming complete mixing within the total aquifer thickness. The actual concentrations at the compliance boundary will be between the concentration calculated by vertical modeling and the concentration calculated by direct dilution. Because the two-dimensional vertical model ignores radial dilution of the chemical constituent, the model results are usually higher than actual concentrations.

Comparison of the dilution ratios with the projected MWDF tailings ponds seepage chemistry and the dilution required to meet U.S. EPA Drinking Water Standards (Table A-4) indicates that all chemical constituents resulting from MWDF seepage will be sufficiently diluted 50 years after the operation phase such that the level of concentrations at the compliance boundary will be below the U.S. EPA Drinking Water Standards. During the first 50 years beyond the operation phase, manganese will require a higher dilution factor (approximately 400) to satisfy the U.S. EPA Drinking Water Standards (Table A-4). However, the higher retardation factor (2) of manganese (Table A-11) will cause it to remain within the till for hundreds of years (Section 6.6).

A.5.2 STEADY-STATE DISPERSION

Results of the transient and steady-state dispersion analyses presented in Figure A-42 indicate that the concentration of chemical constituents resulting from MWDF seepage will not exceed U.S. EPA Drinking Water Standards at the compliance boundary. The steady-state dispersion analyses indicate that the average normalized concentration of a chemical constituent at the compliance boundary for the projected conditions is less than 0.03 (Figure A-42). The source concentration of sulfate, the most mobile chemical constituent studied, is 2,000 parts per million (ppm) (Table A-4). Therefore, the sulfate concentration within the stratified drift will reach a maximum of near 60 ppm in the long-term. Results of the steady-state dispersion sensitivity analysis presented in Attachment A.4 indicate that the maximum concentration of sulfate at the compliance boundary could range from less than 40 ppm to 800 ppm for the long-term. However, it should be noted that the highest concentration at the compliance boundary is within drinking water standards for most cases modeled in Attachment A.4. For the cases where longitudinal dispersivity = 5 m (a_ℓ/a_t = 30) and for a_ℓ/a_t = 1,000 (a_ℓ = 60 m), the contaminant exceeded drinking water standards at the compliance boundary. However, the exceedance are restricted to within the lower till deposits. These exceedances occur for steady-state conditions expected in 8,800 years. Therefore, no long-term water quality impacts from MWDF seepage are very likely.

ATTACHMENT A.5

REFERENCES

Ayres Associates, 1984, "Mine Waste Disposal Facility Reclamation Cap and Compliance Boundary Analysis," Exxon Minerals Company, Crandon Project, Ayres Associates, Eau Claire, Wisconsin.

TABLES

TABLE A.5-1

DILUTION OF MWDF SEEPAGE BY PRECIPITATION RECHARGE

PRECIPITATION RECHARGE RATE		RECHARGE VOLUME[a]		MWDF SEEPAGE VOLUME		DILUTION RATIO
mm/y	in/y	m^3/s	gpm	m^3/s	gpm	
152	6	0.0189	300.0	0.000083	1.33	230
216	8.5	0.0242	384.0	0.000083	1.33	290
279	11	0.0294	466.0	0.000083	1.33	350

[a]Recharge volume equals [compliance area outside MWDF x precipitation recharge rate] plus [MWDF area x reclamation cap infiltration rate]. Reclamation cap infiltration rate equals 119 mm/y (4.67 inches per year) (Ayres Associates, 1984).

ATTACHMENT A.6

HORIZONTAL MODEL SENSITIVITY ANALYSES

ATTACHMENT A.6

TABLE OF CONTENTS

ATTACHMENT A.6

LIST OF TABLES

ATTACHMENT A.6

LIST OF FIGURES

ATTACHMENT A.6

HORIZONTAL MODEL SENSITIVITY ANALYSES

The sensitivity of the horizontal model calibration to different boundary conditions and hydrologic parameters is discussed in this attachment. In addition, the results of model calibration and the hydrologic impact assessment are presented for the low and high recharge rates.

A.6.1 HORIZONTAL MODEL CALIBRATION SENSITIVITY ANALYSES

A.6.1.1 Purpose and Procedure

The purpose of the horizontal model calibration was to develop a model which closely represents the site hydrologic setting, not only during preconstruction, but most importantly during the construction and operation phases in which hydrologic conditions will be altered, particularly by mine inflow. A calibrated model was developed by following the calibration procedure to meet the calibration criteria discussed in Section 5.2.4. These procedures have increased the confidence level in establishing a well-calibrated model. However, for model calibration, concerns were expressed by the WDNR regarding the appropriateness of a constant head boundary along Swamp Creek and the introduction of a low-permeability zone (Zone 2 in Figure A-22). Several model sensitivity analyses were conducted to resolve these concerns. The procedure for these sensitivity analyses was as follows:

1. Incorporate the different parameter values into the model.

2. Calibrate the model with the selected parameter values and compare the computed potentiometric surfaces with measured values.

3. Compute preconstruction ground water discharge rate to Swamp Creek.

4. Compute the maximum mine inflow rate and maximum potentiometric surface drawdown by reducing the potentiometric head in the mine area (24-node

configuration) to the bottom of the aquifer. The location of these nodes and the values of potentiometric head prior to and during maximum mine inflow calculations are shown in Table A.6-1. For one variation of the model, the potentiometric surface was lowered to the top of bedrock. The values of the potentiometric heads at the mine for this case are also shown in Table A.6-1.

5. Compute the maximum reduction of the ground water discharge rate to Swamp Creek resulting from the maximum mine inflow rate.

6. Compare the results of the sensitivity analyses with the selected calibrated model.

The following sections briefly summarize the descriptions of the various model calibration sensitivity analyses and results. Detailed information on the input parameters for the sensitivity analyses is presented in Attachment A.7.

A.6.1.2 Description of Sensitivity Analyses

Six variations of the calibration model were examined:

1. Combined Constant and No-Flow Boundary Conditions (Golder Associates, 1982): A no-flow boundary condition was assigned to the boundary segment between Rice Lake and the southern end of Mole Lake and to the segment from approximately 450 m (1,476 feet) north of Walsh Lake to the southwestern end of St. John's Lake.

2. Swamp Creek No-Flow Boundary Condition: A no-flow boundary condition was assigned to the northern boundary along Swamp Creek.

3. Increased Lake Bottom Permeability: The lake bottom permeability was increased for all lakes from 5×10^{-9} m/s (1.3×10^{-4} feet per day) to 1×10^{-8} m/s (2.6×10^{-4} feet per day).

4. Uniform Permeability: A uniform permeability was assigned to the entire aquifer; that is, Zones 1 and 2 of Figure A-22 had the same permeability which was equal to the permeability of Zone 1 (Table A-15).

5. Maximum Mine Inflow for Drawdown to Top of Bedrock: The potentiometric head in the mine area was reduced to the top of bedrock. The till deposits in the mine area were included in the saturated thickness. For modeling purposes, the till deposits were assumed to have permeability equal to the drift which results in a conservative estimate of the maximum mine inflow.

6. Mine Inflow for Varied Lake Seepage: Lake sediment resistivity values were adjusted in the calibrated model to provide computed seepage rates approximately equal to those estimated by the water balance method. (Dames and Moore, 1985; Table A-10).

For each analysis, simulated potentiometric surfaces were compared with measured values; maximum mine inflow rate and the ground water discharge rate to Swamp Creek were also examined.

A.6.1.3 Results

Results of the model calibration sensitivity analyses are discussed in the following paragraphs.

Best Calibration - Constant Head Boundary Condition

This calibration analysis provided the best match with measured potentiometric values. Comparison of the calibrated and observed potentiometric surfaces is shown in Figure A-24. The predicted potentiometric drawdown for the maximum mine inflow rate is shown in Figure A.6-1. In addition, the computed maximum mine inflow rate and the ground water discharge rates to Swamp Creek are presented in Table A.6-2. Figure A.6-1, maximum mine inflow rate, and the ground water discharge rates to Swamp Creek will be used to evaluate other model calibration sensitivity analyses.

Combined Constant and No-Flow Boundary Conditions

The computed potentiometric surface for this analysis is shown in Figure A.6-2. A comparison of Figures A.6-2 and A-23 indicates that this calibration analysis provided a potentiometric surface identical to the constant head boundary analysis. The maximum mine inflow rate from this analysis is 0.0968 m^3/s (1,534 gallons per minute) and the ground water discharge rate to Swamp Creek is 0.0819 m^3/s (2.89 cubic feet per second) (Table A.6-2). These numbers compare very well with the constant head boundary analysis.

Swamp Creek No-Flow Boundary Condition

The computed potentiometric surface and its predicted potentiometric drawdown for the maximum mine inflow rate are shown in Figures A.6-3 and A.6-4, respectively. As Figure A.6-3 depicts, the Swamp Creek no-flow boundary condition results in elevated potentiometric levels around Swamp Creek and prevents recharge from reaching the Creek. Under this condition, the maximum mine inflow rate is slightly higher than the constant head boundary condition because of higher potentiometric levels around Swamp Creek and the availability of precipitation recharge to flow into the mine rather than to Swamp Creek. The ground water discharge to Swamp Creek is zero (no-flow boundary).

Increased Lake Bottom Permeability

The computed potentiometric surface for this condition is shown in Figure A.6-5. This figure indicates that the computed potentiometric surfaces do not agree very well with measured potentiometric values. The potentiometric surface contours are shifted farther to the west, indicating that the computed lake recharge in this sensitivity analysis is higher than the existing lake recharge.

The potentiometric drawdown from maximum mine inflow for this condition is similar to the constant head boundary analysis. The maximum mine inflow rate and ground water discharge rate to Swamp Creek (Table A.6-2) were higher than those for the constant head boundary analysis because of the increased lake recharge rate.

Uniform Permeability

The computed potentiometric surface and its predicted potentiometric drawdown for the maximum mine inflow rate are shown in Figures A.6-6 and A.6-7, respectively. The computed potentiometric surface matches reasonably well with the measured data, except at the northern boundary (along Swamp Creek) where the potentiometric surfaces are lower than both the measured and the constant head boundary analysis potentiometric surfaces. Observed and calculated potentiometric heads were compared at selected borings. A statistical summary of this comparison along with the statistical summary of the same comparison for the best calibration condition is shown in Table A.6-5. The summary shows that the best calibration is closer to observed conditions. However, maximum mine inflow rate, maximum potentiometric drawdown, and the ground water discharge rate to Swamp Creek are similar to the results of the constant head boundary analysis.

Maximum Mine Inflow for Drawdown to Top of Bedrock

The purpose of this analysis was to determine the influence of reduction of the potentiometric head at the mine to the top of bedrock as opposed to the reduction of the head to the bottom of the aquifer (top of till). The results of this analysis are compared with the other analyses in Table A.6-2. When compared to best calibration conditions, the maximum mine inflow is approximately 9 percent greater when the potentiometric head was lowered to bedrock. Also, when compared to best calibration conditions, the discharge to Swamp Creek is reduced by 0.017 m^3/sec (0.6 cfs) which is approximately 14 percent of the preconstruction discharge to Swamp Creek.

Mine Inflow for Varied Lake Seepage

The purpose of this analysis was to determine the effects of the different lake seepage rates (determined by water balance analyses) on computed mine inflow. A steady-state mine inflow simulation was performed using the mine nodes and head values presented in Table A.7-10. The mine inflow rate increased from 0.0971 m^3/s (1,540 gpm) for the previously calibrated flow model to 0.1129 m^3/s (1,790 gpm). This increased mine inflow is derived from the generally higher lake seepage rates computed using the water balance method.

A.6.1.4 Conclusions

Sensitivity analyses of the different conditions indicated that the selected calibrated model with a constant head boundary and low-permeability zone best represented site area conditions. The assumption of a constant head boundary along Swamp Creek and the introduction of a low-permeability zone were valid and justifiable because (1) for the maximum mine inflow rate, approximately 70 percent of the present base flow would continue to discharge to Swamp Creek; (2) no reversal of ground water flow to Swamp Creek was projected for different calibrated analyses; and (3) the best agreement with the measured potentiometric surface was observed for two permeability zones; however, the potentiometric drawdown from maximum mine inflow and the ground water discharge rate to Swamp Creek were similar for the uniform and two permeability zone(s) analyses.

A.6.2 MODEL CALIBRATION FOR LOW AND HIGH RECHARGE CASES

The calibrated model potentiometric surface for the Middle Recharge case is shown in Figure A-23 and the model calibration summary is presented in Table A-12. The models for the Low and High Recharge cases were calibrated using the same input parameter values and conditions as the Middle Recharge case, with the exception of aquifer permeabilities. The calibration analyses for the Low and High Recharge cases are summarized in Tables A.6-3 and A.6-4, respectively. These tables present the results of calibration parameters on the potentiometric surface, the ground water discharge rate to Swamp Creek, and the model calibration results. Calibrated potentiometric surfaces for the Low and High Recharge cases are shown in Figures A.6-8 and A.6-9, respectively. As Figures A.6-8 and A.6-9 indicate, the three calibrated potentiometric surfaces were nearly identical.

A.6.3 PREDICTED POTENTIOMETRIC DRAWDOWN FOR LOW AND HIGH RECHARGE CASES

The predicted potentiometric drawdown at Project Year 28 for Low and High Recharge cases is shown in Figures A.6-10 and A.6-11, respectively. These analyses used the mine inflow rates (Table A-1) and the hydrologic actions of the proposed facilities (Attachment A.7) associated with the Low and High Recharge rates. The hydrologic actions resulting from the mine and proposed facilities were applied to the calibrated models and allowed to reach steady-state using transient conditions.

The predicted potentiometric drawdown for the Low and High Recharge cases is similar to that for the Middle Recharge case as shown in Figure A-32. These figures indicate that the decline in potentiometric surface will be similar for the three recharge rates; therefore, the impact assessment for the Middle Recharge case, discussed in Section 6.0, is applicable for the Low and High Recharge cases.

A.6.4 HORIZONTAL MODEL DISPERSION SENSITIVITY ANALYSIS

The effect of different longitudinal and transverse dispersivity values on the normalized steady-state concentration profile of chemical constituents adjacent to the MWDF was evaluated. The three sets of longitudinal and transverse dispersivity values tested were:

SENSITIVITY ANALYSIS	LONGITUDINAL DISPERSIVITY (m)	(ft)	TRANSVERSE DISPERSIVITY (m)	(ft)
1	20	66	5	16
2	60	197	15	49
3	100	328	20	66

These values were used as input to the horizontal model for steady-state dispersion analysis. Ground water flow conditions identical to the calibrated model for the Middle Recharge case, with the addition of reclamation cap recharge at the MWDF perimeter and a MWDF steady-state seepage rate of 1.68 mm/y (0.066 inches/yr) to simulate post-operation phase conditions, were used in the analysis. Results of dispersion sensitivity analyses Nos. 1 and 3 are shown in Figures A.6-12 and

A.6-13, respectively. Figure A-36 depicts the results of sensitivity analysis No. 2. Comparison of these figures indicates that lower dispersivity values resulted in less spreading of chemical constituents in the ground water and that chemical constituents advanced further along the dominant ground water flow path. Sensitivity analysis No. 2 was selected as the most representative of site area conditions and was used in subsequent analyses.

ATTACHMENT A.6

REFERENCE

Golder Associates, 1982, Ground Water Impact Screening Model, Project Report No. 9, Exxon Minerals Company, Crandon Project, Golder Associates, Atlanta, Georgia.

TABLES

TABLE A.6-1

POTENTIOMETRIC HEADS FOR MAXIMUM MINE INFLOW MODELING

COMPUTER MODEL MINE INFLOW POINT NUMBER[a]	CALIBRATED POTENTIOMETRIC HEAD (m)	BOTTOM OF AQUIFER LOWERED POTENTIOMETRIC HEAD[b] (m)	TOP OF BEDROCK LOWERED POTENTIOMETRIC HEAD[c]
10	479.6	469.0	469.0
19	480.0	468.0	462.0
11	480.2	470.0	469.0
20	480.5	469.0	462.0
28	480.2	464.0	455.0
29	480.7	466.0	455.0
12	481.1	468.0	450.0
21	481.3	469.0	449.0
30	481.5	465.0	448.0
37	480.4	459.0	449.0
38	480.8	463.0	449.0
39	481.5	462.0	446.0
22	482.1	464.0	446.0
31	482.2	461.0	446.0
40	482.2	458.0	445.0
23	482.9	460.0	451.0
32	482.8	457.0	450.0
41	482.8	456.0	449.0
24	483.5	466.0	460.0
33	483.4	461.0	455.0
35	484.4	466.0	466.0
44	484.3	464.0	463.0
36	484.8	469.0	462.0
45	484.7	464.0	458.0

[a]Refer to Figure A-2 for location of mine inflow points.

[b]Potentiometric heads were lowered to the aquifer bottom elevation and held constant to simulate maximum mine inflow.

[c]For one variation of the model potentiometric heads were lowered to the top of bedrock and held constant to simulate maximum mine inflow.

TABLE A.6-2

COMPUTED MAXIMUM MINE INFLOW RATE AND CHANGES IN GROUND WATER DISCHARGE RATE TO SWAMP CREEK FOR MIDDLE RECHARGE CASE

CALIBRATION CONDITION	MAXIMUM MINE INFLOW RATE		DISCHARGE RATE TO SWAMP CREEK[a] PRECONSTRUCTION		DISCHARGE RATE TO SWAMP CREEK[a] MAXIMUM MINE INFLOW		REMAINING PERCENTAGE OF STREAM FLOW[b]
	m^3/s	gpm	m^3/s	cfs	m^3/s	cfs	
TWO PERMEABILITY ZONES:							
Constant Head Boundary Condition[c]	0.0971	1,540	0.118	4.15	0.0825	2.91	70
Combined Constant Head and No-Flow Boundary Conditions[d]	0.0968	1,534	0.119	4.21	0.0819	2.89	69
Swamp Creek No-Flow Condition	0.1121	1,777	0	0	0	0	-
Increased Lake Bottom Permeability	0.1020	1,617	0.119	4.21	0.0842	2.98	71
Drawdown to Top of Bedrock	0.1063	1,686	0.118	4.15	0.654	2.31	56
UNIFORM PERMEABILITY ZONE:							
Constant Head Boundary Condition	0.0944	1,496	0.119	4.19	0.0836	2.95	71

[a]The discharge rate to Swamp Creek is calculated along segment A'D as depicted in Figure A.2-1 of Attachment A.2.

[b]Remaining percentage of flow equals the amount of ground water discharge rate to Swamp Creek corresponding to maximum mine inflow divided by the preconstruction ground water discharge rate to the Creek.

[c]Best calibration.

[d]Based on Golder Associates (1982).

TABLE A.6-3

SUMMARY OF HORIZONTAL MODEL CALIBRATION FOR LOW RECHARGE CASE

CALIBRATION ANALYSIS NUMBER	PERMEABILITY ZONE 1[a] (m/s)	(ft/day)	ZONE 2[a] (m/s)	(ft/day)	POTENTIOMETRIC SURFACE[b]	CALCULATED GROUND WATER DISCHARGE TO SWAMP CREEK[c] (m^3/s)	(cfs)	CHANGES FOR SUBSEQUENT CALIBRATION ANALYSIS
1	8.88×10^{-5}	25.2	8.88×10^{-5}	25.2	Low within north central area.	--	--	Decrease permeability of Zone 2 to 4.76×10^{-5} m/s.
2	8.88×10^{-5}	25.2	4.76×10^{-5}	13.5	Good agreement overall.	0.084	2.95	End of horizontal model calibration for Low Recharge case.

[a]Refer to Figure A-22 for location of permeability zones.

[b]Calculated potentiometric surface as compared to observed; refer to Figure A-13 for observed potentiometric surface.

[c]The calculated ground water discharge rate from the site area to Swamp Creek also includes the discharge rate to Hemlock Creek (Segment A'D). Refer to Figure A.2-1 of Attachment 2.0 for stream segment locations.

TABLE A.6-4

SUMMARY OF MODEL CALIBRATION
FOR HIGH RECHARGE CASE

CALIBRATION ANALYSIS NUMBER	PERMEABILITY ZONE 1[a] (m/s)	(ft/day)	ZONE 2[a] (m/s)	(ft/day)	POTENTIOMETRIC SURFACE[b]	CALCULATED GROUND WATER DISCHARGE TO SWAMP CREEK[c] (m^3/s)	(cfs)	CHANGES FOR SUBSEQUENT CALIBRATION ANALYSIS
1		1.52×10^{-4}		43.1	7.42×10^{-5}	21.0	High overall.----	Increase permeability of Zone 1 to 1.54×10^{-4} m/s and Zone 2 to 7.61×10^{-5} m/s.
2		1.54×10^{-4}		43.7	7.6×10^{-5}	21.6	High overall.----	Increase permeability of Zones 1 and 2 to 1.55×10^{-4} m/s.
3		1.55×10^{-4}		44.0	1.55×10^{-4}	44.0 central area.	Low within north-----	Decrease permeability of Zone 2 to 7.70×10^{-5} m/s.
4		1.55×10^{-4}		44.0	7.70×10^{-5}	21.8 horizontal overall.	Good agreement1.515.32 model	End of calibration for High Recharge case.

[a]Refer to Figure A-22 for location of permeability zones.

[b]Calculated potentiometric surface as compared to observed; refer to Figure A-13 for observed potentiometric surface.

[c]The calculated ground water discharge rate from the site area to Swamp Creek also includes the discharge rate to Hemlock Creek (Segment A'D). Refer to Figure A.2-1 of Attachment 2.0 for stream segment locations.

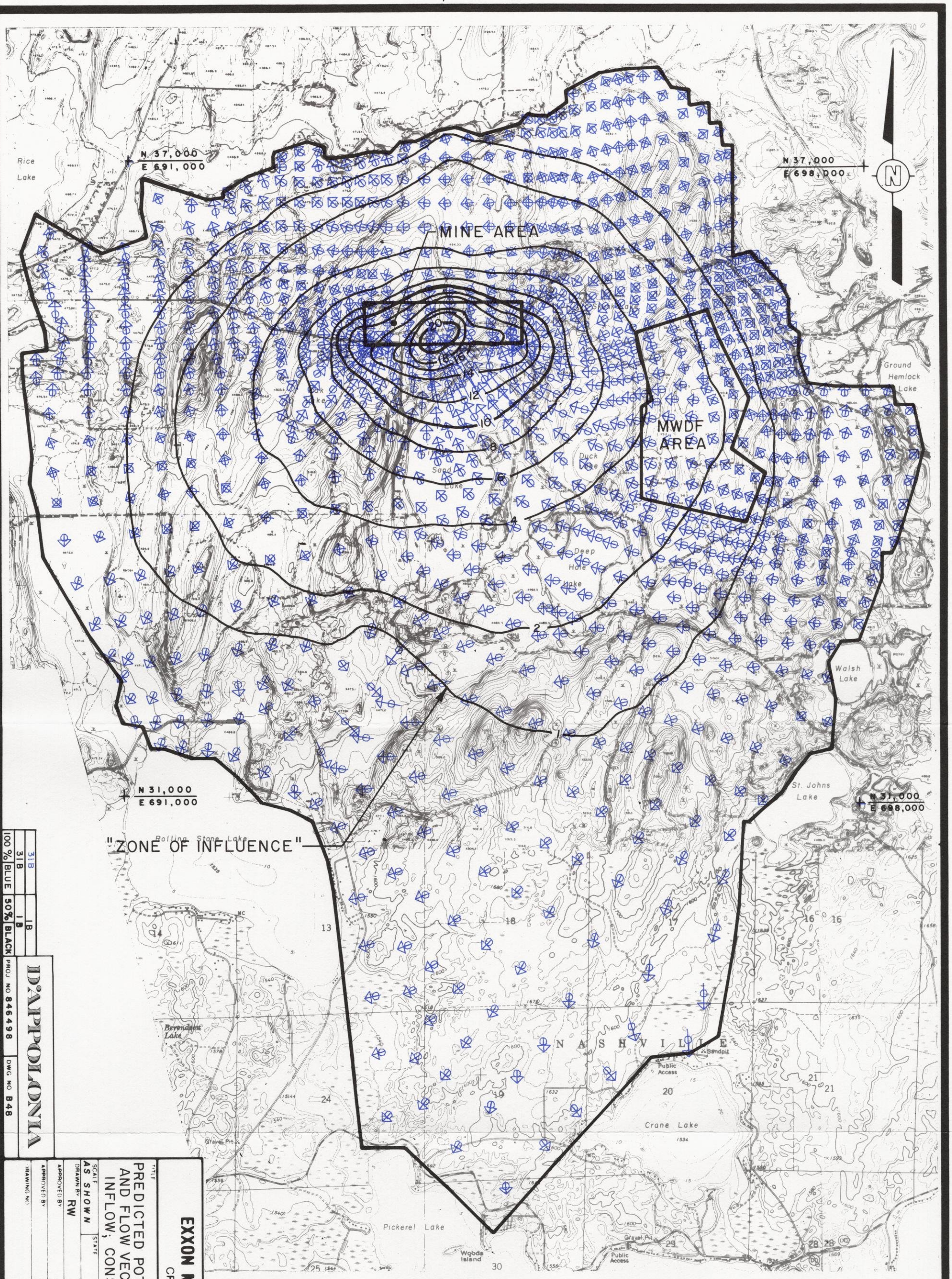
TABLE A.6-5

STATISTICAL COMPARISON OF OBSERVED AND CALCULATED
POTENTIOMETRIC HEADS AT SELECTED BORINGS FOR
BEST CALIBRATED CONDITIONS AND UNIFORM PERMEABILITY CONDITIONS

STATISTIC	STATISTICAL VALUES OF DIFFERENCE BETWEEN OBSERVED AND CALCULATED HEADS(a)			
	BEST CALIBRATED CONDITIONS		UNIFORM PERMEABILITY CONDITIONS	
	(m)	(ft)	(m)	(ft)
Mean of the algebraic differences	0.45	1.48	0.63	2.07
Mean of the absolute differences	0.69	2.26	0.81	2.66
Standard deviation of the algebraic differences	0.83	2.72	0.90	2.95
Root mean square (RMS) of difference	0.94	3.08	1.09	3.58

(a)Statistics were calculated using the difference between observed and calculated heads at 100 borings listed in Table A-13.

FIGURES



NOTES:

1. LIMIT OF ZONE OF INFLUENCE IS SET AT A MAXIMUM DRAWDOWN OF 1.0m (3.3 FEET)
2. LENGTH OF VECTOR IS PROPORTIONAL TO THE MAGNITUDE OF FLOW. EACH cm IS APPROXIMATELY EQUAL TO 1574.8 m^3/y PER HORIZONTAL UNIT WIDTH IN METERS.

LEGEND

—2— PREDICTED POTENTIOMETRIC DRAWDOWN IN METERS

PREDICTED FLOW VECTOR

SCALE

0 1000 2000 meters

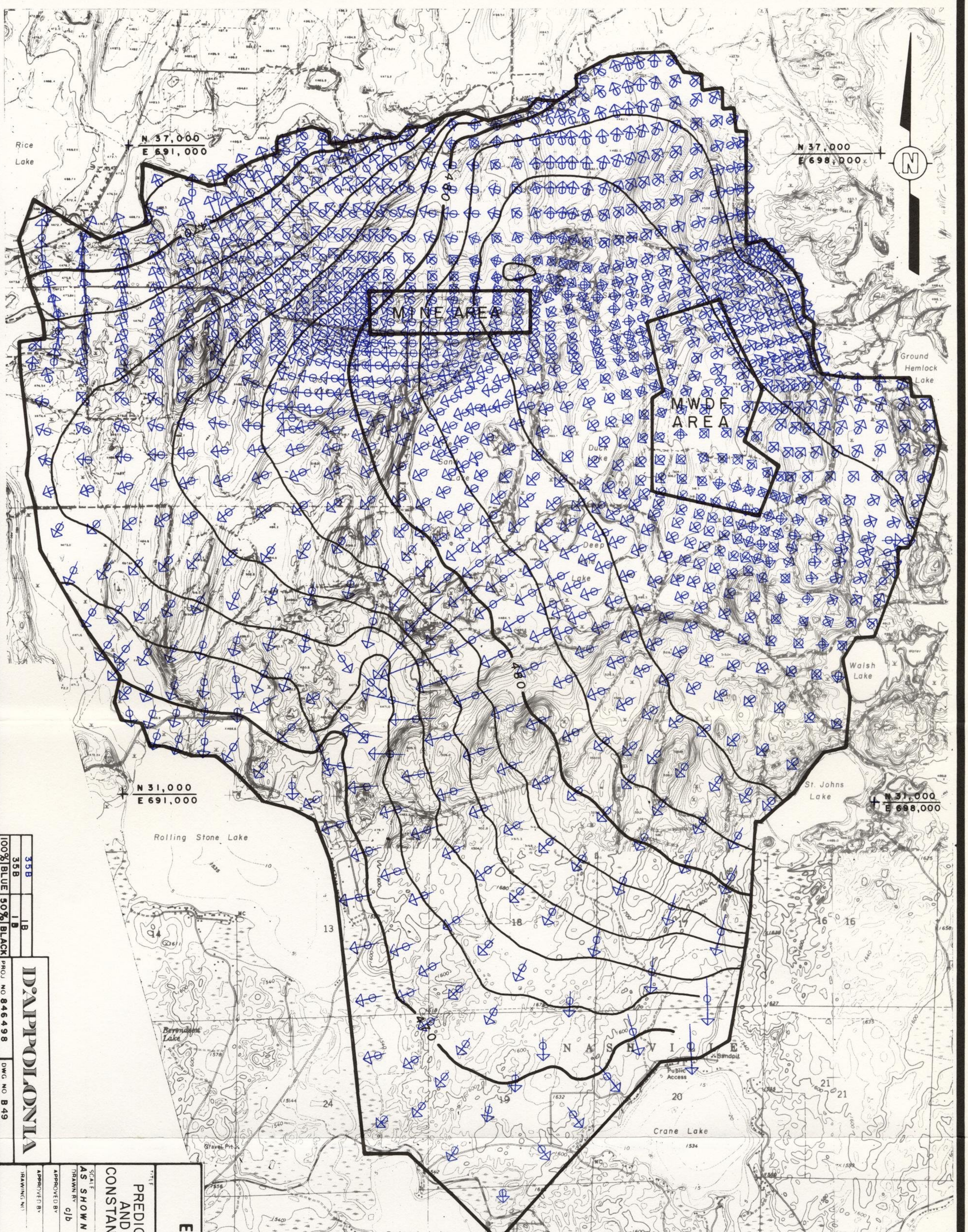
EXXON MINERALS COMPANY
CRANDON PROJECT

FIGURE A.6-1

PREDICTED POTENTIOMETRIC DRAWDOWN AND FLOW VECTORS-FOR MAXIMUM MINE INFLOW; CONSTANT HEAD BOUNDARY

SCALE	AS SHOWN
DRAWN BY	RW
DATE	10-9-84

D'APPOLONIA PROJ NO 846498 DWG NO B48



NOTE:

LENGTH OF VECTOR IS PROPORTIONAL TO THE MAGNITUDE OF FLOW. EACH cm IS APPROXIMATELY EQUAL TO 787.4 m^3/y PER HORIZONTAL UNIT WIDTH IN METERS.

SCALE

0 1000 2000 meters

LEGEND

470 — PREDICTED POTENTIOMETRIC SURFACE IN METERS ABOVE MSL

PREDICTED FLOW VECTOR

FIGURE A.6-2

EXXON MINERALS COMPANY

CRANDON PROJECT

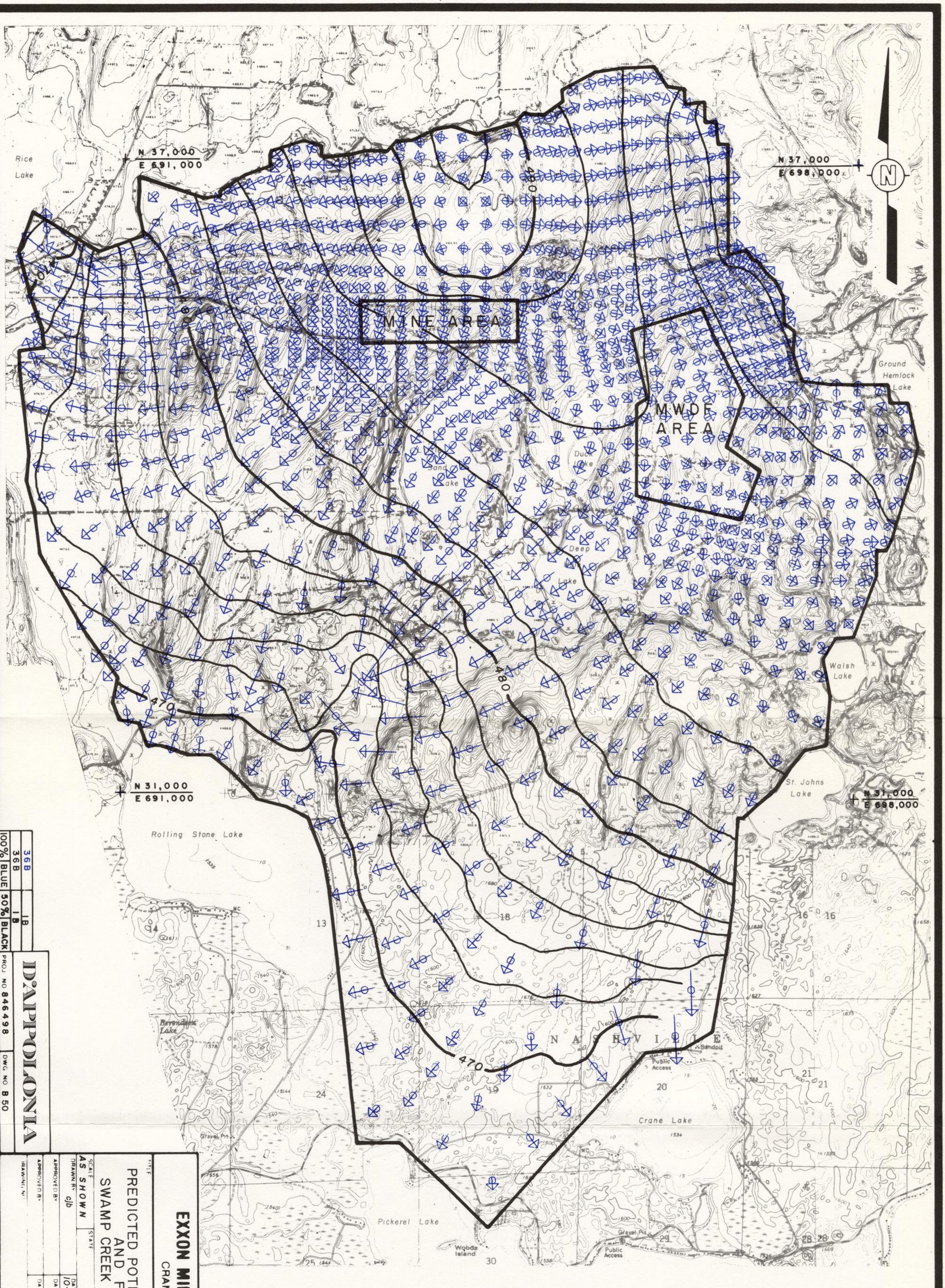
PREDICTED POTENTIOMETRIC SURFACE AND FLOW VECTORS; COMBINED CONSTANT HEAD AND NO-FLOW BOUNDARY

SCALE	AS SHOWN
DRAWN BY	c/b
DATE	10-9-84
APPROVED BY	SHD

D'APPOLONIA

PROJ NO 846498 — DWG NO B49

100% BLUE	35B	35B
50% BLACK	1B	1B



NOTE:

LENGTH OF VECTOR IS PROPORTIONAL TO THE MAGNITUDE OF FLOW. EACH cm IS APPROXIMATELY EQUAL TO .787.4 m^3/y PER HORIZONTAL UNIT WIDTH IN METERS.

SCALE

0 1000 2000 meters

LEGEND

470 — PREDICTED POTENTIOMETRIC SURFACE IN METERS ABOVE MSL

PREDICTED FLOW VECTOR

FIGURE A.6-3

EXXON MINERALS COMPANY

CRANDON PROJECT

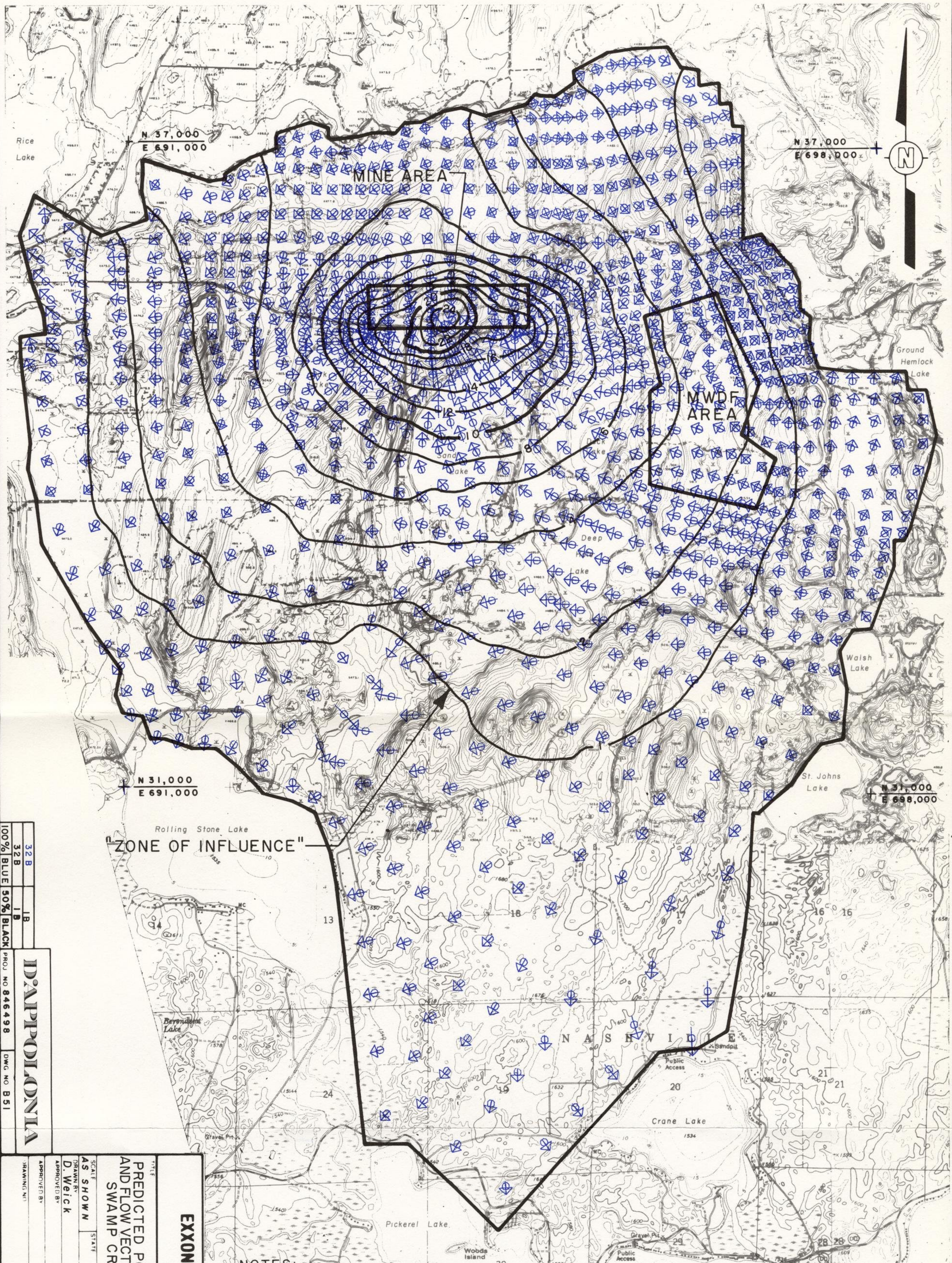
TITLE: PREDICTED POTENTIOMETRIC SURFACE AND FLOW VECTORS; SWAMP CREEK NO-FLOW BOUNDARY

SCALE AS SHOWN	STATE	COUNTY
DRAWN BY cjb	DATE 10-9-84	CHECKED BY MJB-L DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD DATE 12/10/85
APPROVED BY	DATE	EXXON
DRAWING NO.	SHEET OF	REVISION NO.

D'APPOLONIA

PROJ NO 846498 DWG NO B 50

36B	1B
36B	1B
100% BLUE	50% BLACK



NOTES:

1. LIMIT OF ZONE OF INFLUENCE IS SET AT A MAXIMUM DRAWDOWN OF 1.0m (3.3 FEET)
2. LENGTH OF VECTOR IS PROPORTIONAL TO THE MAGNITUDE OF FLOW. EACH cm IS APPROXIMATELY EQUAL TO 1574.8 m^3/y PER HORIZONTAL UNIT WIDTH IN METERS.

SCALE

0 1000 2000 meters

LEGEND

2 PREDICTED POTENTIOMETRIC DRAWDOWN IN METERS

PREDICTED FLOW VECTOR

FIGURE A.6-4

EXXON MINERALS COMPANY

CRANDON PROJECT

PREDICTED POTENTIOMETRIC DRAWDOWN AND FLOW VECTORS FOR MAXIMUM MINE INFLOW; SWAMP CREEK NO-FLOW BOUNDARY

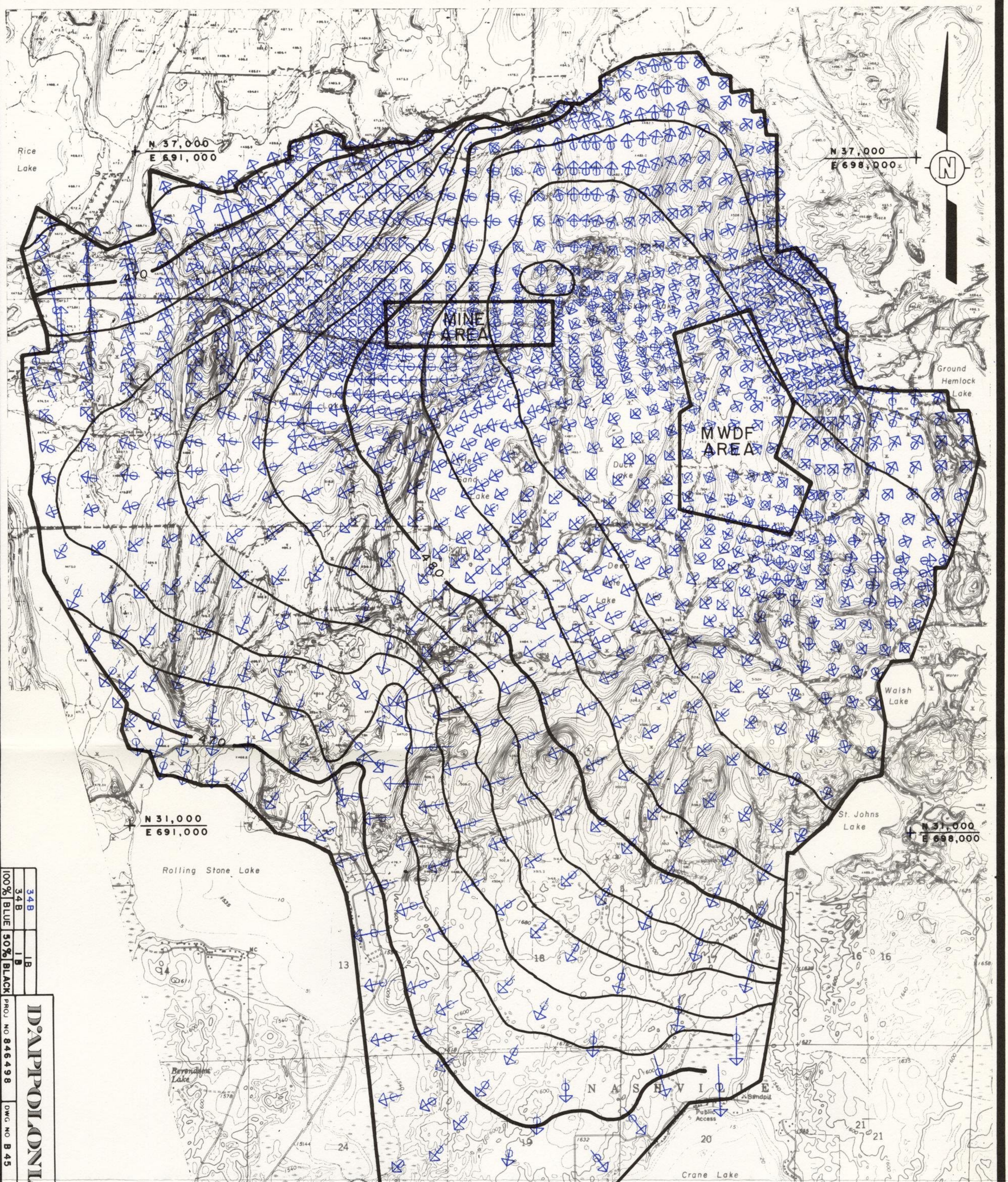
SCALE AS SHOWN

DRAWN BY D. Weick DATE 9-21-84

D'APPOLONIA

PROJ NO 846498 DWG NO B51

32B	1B
100% BLUE	50% BLACK



NOTE:

LENGTH OF VECTOR IS PROPORTIONAL TO THE MAGNITUDE OF FLOW. EACH cm IS APPROXIMATELY EQUAL TO 787.4 m^3/y PER HORIZONTAL UNIT WIDTH IN METERS.

SCALE

0 1000 2000 meters

LEGEND

— 470 — PREDICTED POTENTIOMETRIC SURFACE IN METERS ABOVE MSL

PREDICTED FLOW VECTOR

FIGURE A.6-5

EXXON MINERALS COMPANY

CRANDON PROJECT

PREDICTED POTENTIOMETRIC SURFACE AND FLOW VECTORS; INCREASED LAKE BOTTOM PERMEABILITY

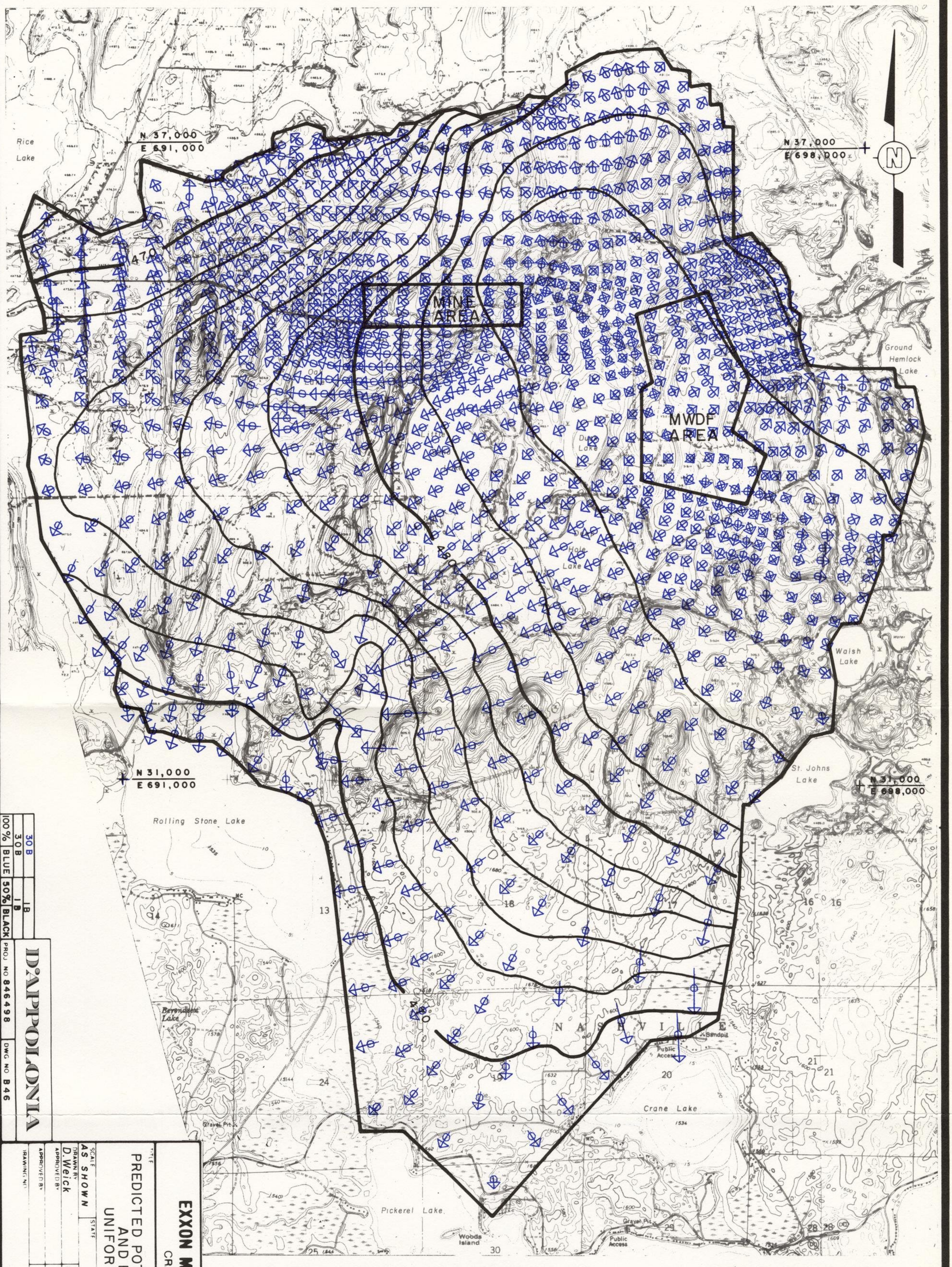
SCALE AS SHOWN

DRAWN D. Weick DATE 9-21-84

D'APPOLONIA

PROJ NO 846498 DWG NO B 45

100% BLUE	34 B	34B
50% BLACK	1 B	



NOTE:

LENGTH OF VECTOR IS PROPORTIONAL TO THE MAGNITUDE OF FLOW. EACH cm IS APPROXIMATELY EQUAL TO 787.4 m^3/y PER HORIZONTAL UNIT WIDTH IN METERS.

LEGEND

470 — PREDICTED POTENTIOMETRIC SURFACE IN METERS ABOVE MSL

PREDICTED FLOW VECTOR

FIGURE A.6-6

EXXON MINERALS COMPANY

CRANDON PROJECT

PREDICTED POTENTIOMETRIC SURFACE AND FLOW VECTORS; UNIFORM PERMEABILITY

SCALE AS SHOWN

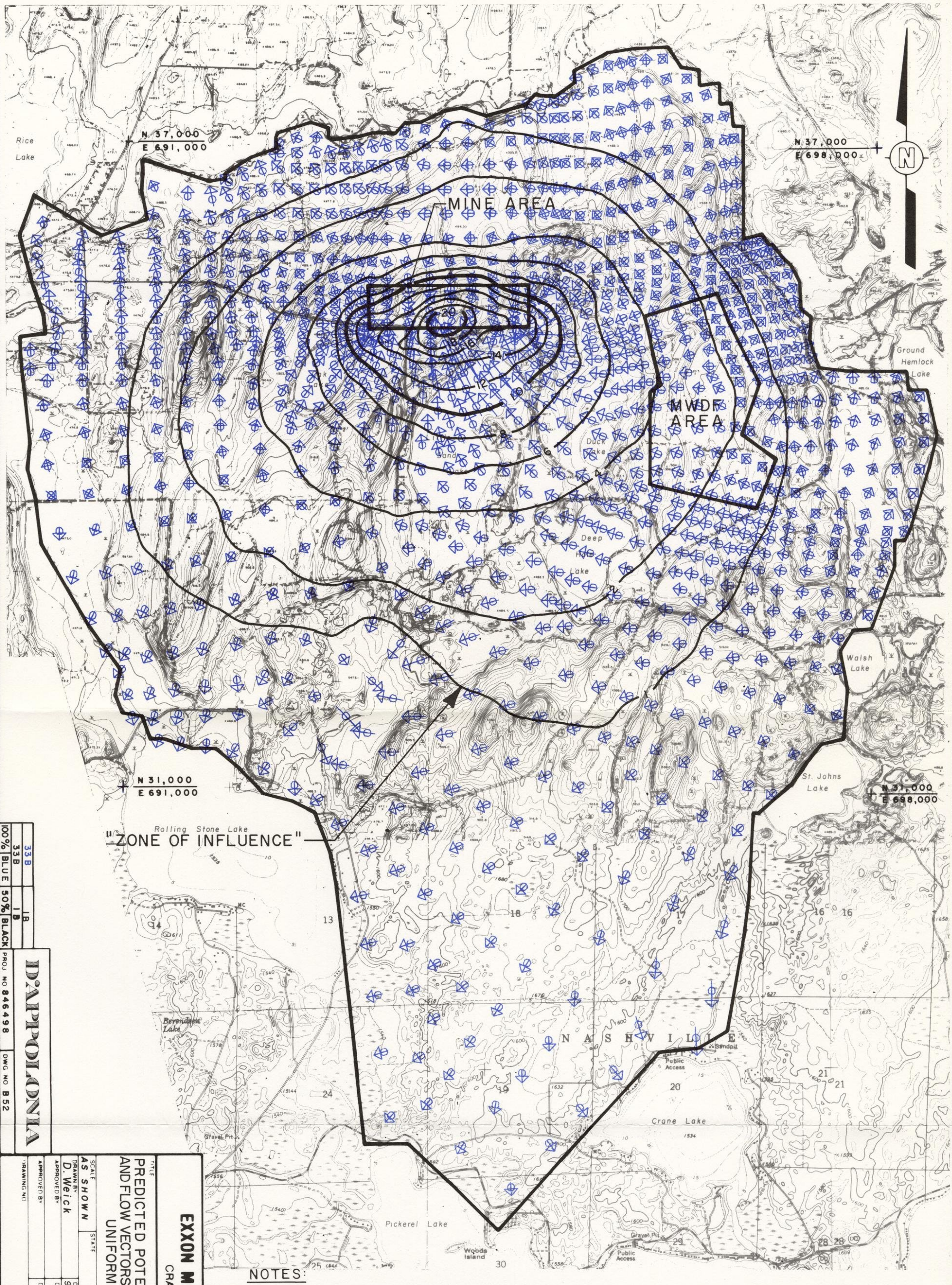
DRAWN BY D. Weick DATE 9-21-84

D'APPOLONIA

PROJ. NO 846498

DWG NO B46

100% BLUE 30B | 50% BLACK 1B



NOTES:

1. LIMIT OF ZONE OF INFLUENCE IS SET AT A MAXIMUM DRAWDOWN OF 1.0m (3.3 FEET)
2. LENGTH OF VECTOR IS PROPORTIONAL TO THE MAGNITUDE OF FLOW. EACH cm IS APPROXIMATELY EQUAL TO 1574.8 m^3/y PER HORIZONTAL UNIT WIDTH IN METERS.

SCALE

0 1000 2000 meters

LEGEND

— 2 — PREDICTED POTENTIOMETRIC DRAWDOWN IN METERS

PREDICTED FLOW VECTOR

FIGURE A.6-7

EXXON MINERALS COMPANY

CRANDON PROJECT

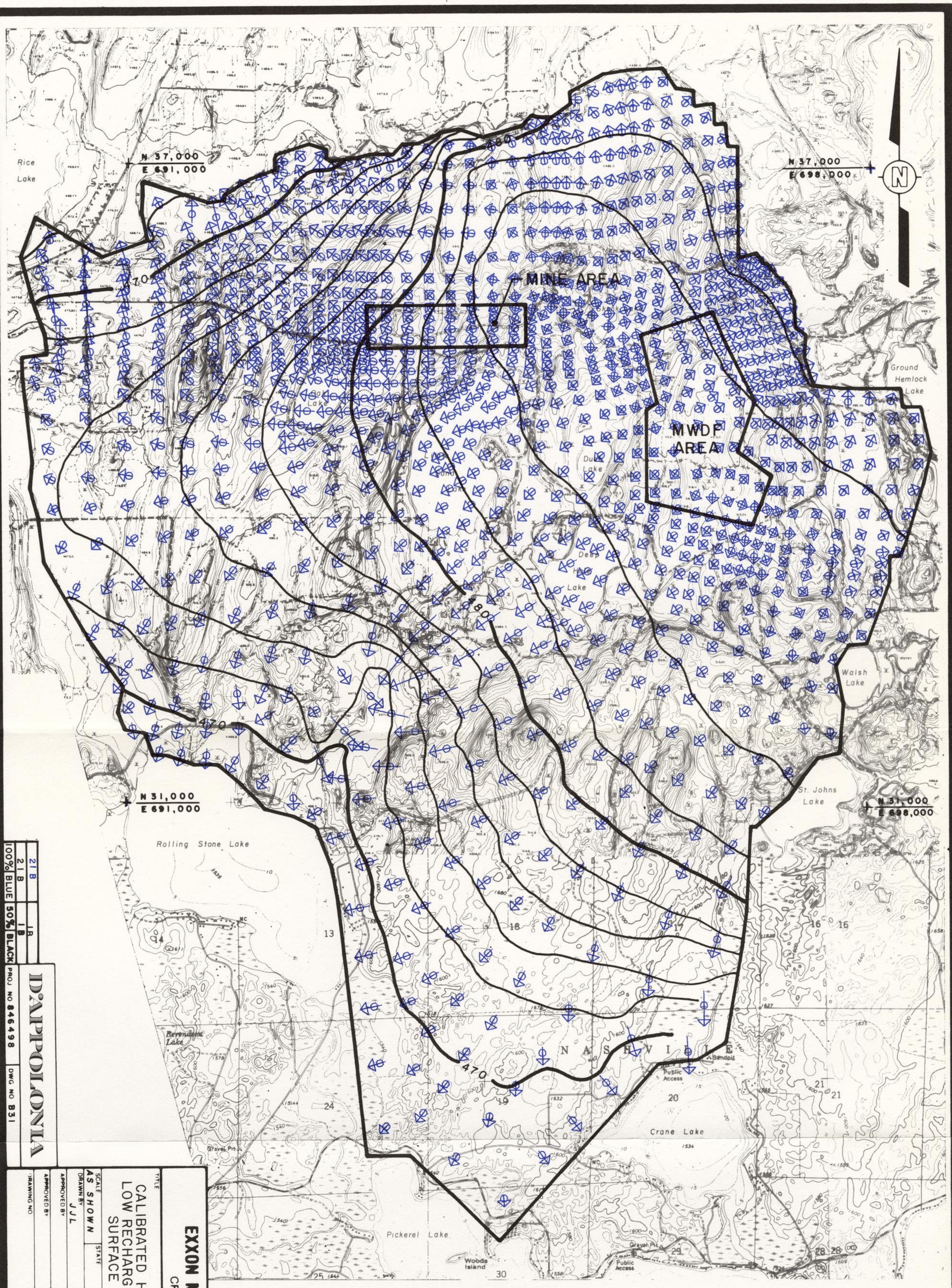
TITLE: PREDICTED POTENTIOMETRIC DRAWDOWN AND FLOW VECTORS FOR MAXIMUM MINE INFLOW; UNIFORM PERMEABILITY

SCALE: AS SHOWN	STATE	COUNTY
DRAWN BY: D. Weick	DATE: 9-14-84	CHECKED BY: MBA
APPROVED BY	DATE	EXXON: SWD
DRAWING NO.	SHEET OF	REVISION NO.

D'APPOLONIA

PROJ NO 846498 DWG NO B52

100% BLUE	33B
50% BLACK	1B



NOTE:

LENGTH OF VECTOR IS PROPORTIONAL TO THE MAGNITUDE OF FLOW. EACH cm IS APPROXIMATELY EQUAL TO 787.4 m^3/y PER HORIZONTAL UNIT WIDTH IN METERS.

SCALE

0 1000 2000 meters

LEGEND

470 — PREDICTED POTENTIOMETRIC SURFACE IN METERS ABOVE MSL

PREDICTED FLOW VECTOR

21 B	21 B	1B
100% BLUE	50%	BLACK

D'APPOLONIA

PROJ NO 846498 DWG NO B31

FIGURE A.6-8

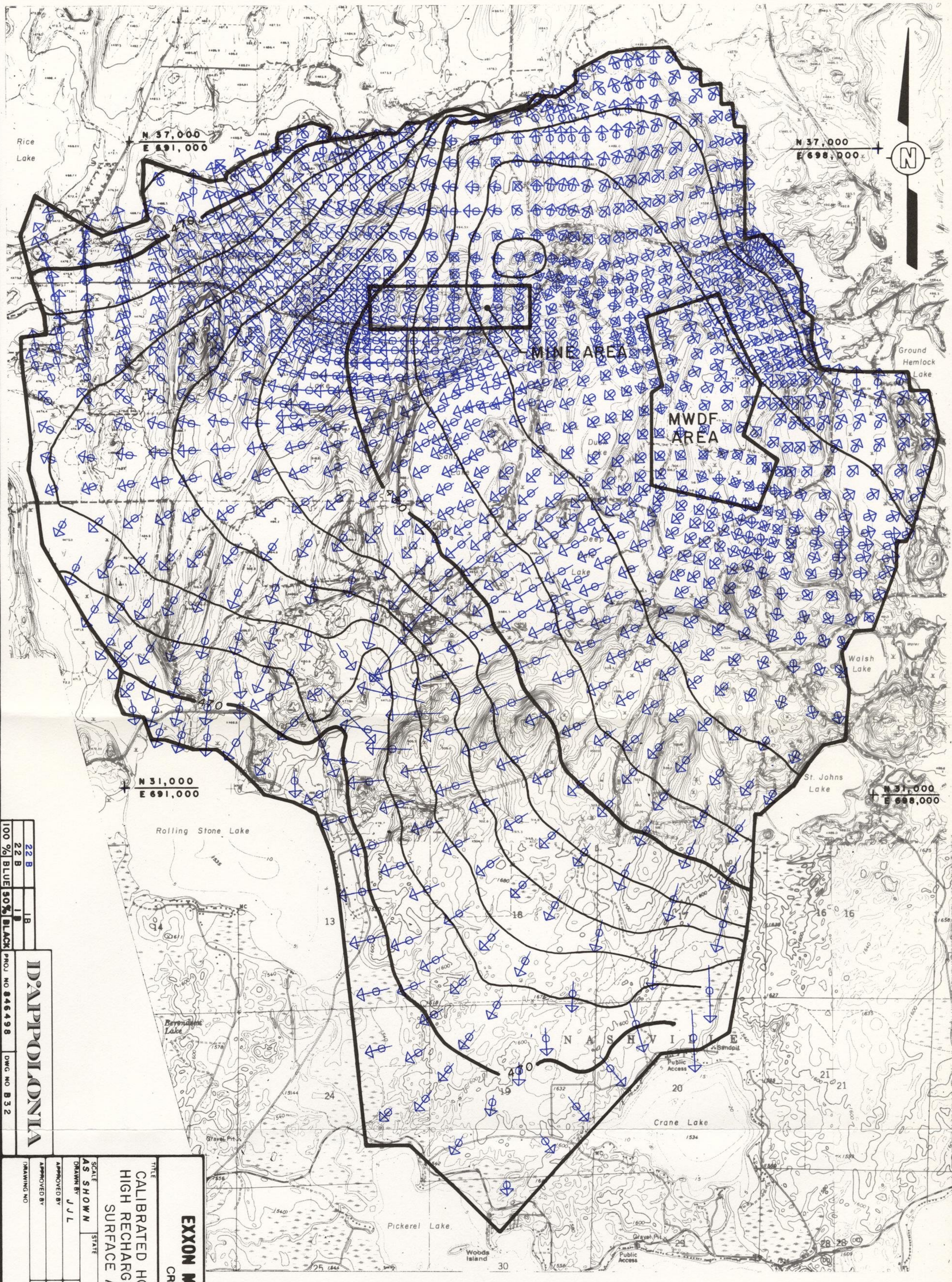
EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE

CALIBRATED HORIZONTAL MODEL FOR LOW RECHARGE CASE; POTENTIOMETRIC SURFACE AND FLOW VECTORS

SCALE: AS SHOWN	STATE		COUNTY
DRAWN BY: JJL	DATE: 9-26-84	CHECKED BY: MDS	DATE: 11/10/85
APPROVED BY	DATE	APPROVED BY: SMP	DATE: 12/11/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET ___ OF ___	REVISION NO



NOTE:

LENGTH OF VECTOR IS PROPORTIONAL TO THE MAGNITUDE OF FLOW. EACH cm IS APPROXIMATELY EQUAL TO 787.4 m^3/y PER HORIZONTAL UNIT WIDTH IN METERS.

SCALE

0 1000 2000 meters

LEGEND

470 PREDICTED POTENTIOMETRIC SURFACE IN METERS ABOVE MSL

PREDICTED FLOW VECTOR

FIGURE A.6-9

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE: CALIBRATED HORIZONTAL MODEL FOR HIGH RECHARGE CASE; POTENTIOMETRIC SURFACE AND FLOW VECTORS

SCALE: AS SHOWN

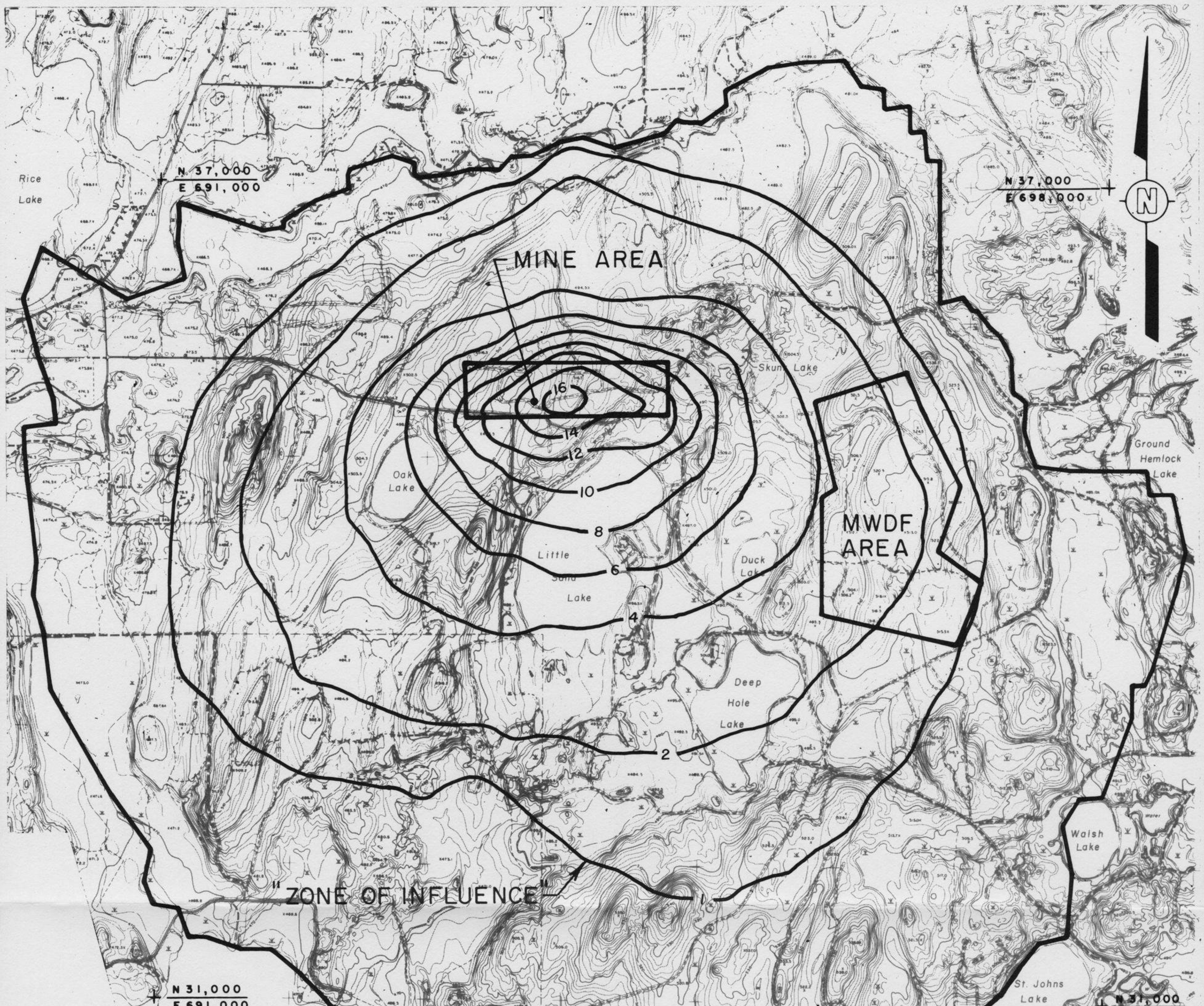
DRAWN BY: JJL DATE: 9-26-84

D'APPOLONIA

PROJ NO 846498 DWG NO B32

22 B 1B

100% BLUE 50% BLACK



SCALE

0 1000 2000 meters

NOTE:

LIMIT OF ZONE OF INFLUENCE IS SET AT A MAXIMUM DRAWDOWN OF 1.0m (3.3 FEET).

LEGEND

—2— PREDICTED POTENTIOMETRIC DRAWDOWN IN METERS

FIGURE A.6-10

EXXON MINERALS COMPANY
CRANDON PROJECT

PREDICTED POTENTIOMETRIC DRAWDOWN AT PROJECT YEAR 28 FOR LOW RECHARGE CASE

SCALE: AS SHOWN	STATE	COUNTY
DRAWN BY: RW	DATE: 10-11-84	CHECKED BY:
APPROVED BY:	DATE: 12/10/85	
DRAWING NO.	SHEET	REVISION NO.

D'APPOLONIA

PROJ NO 846498 DWG NO B53

50% BLACK 1B 1B

SCALE

0 1000 2000 meters

NOTE:

LIMIT OF ZONE OF INFLUENCE IS SET AT A MAXIMUM DRAWDOWN OF 1.0m (3.3 FEET).

LEGEND:

—2— PREDICTED POTENTIOMETRIC DRAWDOWN IN METERS

FIGURE A.6-11

EXXON MINERALS COMPANY

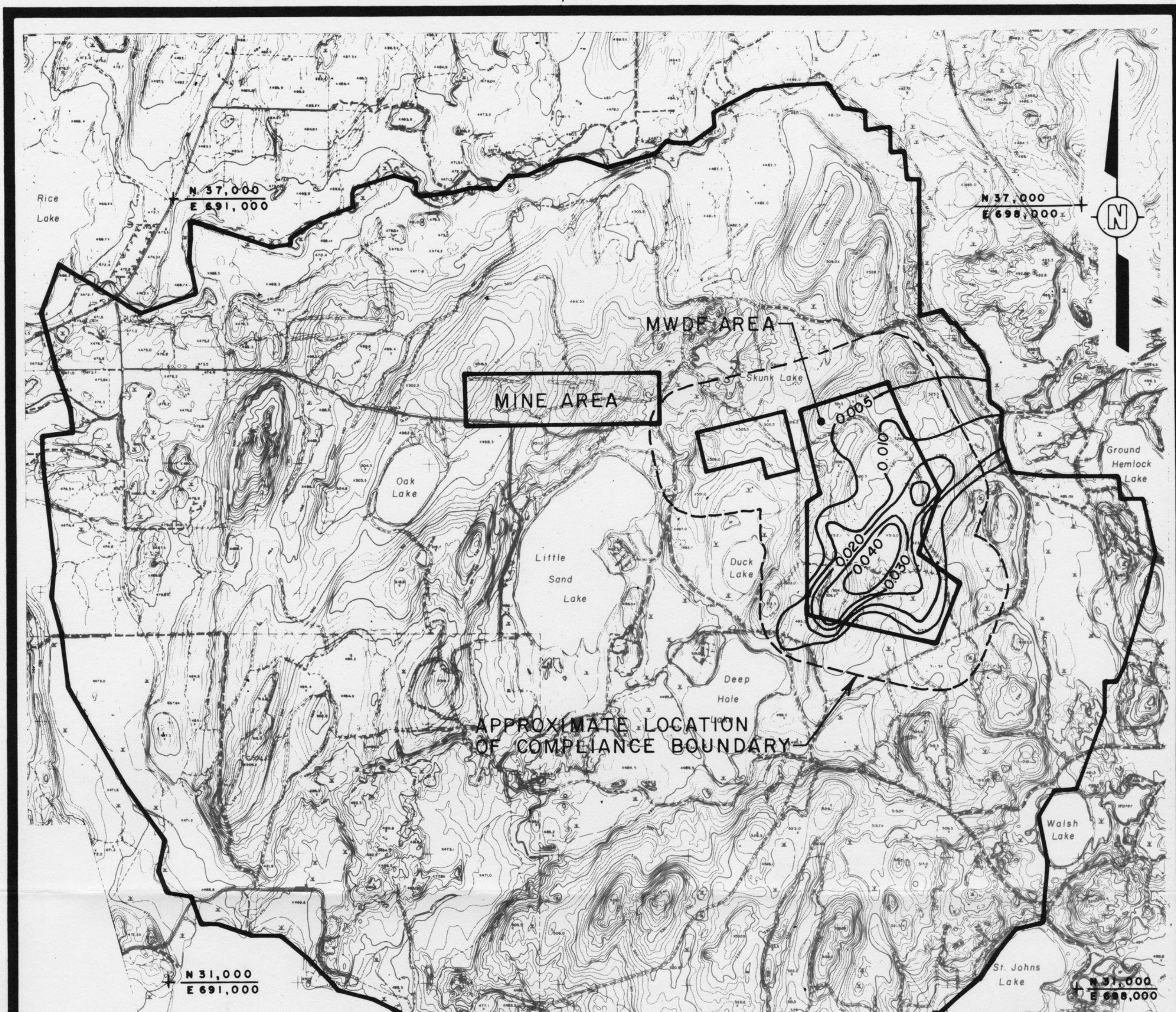
CRANDON PROJECT

TITLE PREDICTED POTENTIOMETRIC DRAWDOWN AT PROJECT YEAR 28 FOR HIGH RECHARGE CASE

SCALE AS SHOWN	STATE
DRAWN BY RW	DATE 10.1.84
APPROVED BY	APPROVED BY EXXON
DRAWING NO	REVISION NO

D'APPOLONIA PROJ NO 846498 DWG NO B54

50% BLACK 1B



NOTES:

1. THE ANALYSIS ASSUMES A CONSTANT MASS FLUX AND A RETARDATION FACTOR OF 1.0.
2. LONGITUDINAL DISPERSIVITY EQUALS 20 m (66 FEET) TRANSVERSE EQUALS 5 m (16 FEET).
3. OTHER INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7.

SCALE

0 1000 2000 meters

LEGEND

0.010 NORMALIZED CONCENTRATION CONTOUR

FIGURE A.6-12

EXXON MINERALS COMPANY

CRANDON PROJECT

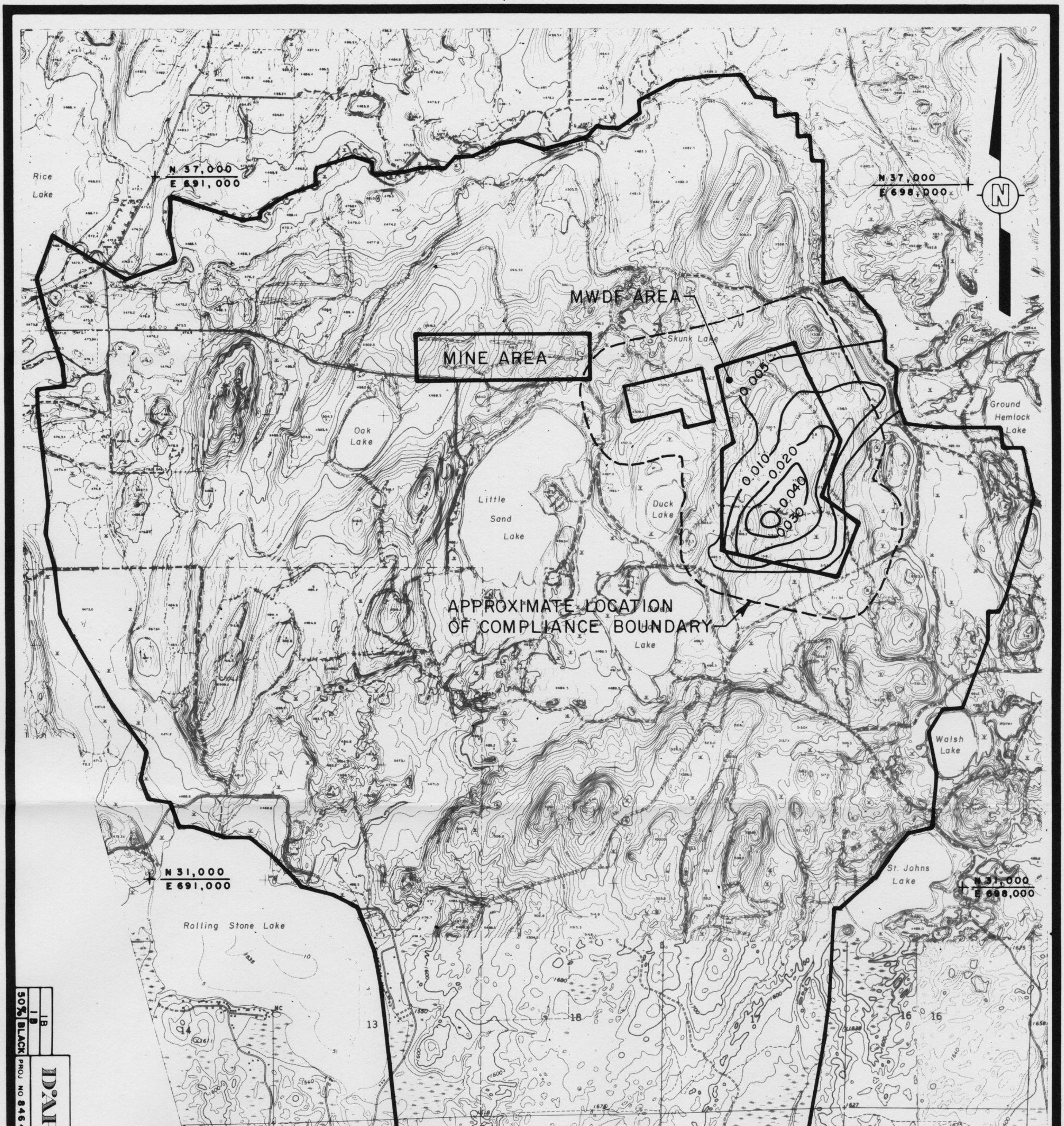
SENSITIVITY ANALYSIS NUMBER 1; PREDICTED STEADY-STATE NORMALIZED CONCENTRATIONS FOR MIDDLE RECHARGE CASE

SCALE: AS SHOWN
DRAWN BY: RW DATE: 9-26-84

D'APPOLONIA

PROJ NO 846498 DWG NO B37

1B
50% BLACK



NOTES:

1. THE ANALYSIS ASSUMES A CONSTANT MASS FLUX AND A RETARDATION FACTOR OF 1.0.
2. LONGITUDINAL DISPERSIVITY EQUALS 100m (328 FEET) TRANSVERSE EQUALS 20m (66 FEET).
3. OTHER INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7.

SCALE

0 1000 2000 meters

LEGEND

0.010 — NORMALIZED CONCENTRATION CONTOUR

FIGURE A.6-13

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE SENSITIVITY ANALYSIS NUMBER 3; PREDICTED STEADY-STATE NORMALIZED CONCENTRATIONS FOR MIDDLE RECHARGE CASE

SCALE AS SHOWN	STATE	COUNTY
DRAWN BY R W	DATE 9-26-84	CHECKED BY
APPROVED BY	DATE	
APPROVED BY	DATE	EXXON
DRAWING NO	SHEET OF	REVISION NO

D'APPOLONIA

PROJ NO 846498 DWG NO B38

1B 50% BLACK

ATTACHMENT A.7

HORIZONTAL AND VERTICAL MODELS INPUT DATA

ATTACHMENT A.7

TABLE OF CONTENTS

ATTACHMENT A.7

LIST OF TABLES

APPENDIX A.7

LIST OF FIGURES

ATTACHMENT A-7

HORIZONTAL AND VERTICAL MODELS INPUT DATA

This attachment has been prepared to consolidate the input data and conditions used in the hydrologic impact assessment models. Included are the data values and their sources either in the main text or cited literature. To assist the reader in locating the necessary information, a cross reference table has been prepared. Table A.7-1 contains a list of parameters, their dimensions, and pertinent references. A discussion of the input data for the various models follows.

A.7.1 TWO-DIMENSIONAL HORIZONTAL MODELING

A two-dimensional horizontal model was used to predict the hydrologic impacts of the proposed mine and related facilities according to the following general procedure:

1. Existing site conditions were incorporated into the model by representing pertinent site features such as the recharge lakes, discharge wetland areas, and lakes and streams along the model boundary (Figures A-1 and A-22).

2. The model was then calibrated by varying aquifer permeability until measured potentiometric heads were reasonably reproduced. The model was calibrated with three recharge rates. The calibrated potentiometric surfaces with low, middle, and high recharge rates are shown in Figures A.6-8, A-23, and A.6-9, respectively.

3. The operation of the mine and related facilities was simulated by applying the appropriate hydrologic action to the calibrated model (Figures A-2 and A.7-1).

A.7.1.1 Input Data For Calibrated Model

Element- and Node-Specific Input Data

Grid System: A finite element grid system consisting of 1,153 quadrilateral elements with 1,227 nodes is shown in Figure A.7-2 and discussed in Section 5.2.1. The Wisconsin State plane coordinates for each node are listed in Table A.7-2. Table A.7-3 lists each element and its corresponding nodes, permeability zone, recharge zone, initial aquifer saturated thickness, and aquifer bottom elevations.

Permeability: The model includes two permeability zones: a uniform permeability for the majority of the site (Zone 1), and an area of lower permeability in the north-central portion of the site where the stratified drift is thinner and/or absent (Zone 2). A lower permeability is used to represent the transmissivity of the saturated till in this north-central area. Calibration analyses also showed that this low permeability zone was necessary to obtain a reasonable match with measured potentiometric heads in this area.

Recharge: Each recharge zone corresponds to a specific recharge rate. A uniform recharge rate (averaged for modeling purposes) is assigned to the site area for each of the three recharge rates with the following exceptions:

1. Areas of zero aquifer saturated thickness are assigned zero recharge. The elements representing these areas are Nos. 35, 36, 37, 226, 227, 267, 268, 309, 310, and 333.

2. Recharge zones are assigned for corresponding elements of each lake depending on the lake bottom thickness. The element number, lake bottom thickness(es), and corresponding recharge zones for each lake are shown in Table A.7-4. As this table also indicates, the lake bottom thicknesses vary within Duck and Little Sand lakes. Specific recharge values are presented later in the summary of input data.

Aquifer Thickness: An initial stratified drift saturated thickness was assigned to each element. An adjustment was necessary where till layers were present within the stratified drift to properly represent aquifer transmissivity because of the lower permeability of the till. The isopach map of aquifer saturated stratified drift (Figure A-14) is the source of these values for model input.

Aquifer Bottom Elevation: An adjustment was made to the aquifer bottom elevations (Figure A-15) when relatively impermeable till layers were present within the saturated stratified drift. In this case, the aquifer bottom elevation was raised by the thickness of the till layer to properly represent the potentiometric surface (Figure A-18). Figure A-18 was used to assign aquifer bottom elevations at each element.

Internal Conditions: Constant potentiometric head values were assigned at ten nodes to properly represent the southern wetlands areas, an area of ground water discharge; potentiometric head values were interpreted from measured heads (Figure A-13). The node number and corresponding potentiometric heads are presented in Table A.7-5.

Boundary Conditions

A constant head boundary condition was assigned to nodes along the grid boundary. Constant head values were interpreted from the aquifer potentiometric surface map (Figure A-13). The node numbers and corresponding potentiometric heads are tabulated in Table A.7-6.

A.7.1.2 Model Calibration Sensitivity Analysis

Several variations were made to test the validity of the calibrated model, as discussed in Section 5.2.6 and Attachment A.6, described below.

Combined Constant Head and No-Flow Boundary Conditions (Golder Associates, 1982): Input parameters were identical to the constant head boundary calibrated model, except a no-flow condition was assigned to the boundary nodes between Rice Lake and the southern end of Mole Lake, and to the boundary segment approximately 450 m (1,476 feet) north of Walsh Lake to the southwestern end of St. John's Lake. The corresponding no-flow boundary nodes are listed in Table A.7-7.

Swamp Creek No-Flow Boundary Condition: Input parameters were identical to the constant head boundary calibrated model, except that a no-flow boundary condition was assigned to the northern grid boundary along Swamp Creek. The corresponding Swamp Creek no-flow boundary nodes are listed in Table A.7-8.

Increased Lake Bottom Permeability: Input parameters identical to the constant head boundary calibrated model were used except that the lake bottom permeability was increased from 5×10^{-9} m/s to 1×10^{-8} m/s for all the lakes inside the site boundary.

Uniform Permeability: Input parameters were identical to the constant head boundary calibrated model, except that a uniform permeability was assigned to the aquifer (i.e., the low permeability zone was assigned a permeability equal to the rest of the site).

Table A.7-9 summarizes the input data for the calibration and sensitivity analyses discussed. The results of these analyses are presented in Attachment A.6.

A.7.2 MAXIMUM MINE INFLOW RATE ANALYSIS

The potentiometric heads were lowered to the base of the aquifer in the mine area (24-node configuration) to compute the maximum mine inflow rate for the constant head boundary calibrated model and sensitivity analyses previously discussed. The node numbers and corresponding values of potentiometric head prior to and during maximum mine analyses are listed in Table A.7-10. The results of these analyses are discussed in Attachment A.6 and summarized in Table A.7-11.

A.7.3 HORIZONTAL MODEL HYDROLOGIC IMPACT ASSESSMENT

Summary of Input Data

The horizontal model input data used in the hydrologic impact assessment for the Middle, Low, and High Recharge cases are presented in Tables A.7-12, A.7-13, and A.7-14, respectively. For the Middle Recharge case, the hydrologic actions were applied to the calibrated model according to the schedule shown in Table A.7-12. The model simulated the hydrologic actions from the beginning of the construction phase (Year 1) through the operation phase and 31 years of post-operation (Year 60) under transient conditions using a time step of 0.25 year and restart capabilities. Restart capability allows the model to combine computed information from a previous analysis (i.e., potentiometric head, saturated thickness) with new conditions (i.e., recharge rates, mine inflow rates) for continued analysis.

For the subsequent analyses of the Low and High Recharge cases, hydrologic actions were modeled for Year 1 through Year 3 as described above (Tables A.7-13 and A.7-14). For the hydrologic impact assessment at Year 28, all of the hydrologic actions were applied to the calibrated models until steady-state conditions were achieved using transient conditions and a time step of 1.0 year.

Correlation of Mine Inflow Model with GEOFLOW Model Nodes

Steady-state mine inflow rates corresponding to the three recharge rates were computed by TAP Associates (1984) for use in the hydrologic impact assessment model. Because of a smaller grid spacing over the mine area (the Mine Inflow model contained 80 nodes, while the GEOFLOW model contained 45 nodes over the same area), the mine inflow nodal rates were equally partitioned between the GEOFLOW model nodes.

Mine Inflow Rate Distribution

At Year 2 and Year 29, mine inflow rates will be approximately 30 percent and 50 percent of the steady-state rate, as discussed in Section 2.1.1. The distribution of the mine inflow rates corresponding to the three recharge rates for Year 2, Year 29, and the steady-state rate are presented in Tables A.7-15, A.7-16, and Table A-2, respectively.

Recharge Rates for Project Facilities

The recharge rates associated with the mine/mill surface facilities for the three recharge cases are presented in Table A.7-17. A detailed description of the Project facilities and corresponding hydrologic action is presented in Chapter 2.0.

MWDF Seepage Rates

Tailings pond seepage rates used in the hydrologic impact assessment are presented in Table A.7-17. These seepage rates were calculated from the data presented in Table A-3 and adjusted for the difference in the actual tailings pond area and the area represented in the model.

Reclamation Cap Recharge Rate

As each tailings pond is reclaimed during the operation phase, the precipitation infiltrating the reclamation cap will be distributed along the MWDF perimeter of the corresponding tailings pond. After closure of Pond T4, a final reclamation cap will be constructed over the MWDF area. Drainage of the cap surface will be divided into seven watersheds and the excess surface runoff from each watershed will be distributed as a recharge along the corresponding segment of the MWDF perimeter (Ayres Associates, 1984). Table A.7-18A presents model nodes along the perimeter of the reclamation cap and the corresponding recharge rates during MWDF operation and after final MWDF reclamation. Tables A.7-18B and A.7-18C present watershed areas, recharge rates, perimeter length, and the corresponding recharge rates used in assigning the rates given in Table A.7-18A. Table A.7-18B presents these parameters for the four tailing ponds during operation while Table A.7-18C presents parameters for the seven watershed areas after operations.

A.7.4 HORIZONTAL TWO-DIMENSIONAL DISPERSION ANALYSIS

Horizontal two-dimensional dispersion was analyzed under conditions identical to the calibrated model (Section A.7.1.1) for three recharge rates with the addition of increased recharge at the MWDF perimeter (Table A.7-18) and steady-state MWDF seepage rates to simulate long-term conditions. Five analyses were made for various recharge cases and dispersivities. The longitudinal and transverse dispersivity values used for these analyses are as follows:

Case	Longitudinal Dispersivity (m)	Transverse Dispersivity (m)
Low Recharge	60	15
Middle Recharge	100	20
	60	15
	20	5
High Recharge	60	15

These values are based on site conditions and published values as discussed in Section 4.4.2.2.

A.7.5 ONE-DIMENSIONAL VERTICAL MODELING

A one-dimensional vertical model of flow and mass transport in the partially saturated zone was developed to simulate the vertical migration of chemical constituents from the MWDF tailings ponds. The model predicted normalized concentrations versus time for various depths within the partially saturated zone. These results were then used as source input to the vertical two-dimensional transient dispersion model.

Analysis

Corey (1977) presents an empirical equation for determining the relationship between partially saturated hydraulic conductivity and percent saturation. This method was applied to laboratory data for glacial till from the Crandon Project site (D'Appolonia, 1982) and to data for the Berea Sandstone (McWhorter, 1971). The resulting relationships were used to define limiting moisture contents for partially saturated flow at the seepage velocities given for the MWDF ponds (Section 6.4.1 and Attachment A.1). Pore velocities were calculated to provide appropriate dispersion coefficients according to the method presented by Biggar and Nielsen (1976).

Grid System and Modeling Conditions

A finite element grid system of 303 nodes and 200 elements was established to model a 40 m vertical strip of partially saturated material. Nodal spacing was as follows:

Depth (m)	Vertical Nodal Spacing (m)
0 to 15	0.25
15 to 30	0.50
30 to 40	1.00

The source was modeled at a constant concentration of 1.0 at the upper boundary of the model. Flow was specified as a uniform velocity equal to the appropriate seepage rate according to the following schedule:

MWDF Pond	Years After Project Initiation	Seepage Rate Category*
T1	4 to 36	Operation
	From 36 On	Steady-State
T4	23 to 31	Operation
	31 to 41	Maximum
	41 to 56	Operation
	From 56 On	Steady-State

*Seepage rates for each category are defined in Table A.7-19.

The modeling assumed a retardation factor of 1.0 and used time steps of one year for the first 32 years of simulation and time steps of 10 years thereafter, until steady-state conditions were achieved.

Modeling Parameters

The parameters used for the one-dimensional vertical model analyses are presented in Table A.7-19. The results of these computer analyses are presented in Figures A-38 and A-39.

A.7.6 TWO-DIMENSIONAL VERTICAL MODELING

A two-dimensional vertical model of ground water flow and mass transport was developed to simulate conditions at the Project site. The model was used to (1) compute steady-state potentiometric heads which matched field measured values within a reasonable degree of accuracy; (2) compute steady-state normalized concentrations for MWDF seepage, testing the model's sensitivity to various parameters; and (3) predict transient normalized concentrations of chemical constituents in the ground water based on expected rates of MWDF seepage and the results of the one-dimensional vertical modeling.

Calibrated Ground Water Flow Model

The grid system used in the two-dimensional vertical model analysis is shown in Figure A-26. The model has 957 elements and 1,089 nodes. Boundary conditions and input values were selected to represent steady-state conditions and are:

1. The top horizontal grid boundary AF (Figure A-26) represents the water table and the inflow line for ground water recharge, defined as 216 m/y (8.5 inches per year); Deep Hole Lake seepage was defined as 144 mm/y (5.65 inches per year) (Table A-10) at the nodes shown in Figure A-26.

2. Constant potentiometric head line AH represents the interpolated head value (476.00 m) for the southwestern model boundary based on Wells EX-1 and G40-Y22.

3. Constant potentiometric head line FG represents the observed and interpolated head values for Well EX-6. For the grid system presented in Figure A-26, the nodes from F to G were assigned the following water level readings: 483.22, 483.22, 483.22, 483.37, 483.52, 483.23, 482.93, and 482.93 m.

4. The bottom horizontal grid line HG is a no-flow boundary approximating the contact with bedrock or other relatively low-permeability units.

5. Constant head Point E represents the interpolated head value (481.33 m) for Hemlock Creek based on water levels at Wells EX-8BU and WP-7U.

The permeabilities used in the calibrated analysis are presented in

Table A.7-20. The model was initially calibrated for the Middle Recharge case using a coarse drift horizontal permeability of 1.22 x 10^{-4} m/s (34.5 feet per day). This value is equal to that used in the calibrated horizontal model for the Middle Recharge case and provided the best simulation of observed heads. The permeability for the fine drift was set at one-half that of the coarse drift based on the ratio of mean permeabilities presented by STS (STS Consultants, Ltd., 1984). The till permeability was selected as the mean STS value for till (STS Consultants, Ltd., 1984). The horizontal to vertical permeability ratio of 50 for the drift units was determined during model calibration. For calibration at Low Recharge and High Recharge rates, all permeabilities were scaled up or down from the Middle Recharge values in proportion to the pertinent recharge rate, thus maintaining good simulation of observed heads. Storage coefficients were based on previously determined values (Table A-5).

Steady-State Dispersion Modeling

The calibrated two-dimensional vertical model was used to calculate steady-state vertical dispersion results, as shown in Attachment A.4. Sensitivity analyses were performed to test various values of vertical to horizontal permeability ratios, longitudinal dispersivities, longitudinal to transverse dispersivity ratios, and recharge rates, at the estimated steady-state MWDF seepage rate. In addition, the model simulated the estimated maximum seepage rate resulting from the MWDF without a synthetic membrane. The resultant concentration profiles are shown in Attachment A.4.

Boundary conditions and input parameters, as described above for the calibrated model, with the addition of seepage from Tailings Ponds T1 and T4 were incorporated into the model. The MWDF seepage was modeled as a series of nodal injection sources corresponding to the lateral extent of the tailings ponds shown in Figure A-26. The injection rate for each node was computed using the steady-state pond seepage rate [1.68 mm/y (0.066 in./y)] and a source concentration of 1.0. Therefore, each MWDF node was assigned an injection rate of 1.84 x 10^{-4} m^3/day (7.52x10^{-8} cfs) at a concentration of 1.0; the nodes at each end of the MWDF were assigned one-half of this value. The seepage rates were increased by a factor of 10 to simulate the absence of a synthetic membrane in the MWDF reclamation cap.

Ground water recharge rates were increased for one element on each side of the MWDF zone (Figure A-26) to represent the infiltration of water collected in the reclamation cap drainage system. This additional recharge was calculated using MWDF reclamation cap design data (Ayres Associates, 1984). For Pond T4, Section N-N crosses the perimeter at the location of Drainage Area 1 indicated in Table A.7-18C. The corresponding recharge rate of 19.01 m^3/yr/m was distributed to a single element which was 40 m wide. Hence, the additional recharge is 19.01/40 = 0.475 m/yr = 14 in/yr at Pond T4.

For Pond T1, Section N-N crosses the perimeter at the location of Drainage Area 5 indicated in Table A.7-18C. The corresponding recharge rate of 43.40 m^3/yr/m was distributed to a single element which is 40 m wide. Hence, the additional recharge is 43.40/40 = 1.085 m/yr = 43 in/yr.

Input parameters for each steady-state dispersion sensitivity analysis are summarized in Table A.7-21. Dispersivity values are based on site conditions and published values as discussed in Section 4.4.2.2.

Transient Dispersion Modeling

The transient vertical dispersion analysis utilized the calibrated flow model for at the Middle Recharge case. Longitudinal dispersivity was set at 60 m (197 feet); the ratio of longitudinal to vertical transverse dispersivities was 50. These values are based on Project site conditions and published values as discussed in Section 4.4.2.2.

The chemical constituent source was defined as a mass influx which varied with time according to the results of the one-dimensional vertical model. The results were used for Tailings Ponds T1 and T4 at a depth of 8 m (26 feet), using input values for glacial till (Figure A-39).

Advective and diffusive fluxes were added to obtain total mass flux. Advective flux was calculated by multiplying partially saturated Darcy velocities by the appropriate normalized concentration. Diffusive flux was computed using values for concentration gradient, dispersion coefficient, and porosity. The curves of advective and diffusive fluxes versus time were approximated by determining discrete values for each parameter to represent every 50 years of simulation time. Total flux below Ponds T1 and T4 for each 50-year time segment were input to the two-dimensional vertical model according to the schedule presented in Table A.7-22.

Time steps of two years were used for Years 0 to 800; time steps were increased to 20 years for Years 800 to 8800. Figures A-40 and A-41 present normalized concentration distributions at Years 800 and 4800, respectively. As shown in Figure A-42, concentrations at Year 8800 are approaching values computed in the steady-state analysis for three selected nodes.

ATTACHMENT A.7

REFERENCES

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TABLES

TABLE A.7-1

LIST AND SOURCE OF INPUT DATA TO PREDICT POTENTIAL IMPACTS OF PROJECT FACILITIES ON THE HYDROLOGIC REGIME

PARAMETER	DIMENSION[a]	UNITS SI	UNITS ENGLISH	REFERENCE SECTION	REFERENCE TABLE OR FIGURE
Recharge rate:					
Precipitation (Zone B)	L/T	mm/y	in/y	4.4.1.2	Table A-15 and Figure A-22
Lake (Zone A)	L/T	mm/y	in/y	4.4.1.2	Figure A-22 and Tables A-10, A-15, and A.7-4
Potentiometric head	L	m	ft	3.2	Figure A-13
Initial aquifer saturated thickness	L	m	ft	A.7.1.1	Table A.7-2 and Figure A-14
Bottom of aquifer elevation	L	m	ft	A.7.1.1	Table A.7-2 and Figure A-18
Suction pressure	L	m	ft	4.4.1.1	Figure A-19
Permeability:					
Partially saturated	L/T	m/s	ft/day	4.4.1.1	Figure A-20
Saturated	L/T	m/s	ft/day	4.4.1.1	Tables A-5 and A-15
Porosity	Dimensionless	-	-	4.4.2.2	Tables A-15 and A.7-19
Effective porosity	Dimensionless	-	-	4.4.2.2	-
Storage coefficient	Dimensionless	-	-	3.2.1	Tables A-5, A-15, and A.7-19
Molecular diffusion	L^2/T	m^2/s	ft^2/day	4.4.2.2	-
Longitudinal dispersivity	L	m	ft	4.4.2.2	-
Transverse dispersivity	L	m	ft	4.4.2.2	-
Dispersion coefficient	L^2/T	m^2/s	ft^2/day	4.4.2.2	-
Sorption equilibrium constant (retardation factor)	Dimensionless	-	-	4.4.2.1	Table A-11
Stream flow rate	L^3/T	m^3/s	ft^3/s	3.3.2	Tables A-8 and A-9
Facility schedule and hydrologic data:					
<u>Mine:</u>					
- Inflow rate	L^3/T	m^3/s	gal/min	2.1.1	Figure A-3a and Tables A-2, A.7-15, and A.7-16
<u>Mill:</u>					
- Surface facilities					
Recharge rate	L/T	mm/y	in/y	2.1.2	Figure A-3a and Table A.7-17
- Potable water well					
Withdrawal rate	L^3/T	m^3/s	gal/min	2.1.2	Figure A-3a
- Sanitary absorption field					
Recharge rate	L/T	mm/y	in/y	2.1.2	Figure A-3a and Table A.7-17
<u>MWDF:</u>					
- Seepage rate	L^3/T	m^3/s	gal/min	2.1.3	Figure A-3b and Tables A-3 and A.7-17
- Seepage concentration	M/L^3	mg/l	mg/l	2.1.3	Table A-4

[a]The dimensions M, L, and T are generic units representing mass, length, and time, respectively.

TABLE A.7-2

NODE NUMBERS AND COORDINATES[a]
HORIZONTAL MODEL

NODE NO.	NORTH COORDINATE	EAST COORDINATE
1	36867.84	692121.38
2	36728.13	692127.41
3	36759.53	692283.05
4	36956.40	692277.14
5	36791.96	691978.33
6	36728.46	691975.01
7	36547.15	692127.01
8	36559.51	692282.61
9	36534.79	691974.58
10	36800.43	692454.60
11	37000.45	692455.04
12	36578.18	692454.10
13	36706.58	691819.39
14	36519.29	691806.27
15	36321.73	692126.51
16	36334.08	692282.11
17	36315.74	691964.57
18	36346.40	692453.59
19	36328.82	691793.15
20	36796.88	692622.86
21	36961.99	692620.05
22	36574.64	692619.20
23	37086.18	692452.05
24	37095.33	692623.52
25	36355.56	692618.71
26	36815.19	691524.35
27	36573.93	691504.77
28	36345.34	691501.09
29	36156.62	692132.49
30	36156.28	692281.72
31	36156.97	691973.75
32	36152.72	692459.51
33	36157.39	691783.25
34	36149.18	692621.43
35	36158.01	691503.85
36	36796.51	692791.14
37	36948.91	692791.48
38	36571.08	692790.64
39	37110.82	692795.01
40	36355.18	692790.16
41	37159.19	692458.56
42	37219.15	692623.80
43	37269.60	692782.66
44	36136.09	692799.20
45	36936.54	691207.13
46	36638.13	691190.58
47	36349.08	691247.09
48	36158.57	691249.85
49	35988.35	692128.95
50	35988.01	692281.35
51	35991.87	691970.20
52	35987.62	692459.15
53	35992.28	691786.05
54	35974.58	692611.52
55	35992.91	691503.48
56	35964.64	692798.82
57	35993.50	691236.78
58	36796.15	692953.06
59	36942.20	692953.39
60	36570.72	692952.56
61	37094.60	692953.72
62	36345.28	692961.59
63	37205.72	692957.14
64	36132.56	692957.94
65	35957.94	692954.38
66	36203.95	690827.67
67	36115.05	690827.47
68	35994.43	690817.68
69	35854.98	692135.00
70	35861.00	692284.24
71	35852.20	691960.38
72	35860.61	692462.04
73	35858.93	691785.76
74	35850.73	692620.77
75	35862.74	691500.02
76	35834.50	692782.66
77	35863.33	691233.32
78	35818.24	692957.25
79	35867.42	690820.58
80	36795.85	693089.59
81	36941.91	693083.56
82	36570.44	693082.74
83	37091.15	693077.54
84	36341.84	693082.23
85	36125.94	693081.75
86	35954.50	693075.02
87	35798.91	693081.03
88	36411.06	690497.93
89	36236.51	690465.79
90	36084.18	690433.70
91	35912.63	690477.77
92	35708.93	692134.68
93	35705.45	692274.38
94	35712.47	691972.76
95	35708.22	692458.53
96	35719.23	691785.45
97	35707.87	692617.28
98	35723.05	691496.53
99	35704.29	692798.24
100	35726.82	691226.67
101	35694.43	692950.63
102	35746.77	690820.31
103	35697.31	693080.80
104	35747.47	690505.98
105	36792.38	693222.93
106	36951.13	693223.28
107	36570.11	693228.79
108	37113.05	693223.64
109	36344.68	693231.46
110	36116.10	693221.43
111	35944.65	693221.05
112	35798.60	693223.90
113	35700.17	693223.69
114	36602.23	690196.73
115	36415.06	690123.29
116	36221.55	690049.83
117	35967.39	690122.30
118	35748.20	690172.61
119	35572.40	692140.73
120	35571.99	692324.88
121	35572.78	691969.28
122	35546.27	692467.69
123	35573.20	691775.60
124	35596.74	692617.03
125	35573.82	691496.20
126	35605.86	692801.20
127	35580.76	691232.69
128	35602.37	692944.07
129	35588.01	690826.31
130	35602.08	693074.24
131	35594.99	690537.40
132	35601.75	693220.29
133	35598.86	690226.25
134	36792.11	693343.58
135	36966.73	693347.14
136	36569.86	693343.09
137	37154.05	693347.56
138	36347.60	693348.94
139	36112.68	693335.72
140	35934.91	693319.46

See footnotes at end of table.

TABLE A.7-2
(Continued)

NODE NO.	NORTH COORDINATE	EAST COORDINATE
141	35798.41	693308.63
142	35700.00	693299.89
143	35601.58	693299.67
144	35423.16	692143.57
145	35422.68	692362.64
146	35423.55	691968.95
147	35396.78	692588.01
148	35420.79	691781.61
149	35501.39	692661.27
150	35430.95	691495.89
151	35501.07	692807.32
152	35431.54	691229.19
153	35503.94	692947.03
154	35435.59	690835.50
155	35494.13	693074.00
156	35445.71	690565.64
157	35500.15	693220.07
158	35446.32	690289.42
159	35499.95	693300.14
160	36791.80	693483.28
161	36985.47	693483.71
162	36569.55	693482.79
163	37163.27	693487.28
164	36347.34	693463.24
165	36109.27	693440.49
166	35934.69	693421.06
167	35798.18	693411.23
168	35696.62	693395.13
169	35601.35	693404.44
170	35502.93	693401.05
171	35324.72	692152.88
172	35301.99	692381.43
173	35267.99	691962.25
174	35291.95	692610.01
175	35268.40	691778.10
176	35393.12	692807.08
177	35297.87	692806.88
178	35275.39	691489.19
179	35275.98	691222.49
180	35392.80	692953.13
181	35283.19	690831.98
182	35389.34	693080.13
183	35293.41	690517.68
184	35389.03	693219.82
185	35293.88	690308.13
186	35392.02	693302.38
187	35394.97	693407.16
188	36788.39	693588.05
189	36991.60	693585.32
190	36563.31	693590.74
191	37159.87	693585.69
192	36343.87	693596.59
193	36108.92	693599.24
194	35934.31	693589.33
195	35797.75	693608.08
196	35705.69	693601.52
197	35604.09	693601.30
198	35496.12	693607.41
199	35397.69	693610.38
200	35232.51	692213.00
201	35216.27	692378.06
202	35150.26	692076.29
203	35212.58	692609.83
204	35147.75	691774.66
205	35212.16	692800.33
206	35148.38	691492.08
207	35297.55	692952.92
208	35211.84	692943.20
209	35148.97	691225.39
210	35149.82	690841.21
211	35297.26	693083.09
212	35153.79	690482.44
213	35296.96	693218.63
214	35151.05	690288.76
215	35296.79	693295.82
216	35281.73	690060.45
217	35151.56	690056.99
218	35296.55	693403.77
219	35292.92	693606.96
220	36797.45	693800.79
221	37016.52	693801.28
222	36568.85	693800.28
223	37168.93	693798.44
224	36343.42	693802.96
225	37242.27	693655.73
226	37248.31	693795.44
227	36105.29	693802.43
228	35933.84	693802.05
229	35794.14	693804.92
230	35702.05	693807.89
231	35600.47	693801.32
232	35502.05	693797.92
233	35397.25	693810.39
234	35295.65	693810.17
235	35149.63	692362.04
236	35145.91	692609.68
237	35013.72	692085.51
238	34917.71	692428.20
239	35014.40	691777.54
240	35139.13	692803.34
241	35015.05	691485.44
242	35157.89	692933.56
243	35015.65	691212.39
244	35214.71	693079.74
245	35084.54	693079.45
246	35016.47	690840.92
247	35017.30	690466.27
248	35214.41	693219.44
249	35024.08	690272.61
250	35211.03	693311.50
251	34840.35	690084.88
252	35210.78	693422.63
253	35207.18	693616.30
254	35206.76	693803.63
255	36787.51	693988.10
256	37016.11	693988.60
257	36565.25	693990.78
258	37181.21	693988.97
259	36339.81	693996.63
260	37346.33	693979.81
261	36104.85	694002.46
262	35933.39	694005.25
263	35793.69	694008.13
264	35701.63	693998.39
265	35600.02	694001.34
266	35501.59	694004.30
267	35403.18	693997.73
268	35298.38	694010.20
269	35206.31	694006.82
270	35009.47	692571.28
271	35012.35	692704.64
272	34832.75	692081.94
273	34743.17	692389.71
274	34836.60	691777.14
275	34860.09	692637.63
276	34730.00	692599.24
277	34834.08	691478.69
278	35005.55	692907.82
279	34834.66	691218.34
280	34995.63	693085.60

See footnotes at end of table.

TABLE A.7-2
(Continued)

NODE NO.	NORTH COORDINATE	EAST COORDINATE
281	34838.65	690850.05
282	35135.04	693216.08
283	34969.93	693218.89
284	34836.29	690481.74
285	35134.81	693317.68
286	35121.84	693441.48
287	34570.41	690112.85
288	34588.63	690487.54
289	35108.69	693644.65
290	35108.32	693809.75
291	35107.87	694012.95
292	36787.06	694188.13
293	37015.66	694188.63
294	36564.81	694187.63
295	37199.82	694185.86
296	36336.19	694196.65
297	37380.79	694189.43
298	36101.24	694196.13
299	35929.80	694195.75
300	35790.08	694201.79
301	35701.18	694201.59
302	35602.76	694198.20
303	35501.14	694207.50
304	35399.55	694204.10
305	35297.94	694207.05
306	35205.88	694200.49
307	35101.13	694190.74
308	34856.39	692875.74
309	34620.02	692084.64
310	34562.20	692386.14
311	34617.53	691773.48
312	34637.96	692583.16
313	34605.47	691484.53
314	34726.36	692811.95
315	34548.82	692694.08
316	34599.73	691208.29
317	34855.96	693072.59
318	34594.18	690849.51
319	34846.16	693193.22
320	34966.50	693333.19
321	34842.66	693339.26
322	34966.19	693476.06
323	34981.64	693666.60
324	34287.78	690137.63
325	34299.66	690505.95
326	34317.94	690855.25
327	34997.16	693828.55
328	35009.43	694022.26
329	35031.27	694196.93
330	36786.59	694400.84
331	37015.19	694404.52
332	36564.34	694403.53
333	37189.83	694395.39
334	36338.91	694406.20
335	37307.30	694398.82
336	36097.61	694402.49
337	35929.34	694402.13
338	35786.46	694401.80
339	35703.91	694404.80
340	35602.31	694401.40
341	35500.71	694404.35
342	35402.28	694407.30
343	35297.51	694403.90
344	35205.46	694390.99
345	35075.31	694378.01
346	34992.88	694327.02
347	34725.94	693002.45
348	34391.36	692112.71
349	34377.91	692449.23
350	34376.21	691782.48

NODE NO.	NORTH COORDINATE	EAST COORDINATE
351	34488.52	692681.25
352	34386.58	692836.60
353	34354.64	691487.15
354	34342.51	691229.95
355	34542.14	692843.30
356	34722.37	693180.25
357	34715.62	693361.21
358	34842.33	693491.66
359	34651.81	693497.59
360	34841.94	693666.29
361	34854.25	693844.11
362	34017.96	690111.63
363	34026.57	690524.40
364	34048.04	690864.17
365	34072.60	691245.23
366	34895.23	693974.38
367	34939.34	694130.05
368	34910.59	694206.19
369	36786.16	694594.52
370	37011.60	694591.84
371	36557.56	694594.01
372	37189.39	694595.41
373	36338.48	694599.88
374	37354.49	694592.60
375	36097.17	694602.52
376	35928.91	694595.80
377	35792.36	694605.02
378	35706.63	694608.00
379	35601.87	694601.42
380	35506.62	694604.39
381	35401.83	694607.33
382	35300.25	694597.58
383	35201.86	694581.49
384	35033.68	694539.84
385	34929.09	694457.06
386	34802.28	694371.05
387	34484.33	693141.63
388	34146.82	692137.57
389	34171.42	692502.75
390	34115.86	691781.90
391	34196.06	692842.53
392	34097.44	691496.11
393	34366.85	693141.36
394	34211.27	693144.19
395	34483.91	693328.94
396	34366.18	693442.98
397	34581.70	693614.91
398	34235.73	693566.52
399	34609.75	693853.10
400	34758.76	693951.85
401	34473.44	693757.54
402	34844.15	694104.44
403	33744.72	690199.92
404	33769.35	690546.05
405	33774.97	690873.09
406	33818.55	691266.89
407	33843.40	691514.59
408	34704.16	694234.31
409	36785.71	694797.72
410	37014.31	694798.22
411	36557.11	694797.21
412	37204.82	694795.47
413	36334.87	694796.72
414	37408.05	694780.05
415	36096.74	694796.19
416	35928.45	694802.17
417	35795.10	694801.88
418	35703.01	694808.02
419	35601.45	694791.92
420	35503.02	694794.88

See footnotes at end of table.

TABLE A.7-2
(Continued)

NODE NO.	NORTH COORDINATE	EAST COORDINATE
421	35407.75	694801.02
422	35306.15	694800.79
423	35198.27	694771.98
424	35096.76	694730.48
425	34893.60	694710.98
426	34950.50	694825.40
427	34836.73	694587.03
428	34741.67	694501.09
429	34522.82	694399.01
430	34497.14	694522.77
431	34577.05	694284.83
432	33889.61	692156.05
433	33914.21	692514.88
434	33845.97	691787.65
435	33932.52	692848.30
436	33957.26	693149.98
437	33966.09	693461.15
438	34238.59	693709.40
439	33984.63	693692.96
440	34453.92	693970.23
441	34640.98	694091.29
442	34336.61	693893.77
443	34136.58	693896.50
444	33325.49	690256.15
445	33365.86	690665.81
446	33396.99	690945.28
447	33431.15	691291.43
448	33459.17	691542.32
449	33483.96	691815.42
450	34501.07	694183.06
451	36785.41	694934.24
452	37014.02	694931.57
453	36556.81	694933.74
454	37239.44	694932.07
455	36328.21	694936.41
456	37398.21	694926.08
457	36096.42	694939.07
458	37509.42	694885.05
459	37493.46	694926.29
460	35928.15	694938.69
461	35791.60	694947.92
462	35702.84	694887.40
463	35604.27	694953.85
464	35486.90	694902.79
465	35385.29	694908.92
466	35277.31	694921.38
467	35185.20	694940.22
468	35096.29	694943.20
469	34953.32	694984.16
470	34728.38	694767.76
471	34750.30	694904.34
472	34649.18	694685.04
473	34765.85	695050.42
474	34332.55	694293.81
475	34160.66	694493.45
476	34356.94	694751.06
477	34543.98	694878.48
478	34128.37	694737.86
479	33514.87	692193.32
480	33558.58	692529.97
481	33595.96	692857.08
482	33620.68	693161.93
483	33654.88	693489.03
484	33673.30	693771.65
485	33841.26	693914.90
486	33622.16	693927.11
487	34355.25	694081.13
488	34279.19	694017.47
489	34164.77	694071.19
490	33910.71	694096.02
491	33992.99	694220.03
492	33656.87	694168.41
493	32940.84	690468.02
494	32965.56	690779.22
495	32993.57	691033.29
496	33021.51	691319.10
497	33049.54	691563.64
498	33077.47	691855.80
499	33111.58	692224.18
500	34234.38	694179.29
501	36785.14	695058.07
502	37013.75	695052.22
503	36556.55	695051.21
504	37239.17	695055.90
505	36324.77	695053.88
506	37382.02	695065.74
507	36096.16	695056.54
508	37490.01	695050.10
509	35892.98	695049.74
510	35816.84	695024.17
511	35654.77	695087.31
512	35772.20	695106.63
513	35473.80	695086.91
514	35346.75	695105.68
515	35215.59	695094.49
516	35158.88	695095.21
517	35073.56	695124.58
518	34930.12	695149.56
519	34787.65	695240.97
520	34549.88	695081.69
521	34587.52	695288.15
522	34100.74	694309.17
523	33913.14	694432.58
524	33928.42	694702.49
525	34330.87	695052.63
526	34108.72	695004.52
527	33886.60	694946.88
528	33142.58	692560.80
529	33164.06	692900.57
530	33274.45	693231.01
531	33378.57	693526.52
532	33467.06	693714.04
533	33380.97	693875.78
534	33513.33	694121.19
535	33298.12	694012.13
536	33786.31	694356.10
537	33570.59	694273.07
538	33392.84	694253.63
539	32556.17	690692.59
540	32574.72	690918.06
541	32593.35	691108.60
542	32624.58	691343.63
543	32655.78	691591.34
544	32696.41	691883.53
545	32740.06	692245.58
546	32799.62	692591.79
547	36781.74	695156.48
548	37010.36	695150.64
549	36553.15	695152.80
550	37238.96	695151.15
551	36324.55	695155.47
552	37391.35	695154.66
553	36086.40	695164.47
554	37543.76	695151.82
555	35854.65	695154.43
556	35629.08	695217.43
557	35762.45	695211.38
558	35555.93	695274.42
559	35854.46	695240.16
560	35422.50	695312.23

See footnotes at end of table.

TABLE A.7-2
(Continued)

NODE NO.	NORTH COORDINATE	EAST COORDINATE	NODE NO.	NORTH COORDINATE	EAST COORDINATE
561	35272.23	695306.21	631	31935.55	691367.50
562	35196.48	695325.72	632	31898.43	690922.91
563	35113.86	695354.11	633	31969.97	691596.17
564	34985.42	695395.09	634	31985.11	691926.41
565	34834.79	695460.15	635	32006.82	692158.23
566	34625.18	695488.26	636	32101.56	692390.21
567	34330.27	695322.51	637	31971.09	692523.28
568	34456.86	695510.11	638	31719.55	692846.57
569	33747.61	694629.07	639	36765.29	695416.80
570	33712.08	694902.04	640	37012.95	695414.17
571	34101.78	695271.20	641	36527.18	695413.10
572	33867.00	695197.66	642	37238.39	695408.32
573	33686.18	695127.40	643	36285.89	695406.21
574	32709.84	692985.29	644	37441.59	695405.60
575	32921.77	693347.71	645	37651.14	695406.06
576	33124.29	693652.96	646	37721.38	695231.59
577	32993.67	693852.69	647	37809.90	695403.24
578	33173.92	694180.13	648	35736.36	695522.47
579	32853.57	694036.53	649	35853.76	695554.48
580	33496.98	694539.61	650	35643.97	695661.97
581	33224.13	694446.93	651	35755.09	695665.39
582	33036.94	694389.38	652	35520.15	695661.69
583	32336.74	690854.03	653	36034.73	695558.06
584	32361.90	690962.04	654	35353.21	695637.68
585	32152.02	691110.80	655	36314.13	695558.68
586	32189.58	691352.18	656	35272.44	695659.72
587	32223.97	691596.73	657	35181.66	695686.75
588	32248.70	691898.41	658	35048.26	695713.68
589	32302.00	692203.33	659	34913.08	695741.42
590	32333.12	692485.98	660	34684.79	695812.24
591	32227.78	692742.92	661	34487.96	695802.28
592	36781.55	695242.21	662	34265.77	695773.22
593	37010.15	695242.72	663	34027.75	695725.06
594	36549.78	695241.70	664	33805.81	695588.05
595	37235.59	695240.04	665	33283.23	694999.51
596	36308.48	695241.16	666	32981.62	694995.67
597	37403.85	695246.76	667	33628.26	695476.53
598	36057.64	695250.13	668	33409.42	695368.09
599	37613.40	695244.05	669	33187.51	695212.03
600	35641.49	695350.81	670	32210.14	693539.81
601	35714.50	695354.15	671	31832.91	693269.10
602	35596.80	695458.66	672	31566.71	693043.08
603	35822.36	695398.84	673	32035.09	693729.92
604	35485.57	695502.88	674	32233.99	694238.36
605	36031.88	695408.83	675	31856.73	693983.53
606	35322.56	695526.05	676	32746.89	694896.72
607	35234.62	695531.73	677	32486.81	694772.32
608	35154.69	695557.41	678	32118.96	694568.31
609	35028.09	695578.85	679	31710.53	691182.85
610	34880.59	695616.14	680	31697.36	691395.54
611	34659.73	695656.61	681	31749.06	690989.26
612	34396.32	695605.23	682	31690.51	691620.95
613	34215.42	695573.08	683	31693.10	691887.66
614	34015.66	695451.99	684	31641.43	692278.07
615	33413.90	694780.73	685	31415.28	692607.77
616	33527.63	695034.98	686	31249.74	692804.25
617	33876.04	695416.75	687	36787.22	695553.38
618	33669.80	695352.80	688	37028.52	695550.73
619	33476.39	695234.89	689	36555.43	695559.21
620	32375.65	693352.85	690	37263.46	695554.43
621	32676.70	693613.88	691	37469.85	695548.54
622	31992.13	693059.90	692	37679.39	695555.35
623	32527.06	693804.04	693	37898.46	695555.83
624	32745.13	694255.38	694	35878.92	695662.49
625	32386.95	693987.88	695	36056.72	695662.88
626	33099.72	694710.18	696	35675.43	695795.39
627	32899.88	694627.19	697	35780.21	695792.44
628	32623.90	694515.45	698	35548.45	695785.58
629	32161.83	690980.64	699	35910.37	695799.08
630	31923.34	691145.22	700	35376.51	695756.57

See footnotes at end of table.

TABLE A.7-2
(Continued)

NODE NO.	NORTH COORDINATE	EAST COORDINATE
701	36342.45	695673.04
702	35299.09	695774.45
703	36577.41	695670.39
704	35203.63	695809.28
705	35078.38	695830.74
706	34936.35	695863.01
707	34717.65	695925.13
708	34487.62	695924.68
709	34265.39	695924.66
710	34078.06	695932.43
711	33907.02	695762.90
712	33941.54	695928.95
713	33742.08	695692.68
714	33570.80	695612.93
715	32898.83	695103.44
716	32686.27	695026.77
717	33345.62	695504.48
718	33110.96	695373.78
719	32835.05	695230.30
720	31676.91	693462.43
721	31398.00	693239.56
722	31084.19	693007.09
723	31482.68	693712.82
724	31716.28	694322.94
725	31335.88	694049.05
726	32378.16	695089.58
727	32023.00	694888.77
728	31598.16	694614.78
729	31507.19	691249.07
730	31506.82	691414.17
731	31414.26	691633.04
732	31413.72	691877.52
733	31260.94	692048.63
734	30993.72	692282.99
735	30920.06	692571.75
736	30814.78	692800.13
737	36802.84	695667.71
738	37047.30	695671.43
739	37275.90	695675.11
740	37482.27	695675.56
741	37694.99	695679.21
742	37910.89	695679.69
743	36088.16	695802.65
744	36370.76	695793.75
745	35710.01	695951.04
746	35821.13	695954.46
747	35586.22	695934.89
748	35944.95	695954.74
749	35404.32	695871.83
750	36119.60	695942.42
751	35322.21	695894.50
752	36596.20	695787.90
753	35226.93	695923.17
754	36824.80	695788.41
755	35098.51	695951.45
756	34931.85	695989.38
757	34810.38	696010.61
758	34734.31	696119.17
759	34826.27	696175.33
760	34499.86	696094.26
761	34273.10	696097.40
762	34076.26	696105.61
763	33931.56	696120.30
764	33763.89	695880.05
765	33832.66	695927.40
766	33652.87	695832.18
767	33784.56	696120.02
768	33500.61	695768.34
769	33278.60	695656.73
770	32714.48	695191.93
771	32558.70	695283.66
772	33028.06	695532.35
773	32796.55	695408.01
774	31181.49	693515.30
775	30867.65	693295.53
776	30373.13	692942.01
777	30993.50	693816.51
778	31192.38	694334.48
779	30824.64	694082.84
780	32234.52	695435.34
781	32472.33	695578.74
782	31898.52	695186.95
783	31473.68	694909.78
784	31045.67	694629.43
785	37059.76	695782.58
786	37301.05	695786.29
787	37504.27	695777.21
788	37713.81	695780.85
789	37923.37	695778.14
790	36389.51	695927.14
791	36621.31	695914.96
792	35744.57	696113.04
793	35852.51	696119.63
794	35617.57	696115.93
795	35982.69	696116.74
796	35481.51	696118.79
797	36157.39	696085.38
798	35376.20	696143.98
799	36417.83	696044.68
800	35280.88	696175.51
801	36837.24	695905.91
802	35153.80	696213.33
803	37084.88	695909.63
804	34991.78	696254.25
805	34748.93	696280.63
806	34870.67	696353.53
807	34502.62	696291.59
808	35031.99	696451.06
809	34287.67	696295.07
810	34061.32	696321.09
811	33910.74	696320.75
812	33746.51	696333.59
813	33684.00	696108.48
814	33557.11	696060.57
815	33420.70	696009.47
816	33629.58	696311.56
817	33182.76	695923.22
818	32932.20	695805.19
819	32700.65	695703.07
820	30641.61	693577.61
821	30264.35	693319.60
822	29769.69	693029.58
823	30010.04	693458.74
824	30456.90	693828.03
825	30655.71	694374.57
826	30253.09	694100.63
827	32141.87	695695.49
828	32398.77	695816.71
829	31796.24	695494.70
830	32627.13	695928.34
831	31371.34	695242.93
832	30902.11	694940.26
833	30486.76	694682.17
834	37319.84	695903.80
835	37516.70	695897.89
836	37729.44	695892.01
837	37935.82	695889.28
838	36652.77	696048.38
839	36865.51	696042.50
840	35791.78	696303.65

See footnotes at end of table.

TABLE A.7-2
(Continued)

NODE NO.	NORTH COORDINATE	EAST COORDINATE
841	35906.07	696307.07
842	35661.59	696309.71
843	36026.76	696288.29
844	35545.07	696306.23
845	36198.29	696253.75
846	35423.37	696353.63
847	36461.83	696247.98
848	35331.19	696397.88
849	36684.09	696242.13
850	35195.90	696421.56
851	37106.81	696039.86
852	37332.24	696037.18
853	34708.54	696528.42
854	34800.08	696544.05
855	34508.57	696532.58
856	34971.75	696638.71
857	35076.58	696613.54
858	34889.07	696665.67
859	34300.98	696506.63
860	35231.83	696587.23
861	34045.11	696490.28
862	33876.88	696467.68
863	33707.70	696448.30
864	33600.76	696422.63
865	33499.51	696263.64
866	33350.37	696225.21
867	33172.71	696161.32
868	33464.30	696390.57
869	32918.94	696059.16
870	29439.41	693066.95
871	29425.73	693511.42
872	29764.82	693794.74
873	29387.15	693727.23
874	30023.84	694395.39
875	29535.58	694083.16
876	32052.49	695911.19
877	32322.07	696045.14
878	31703.63	695732.63
879	32559.96	696147.26
880	31345.35	695509.57
881	32778.85	696233.47
882	30761.72	695251.10
883	30311.46	694986.58
884	29807.29	694690.19
885	37541.80	696034.47
886	37748.16	696041.28
887	37945.03	696035.36
888	36893.64	696242.59
889	37131.76	696246.29
890	35826.36	696456.13
891	35940.66	696459.55
892	35693.01	696459.00
893	36061.30	696462.99
894	35592.81	696463.24
895	36239.12	696453.86
896	35454.76	696515.63
897	36499.55	696416.34
898	35356.25	696553.51
899	36715.46	696413.64
900	36921.84	696414.10
901	37366.71	696246.81
902	37566.74	696240.90
903	34711.25	696697.98
904	34516.31	696714.44
905	34285.61	696676.73
906	34993.12	696835.23
907	35106.15	696785.54
908	34910.95	696879.47
909	35261.90	696706.51
910	34788.93	696940.23
911	34044.77	696642.68
912	35385.86	696643.28
913	33838.47	696610.47
914	33686.13	696581.56
915	33562.36	696555.88
916	33432.26	696523.85
917	33312.01	696342.60
918	33143.85	696291.43
919	33026.47	696249.90
920	33270.43	696482.21
921	32905.53	696379.80
922	28905.90	693116.56
923	28914.47	693545.21
924	29161.39	693875.96
925	29303.09	694406.50
926	29014.81	694113.76
927	31972.59	696145.96
928	32239.00	696279.90
929	31630.11	695957.88
930	32486.41	696388.40
931	31357.42	695792.18
932	32689.40	696484.10
933	30903.58	695711.79
934	31214.28	695915.68
935	30618.20	695546.06
936	32863.94	696522.59
937	30148.88	695278.32
938	29603.41	694994.54
939	29073.76	694736.19
940	37757.24	696244.50
941	37948.01	696121.10
942	37159.94	696424.15
943	37385.38	696415.13
944	35867.32	696602.26
945	35981.60	696612.04
946	35737.15	696598.80
947	36102.27	696599.61
948	35623.76	696564.38
949	36280.04	696612.70
950	35481.18	696611.75
951	36546.74	696616.47
952	36756.28	696620.11
953	36959.48	696620.56
954	37188.08	696617.89
955	37591.76	696415.58
956	37725.11	696415.88
957	34529.59	696849.52
958	34300.34	696772.38
959	33990.51	696772.73
960	35015.63	696955.98
961	35123.67	696914.94
962	34910.75	697003.38
963	35288.92	696848.63
964	34736.93	697049.63
965	35406.51	696794.92
966	34444.06	696989.64
967	33790.49	696769.13
968	35511.39	696750.70
969	33641.32	696743.38
970	33523.95	696698.68
971	33384.33	696663.44
972	33222.48	696628.16
973	33114.96	696434.24
974	33066.99	696586.54
975	28350.15	693172.48
976	28380.95	693598.00
977	28726.43	693868.64
978	28367.82	693794.82
979	28763.16	694491.03
980	28462.09	694236.36

See footnotes at end of table.

TABLE A.7-2
(Continued)

NODE NO.	NORTH COORDINATE	EAST COORDINATE
981	31895.82	696402.97
982	32155.88	696533.72
983	31534.30	696211.67
984	32409.65	696639.06
985	32634.89	696725.28
986	32799.90	696763.75
987	30708.95	696139.99
988	31057.87	696293.16
989	30401.31	695990.08
990	31435.28	696478.15
991	29855.69	695772.97
992	33015.70	696808.68
993	29211.65	695552.47
994	28666.11	695300.44
995	28380.91	695052.16
996	37413.53	696608.86
997	37616.74	696602.96
998	35889.32	696703.91
999	36000.43	696710.51
1000	35762.30	696713.16
1001	36127.43	696707.63
1002	35622.61	696706.50
1003	36302.03	696720.70
1004	36565.58	696711.76
1005	36775.12	696712.22
1006	36968.81	696709.48
1007	37206.90	696722.71
1008	37426.00	696710.49
1009	34171.12	696938.23
1010	33961.65	696899.67
1011	33768.06	696861.14
1012	35034.47	697051.27
1013	35142.52	697007.06
1014	34907.36	697098.61
1015	35304.59	696940.74
1016	34731.76	697135.82
1017	35434.87	696893.41
1018	34532.72	697094.61
1019	35533.39	696852.35
1020	34373.83	697157.76
1021	34510.27	697199.33
1022	34053.31	697090.38
1023	33623.04	696825.85
1024	35647.79	696804.98
1025	33501.52	696790.70
1026	33355.53	696764.98
1027	33168.27	696732.81
1028	37715.00	693234.58
1029	37726.79	693647.36
1030	28195.88	694016.69
1031	28076.72	694775.26
1032	37785.17	694523.79
1033	31822.26	696644.11
1034	32120.43	696771.77
1035	32390.06	696883.49
1036	32618.50	696953.84
1037	32789.88	696985.97
1038	32996.15	697037.23
1039	30543.05	696504.75
1040	30923.79	696619.89
1041	30200.36	696405.56
1042	31333.04	696766.85
1043	29600.66	696235.96
1044	31735.91	696929.66
1045	28962.83	696082.15
1046	33161.46	696939.17
1047	33145.34	697050.26
1048	33228.34	696847.25
1049	28566.11	696011.42
1050	28138.36	695616.77
1051	37745.46	695253.95
1052	35920.83	696808.76
1053	36022.42	696815.33
1054	35787.47	696814.81
1055	36146.24	696815.61
1056	36324.04	696819.18
1057	36593.91	696819.77
1058	36793.94	696820.22
1059	36987.62	696814.30
1060	37216.22	696814.80
1061	33935.92	697048.84
1062	33739.24	696975.38
1063	33594.23	696909.56
1064	35050.07	697175.13
1065	35164.45	697140.46
1066	34938.86	697212.98
1067	35332.87	697074.16
1068	34716.56	697234.72
1069	35459.96	697033.16
1070	35564.80	697004.82
1071	35682.37	696960.63
1072	34346.15	697284.70
1073	34509.98	697326.33
1074	34068.97	697185.66
1075	34722.72	697323.63
1076	33916.69	697131.35
1077	33469.51	696908.11
1078	35818.96	696932.36
1079	33333.07	696869.70
1080	37297.18	694094.08
1081	37434.94	694967.51
1082	36899.45	694480.55
1083	32088.03	697066.97
1084	32370.41	697156.50
1085	32592.56	697201.44
1086	32776.65	697227.25
1087	32973.42	697262.61
1088	33151.14	697297.92
1089	30399.38	696850.03
1090	30818.41	696892.71
1091	30002.54	696846.45
1092	31237.28	697001.59
1093	29307.44	696743.31
1094	31646.40	697202.52
1095	28758.38	696646.85
1096	32036.67	697320.86
1097	28590.76	696351.20
1098	33304.26	696977.59
1099	33291.29	697098.21
1100	33281.28	697314.09
1101	35942.84	696907.23
1102	36038.10	696901.09
1103	36165.17	696872.80
1104	33700.90	697083.24
1105	33548.58	697044.80
1106	33434.36	697009.63
1107	35072.08	697270.43
1108	35189.62	697245.29
1109	34960.91	697292.41
1110	35354.83	697194.86
1111	35494.61	697157.07
1112	35586.74	697131.88
1113	35713.81	697103.57
1114	35850.47	697040.38
1115	34322.47	697411.65
1116	34522.39	697459.71
1117	34084.61	697293.64
1118	34728.79	697447.47
1119	33881.55	697229.68
1120	34963.86	697394.02

See footnotes at end of table.

TABLE A.7-2
(Continued)

NODE NO.	NORTH COORDINATE	EAST COORDINATE
1121	33691.16	697178.47
1122	35964.85	697002.53
1123	32341.28	697404.08
1124	32560.29	697433.14
1125	32750.72	697465.32
1126	32963.38	697494.36
1127	33141.12	697523.33
1128	33258.56	697539.46
1129	30802.43	696943.47
1130	31112.79	697299.76
1131	31429.83	697506.84
1132	32001.15	697587.48
1133	32325.05	697565.97
1134	33408.70	697127.04
1135	33395.58	697317.52
1136	33375.99	697561.95
1137	36063.33	696980.52
1138	36184.06	696942.69
1139	33513.39	697165.38
1140	35087.73	697375.24
1141	35211.61	697350.11
1142	35383.17	697299.69
1143	35510.26	697258.70
1144	35611.92	697233.52
1145	35742.16	697202.06
1146	35875.62	697151.56
1147	35990.04	697101.01
1148	34325.29	697570.40
1149	34525.26	697596.24
1150	34093.68	697496.86
1151	34725.32	697580.81
1152	33874.78	697417.00
1153	34969.92	697524.20
1154	33678.01	697381.64
1155	35106.57	697467.36
1156	33506.64	697346.34
1157	36091.72	697063.14
1158	32543.97	697636.31
1159	32734.38	697678.00
1160	32950.21	697710.23
1161	33137.45	697745.57
1162	33251.72	697761.70
1163	33369.14	697784.18
1164	31483.31	697729.21
1165	31972.14	697784.27
1166	32312.03	697708.82
1167	32521.28	697845.81
1168	33496.59	697584.44
1169	33486.56	697809.84
1170	36196.62	697006.22
1171	35233.65	697432.71
1172	35417.76	697449.00
1173	35535.49	697338.13
1174	35643.42	697344.72
1175	35773.62	697335.48
1176	35903.94	697269.10
1177	36008.95	697164.55
1178	36097.99	697098.08
1179	34328.05	697760.91
1180	34534.41	697764.54
1181	34096.39	697706.42
1182	34740.80	697761.82
1183	33867.88	697667.81
1184	34921.82	697740.00
1185	33667.95	697622.92
1186	32733.89	697897.08
1187	32937.01	697932.45
1188	33130.62	697964.63
1189	33241.69	697987.10
1190	33359.11	698015.94
1191	33473.36	698038.42
1192	32517.73	698014.08
1193	32714.42	698087.54
1194	33667.50	697826.13
1195	33660.62	698064.23
1196	34327.67	697929.18
1197	34540.38	697936.00
1198	34099.13	697903.28
1199	34740.40	697939.63
1200	33867.43	697871.01
1201	34924.54	697943.20
1202	32920.62	698167.38
1203	33123.66	698237.67
1204	33237.97	698234.75
1205	33349.09	698238.17
1206	33460.23	698232.06
1207	33647.50	698257.88
1208	33866.91	698105.96
1209	33853.77	698302.78
1210	34346.22	698157.82
1211	34543.08	698151.91
1212	34104.94	698147.76
1213	34746.30	698146.01
1214	34920.92	698146.40
1215	33345.73	698320.71
1216	33456.72	698381.28
1217	33643.92	698438.84
1218	33853.33	698499.63
1219	34110.83	698357.33
1220	34103.99	698576.39
1221	34345.74	698373.72
1222	34548.97	698358.30
1223	34755.36	698352.40
1224	34926.83	698346.43
1225	34345.17	698630.90
1226	34551.68	698571.03
1227	34758.15	698527.03

[a]Wisconsin State Plane Coordinates (meters).

TABLE A.7-3

GRID ELEMENTS WITH CORRESPONDING NODES, INITIAL AQUIFER SATURATED THICKNESS, AND BOTTOM OF AQUIFER ELEVATION

0***** ELEMENT DATA *****

0 ELEMENT NO.	NODE 1	2	3	4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
1	941	887	886	940	1	1	23.00	459.00
2	837	836	886	887	1	1	22.00	459.00
3	789	788	836	837	1	1	21.00	459.00
4	742	741	788	789	1	1	20.00	460.00
5	693	692	741	742	1	1	19.00	461.00
6	647	645	692	693	1	1	16.00	463.00
7	646	599	645	647	1	1	14.00	465.00
8	940	902	955	956	1	1	25.00	459.00
9	886	885	902	940	1	1	23.00	458.00
10	836	835	885	886	1	1	21.00	458.00
11	788	787	835	836	1	1	20.00	458.00
12	741	740	787	788	1	1	19.00	459.00
13	692	691	740	741	1	1	17.00	460.00
14	645	644	691	692	1	1	15.00	462.00
15	599	597	644	645	1	1	13.00	465.00
16	554	552	597	599	1	1	11.00	465.00
17	508	506	552	554	1	1	10.00	465.00
18	459	456	506	508	1	1	7.00	465.00
19	458	414	456	459	2	1	7.00	468.00
20	955	943	996	997	1	1	25.00	459.00
21	902	901	943	955	1	1	23.00	458.00
22	885	852	901	902	1	1	21.00	458.00
23	835	834	852	885	1	1	20.00	457.00
24	787	786	834	835	1	1	18.00	457.00
25	740	739	786	787	1	1	17.00	457.00
26	691	690	739	740	1	1	15.00	458.00
27	644	642	690	691	1	1	14.00	460.00
28	597	595	642	644	1	1	13.00	461.00
29	552	550	595	597	1	1	11.00	462.00
30	506	504	550	552	1	1	9.00	462.00
31	456	454	504	506	1	1	8.00	462.00
32	414	412	454	456	2	1	6.00	462.00
33	374	372	412	414	2	1	4.00	468.00
34	335	333	372	374	2	1	1.00	470.00
35	297	295	333	335	2	0	0.10	470.00
36	260	258	295	297	2	0	0.10	470.00
37	226	223	258	260	2	0	0.10	470.00
38	225	191	223	226	2	1	2.00	465.00
39	43	39	61	63	2	1	19.00	453.00
40	42	24	39	43	2	1	22.00	451.00
41	41	23	24	42	2	1	24.00	448.00
42	996	954	1007	1008	1	1	25.00	459.00
43	943	942	954	996	1	1	23.00	458.00
44	901	889	942	943	1	1	22.00	457.00
45	852	851	889	901	1	1	20.00	457.00
46	834	803	851	852	1	1	17.00	456.00
47	786	785	803	834	1	1	15.00	456.00
48	739	738	785	786	1	1	15.00	456.00
49	690	688	738	739	1	1	13.00	456.00
50	642	640	688	690	1	1	11.00	458.00
51	595	593	640	642	1	1	10.00	458.00
52	550	548	593	595	1	1	9.00	458.00
53	504	502	548	550	1	1	8.00	458.00
54	454	452	502	504	1	1	8.00	458.00
55	412	410	452	454	2	1	6.00	458.00
56	372	370	410	412	2	1	5.00	458.00
57	333	331	370	372	2	1	3.00	458.00
58	295	293	331	333	2	1	2.00	458.00
59	258	256	293	295	2	1	2.00	458.00
60	223	221	256	258	2	1	3.00	456.00
61	191	189	221	223	2	1	6.00	456.00
62	163	161	189	191	2	1	8.00	455.00
63	137	135	161	163	2	1	10.00	455.00
64	108	106	135	137	2	1	13.00	455.00
65	83	81	106	108	2	1	19.00	454.00
66	61	59	81	83	2	1	21.00	453.00
67	39	37	59	61	2	1	22.00	452.00
68	24	21	37	39	2	1	24.00	450.00
69	23	11	21	24	2	1	25.00	447.00
70	1007	1006	1059	1060	1	1	25.00	459.00

TABLE A.7-3
(Continued)

0***** ELEMENT DATA *****

ELEMENT NO.	NODE 1	NODE 2	NODE 3	NODE 4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
71	954	953	1006	1007	1	1	23.00	458.00
72	942	900	953	954	1	1	22.00	456.00
73	889	888	900	942	1	1	20.00	455.00
74	851	839	888	889	1	1	18.00	454.00
75	803	801	839	851	1	1	16.00	454.00
76	785	754	801	803	1	1	14.00	454.00
77	738	737	754	785	1	1	12.00	455.00
78	688	687	737	738	1	1	11.00	455.00
79	640	639	687	688	1	1	10.00	455.00
80	593	592	639	640	1	1	9.00	455.00
81	548	547	592	593	1	1	9.00	455.00
82	502	501	547	548	1	1	8.00	455.00
83	452	451	501	502	1	1	8.00	455.00
84	410	409	451	452	2	1	7.00	455.00
85	370	369	409	410	2	1	6.00	455.00
86	331	330	369	370	2	1	6.00	455.00
87	293	292	330	331	2	1	5.00	455.00
88	256	255	292	293	2	1	6.00	455.00
89	221	220	255	256	2	1	8.00	455.00
90	189	188	220	221	2	1	10.00	455.00
91	161	160	188	189	2	1	13.00	456.00
92	135	134	160	161	2	1	15.00	456.00
93	106	105	134	135	2	1	20.00	456.00
94	81	80	105	106	2	1	21.00	455.00
95	59	58	80	81	2	1	22.00	454.00
96	37	36	58	59	2	1	24.00	452.00
97	21	20	36	37	2	1	25.00	449.00
98	11	10	20	21	2	1	27.00	447.00
99	4	3	10	11	1	1	29.00	443.00
100	1	2	3	4	1	1	30.00	441.00
101	5	6	2	1	1	1	30.00	440.00
102	1006	1005	1058	1059	1	1	24.00	457.00
103	953	952	1005	1006	1	1	22.00	455.00
104	900	899	952	953	1	1	21.00	454.00
105	888	849	899	900	1	1	19.00	453.00
106	839	838	849	888	1	1	17.00	453.00
107	801	791	838	839	1	1	15.00	452.00
108	754	752	791	801	1	1	13.00	452.00
109	737	703	752	754	1	1	11.00	453.00
110	687	689	703	737	1	1	10.00	453.00
111	639	641	689	687	1	1	10.00	456.00
112	592	594	641	639	1	1	9.00	455.00
113	547	549	594	592	1	1	9.00	455.00
114	501	503	549	547	1	1	8.00	455.00
115	451	453	503	501	1	1	8.00	456.00
116	409	411	453	451	2	1	7.00	456.00
117	369	371	411	409	2	1	7.00	456.00
118	330	332	371	369	2	1	7.00	456.00
119	292	294	332	330	2	1	8.00	457.00
120	255	257	294	292	2	1	9.00	457.00
121	220	222	257	255	2	1	12.00	457.00
122	188	190	222	220	2	1	14.00	457.00
123	160	162	190	188	2	1	17.00	457.00
124	134	136	162	160	2	1	19.00	457.00
125	105	107	136	134	2	1	21.00	457.00
126	80	82	107	105	2	1	22.00	457.00
127	58	60	82	80	2	1	23.00	456.00
128	36	38	60	58	2	1	24.00	453.00
129	20	22	38	36	2	1	25.00	449.00
130	10	12	22	20	2	1	27.00	448.00
131	3	8	12	10	1	1	28.00	445.00
132	2	7	8	3	1	1	29.00	443.00
133	6	9	7	2	1	1	30.00	441.00
134	13	14	9	6	1	1	31.00	440.00
135	26	27	14	13	1	1	32.00	440.00
136	45	46	27	26	1	1	33.00	440.00
137	1005	1004	1057	1058	1	1	23.00	455.00
138	952	951	1004	1005	1	1	22.00	452.00
139	899	897	951	952	1	1	20.00	451.00
140	849	847	897	899	1	1	17.00	450.00

0***** ELEMENT DATA *****

ELEMENT NO.	NODE 1	NODE 2	NODE 3	NODE 4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
141	838	799	847	849	1	1	15.00	449.00
142	791	790	799	838	1	1	13.00	449.00
143	752	744	790	791	1	1	13.00	450.00
144	703	701	744	752	1	1	11.00	451.00
145	689	655	701	703	1	1	10.00	452.00
146	641	643	655	689	1	1	9.00	453.00
147	594	596	643	641	1	1	9.00	455.00
148	549	551	596	594	1	1	8.00	456.00
149	503	505	551	549	1	1	8.00	456.00
150	453	455	505	503	1	1	7.00	457.00
151	411	413	455	453	1	1	6.00	457.00
152	371	373	413	411	1	1	5.00	457.00
153	332	334	373	371	1	1	5.00	458.00
154	294	296	334	332	1	1	8.00	458.00
155	257	259	296	294	1	1	8.00	459.00
156	222	224	259	257	1	1	11.00	459.00
157	190	192	224	222	1	1	12.00	459.00
158	162	164	192	190	1	1	14.00	459.00
159	136	138	164	162	1	1	18.00	459.00
160	107	109	138	136	1	1	20.00	459.00
161	82	84	109	107	1	1	21.00	459.00
162	60	62	84	82	1	1	22.00	459.00
163	38	40	62	60	1	1	23.00	458.00
164	22	25	40	38	1	1	25.00	453.00
165	12	18	25	22	1	1	26.00	450.00
166	8	16	18	12	1	1	27.00	447.00
167	7	15	16	8	1	1	28.00	444.00
168	9	17	15	7	1	1	29.00	443.00
169	14	19	17	9	1	1	30.00	440.00
170	27	28	19	14	1	1	31.00	440.00
171	46	47	28	27	1	1	33.00	440.00
172	1004	1003	1056	1057	1	1	21.00	453.00
173	951	949	1003	1004	1	1	20.00	450.00
174	897	895	949	951	1	1	19.00	448.00
175	847	845	895	897	1	1	17.00	447.00
176	799	797	845	847	1	1	15.00	447.00
177	790	750	797	799	1	1	14.00	447.00
178	744	743	750	790	1	1	12.00	447.00
179	701	695	743	744	1	1	11.00	448.00
180	655	653	695	701	1	1	10.00	450.00
181	643	605	653	655	1	1	9.00	453.00
182	596	598	605	643	1	1	9.00	456.00
183	551	553	598	596	1	1	8.00	457.00
184	505	507	553	551	1	1	7.00	458.00
185	455	457	507	505	1	1	6.00	459.00
186	413	415	457	455	1	1	4.00	460.00
187	373	375	415	413	1	1	3.00	461.00
188	334	336	375	373	1	1	1.00	464.00
189	296	298	336	334	1	1	1.00	464.00
190	259	261	298	296	1	1	4.00	462.00
191	224	227	261	259	1	1	6.00	465.00
192	192	193	227	224	1	1	8.00	462.00
193	164	165	193	192	1	1	12.00	464.00
194	138	139	165	164	1	1	13.00	467.00
195	109	110	139	138	1	1	15.00	467.00
196	84	85	110	109	1	1	17.00	465.00
197	62	64	85	84	1	1	20.00	463.00
198	40	44	64	62	1	1	21.00	461.00
199	25	34	44	40	1	1	22.00	457.00
200	18	32	34	25	1	1	24.00	453.00
201	16	30	32	18	1	1	26.00	450.00
202	15	29	30	16	1	1	27.00	446.00
203	17	31	29	15	1	1	28.00	443.00
204	19	33	31	17	1	1	29.00	442.00
205	28	35	33	19	1	1	30.00	440.00
206	47	48	35	28	1	1	31.00	440.00
207	66	67	48	47	1	1	33.00	440.00
208	88	89	67	66	1	1	36.00	440.00
209	114	115	89	88	1	1	38.00	440.00
210	1003	1001	1055	1056	1	1	21.00	449.00

TABLE A.7-3
(Continued)

0***** ELEMENT DATA *****

ELEMENT NO.	NODE 1	NODE 2	NODE 3	NODE 4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
211	949	947	1001	1003	1	1	19.00	446.00
212	895	893	947	949	1	1	18.00	445.00
213	845	843	893	895	1	1	17.00	445.00
214	797	795	843	845	1	1	15.00	445.00
215	750	748	795	797	1	1	14.00	445.00
216	743	699	748	750	1	1	12.00	446.00
217	695	694	699	743	1	1	10.00	447.00
218	653	649	694	695	1	1	10.00	449.00
219	605	603	649	653	1	1	9.00	452.00
220	598	559	603	605	1	1	9.00	455.00
221	553	555	559	598	1	1	8.00	458.00
222	507	509	555	553	1	1	7.00	459.00
223	457	460	509	507	1	1	6.00	462.00
224	415	416	460	457	1	1	3.00	465.00
225	375	376	416	415	1	1	1.00	465.00
226	336	337	376	375	1	0	0.10	472.00
227	298	299	337	336	1	0	0.10	472.00
228	261	262	299	298	1	1	1.00	470.00
229	227	228	262	261	1	1	3.00	468.00
230	193	194	228	227	1	1	5.00	463.00
231	165	166	194	193	1	1	7.00	466.00
232	139	140	166	165	1	1	9.00	470.00
233	110	111	140	139	1	1	10.00	470.00
234	85	86	111	110	1	1	12.00	469.00
235	64	65	86	85	1	1	15.00	466.00
236	44	56	65	64	1	1	18.00	464.00
237	34	54	56	44	1	1	20.00	461.00
238	32	52	54	34	1	1	22.00	454.00
239	30	50	52	32	1	1	23.00	451.00
240	29	49	50	30	1	1	25.00	447.00
241	31	51	49	29	1	1	26.00	444.00
242	33	53	51	31	1	1	27.00	443.00
243	35	55	53	33	1	1	28.00	440.00
244	48	57	55	35	1	1	30.00	440.00
245	67	68	57	48	1	1	33.00	440.00
246	89	90	68	67	1	1	36.00	440.00
247	115	116	90	89	1	1	38.00	440.00
248	1138	1137	1157	1170	1	1	24.00	454.00
249	1103	1102	1137	1138	1	1	23.00	452.00
250	1055	1053	1102	1103	1	1	22.00	449.00
251	1001	999	1053	1055	1	1	21.00	447.00
252	947	945	999	1001	1	1	19.00	445.00
253	893	891	945	947	1	1	18.00	445.00
254	843	841	891	893	1	1	17.00	445.00
255	795	793	841	843	1	1	15.00	445.00
256	748	746	793	795	1	1	15.00	455.00
257	699	697	746	748	1	1	12.00	445.00
258	694	651	697	699	1	1	11.00	446.00
259	649	648	651	694	1	1	10.00	448.00
260	603	601	648	649	1	1	9.00	452.00
261	559	557	601	603	1	4	9.00	455.00
262	555	512	557	559	1	4	8.00	458.00
263	509	510	512	555	1	4	8.00	461.00
264	460	461	510	509	1	1	7.00	464.00
265	416	417	461	460	1	1	4.00	468.00
266	376	377	417	416	1	1	1.00	470.00
267	337	338	377	376	1	0	0.10	472.00
268	299	300	338	337	1	0	0.10	472.00
269	262	263	300	299	1	1	1.00	470.00
270	228	229	263	262	1	1	2.00	468.00
271	194	195	229	228	1	1	4.00	464.00
272	166	167	195	194	1	1	5.00	470.00
273	140	141	167	166	1	1	6.00	470.00
274	111	112	141	140	1	1	8.00	470.00
275	86	87	112	111	1	1	9.00	468.00
276	65	78	87	86	1	1	10.00	466.00
277	56	76	78	65	1	1	13.00	463.00
278	54	74	76	56	1	1	17.00	460.00
279	52	72	74	54	1	1	20.00	456.00
280	50	70	72	52	1	1	22.00	451.00

TABLE A.7-3
(Continued)

0***** ELEMENT DATA *****

ELEMENT NO.	NODE 1	2	3	4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
281	49	69	70	50	1	1	23.00	447.00
282	51	71	69	49	1	1	24.00	444.00
283	53	73	71	51	1	1	25.00	442.00
284	55	75	73	53	1	1	27.00	440.00
285	57	77	75	55	1	1	29.00	440.00
286	68	79	77	57	1	1	32.00	440.00
287	90	91	79	68	1	1	35.00	440.00
288	116	117	91	90	1	1	38.00	440.00
289	1157	1147	1177	1178	1	1	25.00	455.00
290	1137	1122	1147	1157	1	1	24.00	455.00
291	1102	1101	1122	1137	1	1	23.00	452.00
292	1053	1052	1101	1102	1	1	22.00	448.00
293	999	998	1052	1053	1	1	21.00	446.00
294	945	944	998	999	1	1	19.00	445.00
295	891	890	944	945	1	1	18.00	445.00
296	841	840	890	891	1	1	17.00	445.00
297	793	792	840	841	1	1	16.00	445.00
298	746	745	792	793	1	1	17.00	445.00
299	697	696	745	746	1	1	13.00	445.00
300	651	650	696	697	1	1	12.00	446.00
301	648	602	650	651	1	1	10.00	448.00
302	601	600	602	648	1	1	9.00	452.00
303	557	556	600	601	1	1	9.00	455.00
304	512	511	556	557	1	1	8.00	457.00
305	510	461	511	512	1	1	8.00	463.00
306	461	462	463	511	1	1	8.00	464.00
307	417	418	462	461	1	1	6.00	469.00
308	377	378	418	417	1	1	2.00	470.00
309	338	339	378	377	1	0	0.10	471.00
310	300	301	339	338	1	0	0.10	471.00
311	263	264	301	300	1	1	1.00	469.00
312	229	230	264	263	1	1	2.00	468.00
313	195	196	230	229	1	1	3.00	464.00
314	167	168	196	195	1	1	5.00	470.00
315	141	142	168	167	1	1	6.00	470.00
316	112	113	142	141	1	1	7.00	469.00
317	87	103	113	112	1	1	8.00	468.00
318	78	101	103	87	1	1	9.00	466.00
319	76	99	101	78	1	1	10.00	463.00
320	74	97	99	76	1	1	13.00	460.00
321	72	95	97	74	1	1	17.00	455.00
322	70	93	95	72	1	1	20.00	450.00
323	69	92	93	70	1	1	22.00	446.00
324	71	94	92	69	1	1	23.00	444.00
325	73	96	94	71	1	1	24.00	443.00
326	75	98	96	73	1	1	26.00	442.00
327	77	100	98	75	1	1	28.00	440.00
328	79	102	100	77	1	1	30.00	440.00
329	91	104	102	79	1	1	35.00	440.00
330	117	118	104	91	1	1	37.00	440.00
331	418	419	463	462	1	1	7.00	469.00
332	378	379	419	418	1	1	5.00	470.00
333	339	340	379	378	1	0	0.10	470.00
334	301	302	340	339	1	1	1.00	470.00
335	264	265	302	301	1	1	2.00	467.00
336	230	231	265	264	1	1	3.00	467.00
337	196	197	231	230	1	1	5.00	466.00
338	168	169	197	196	1	1	5.00	470.00
339	142	143	169	168	1	1	6.00	469.00
340	113	132	143	142	1	1	7.00	468.00
341	103	130	132	113	1	1	8.00	467.00
342	101	128	130	103	1	1	8.00	465.00
343	99	126	128	101	1	1	9.00	463.00
344	97	124	126	99	1	1	11.00	459.00
345	95	122	124	97	1	1	14.00	455.00
346	93	120	122	95	1	1	15.00	447.00
347	92	119	120	93	1	1	19.00	446.00
348	94	121	119	92	1	1	21.00	444.00
349	96	123	121	94	1	1	22.00	443.00
350	98	125	123	96	1	1	24.00	442.00

TABLE A.7-3
(Continued)

0***** ELEMENT DATA *****

ELEMENT NO.	NODE 1	2	3	4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
351	100	127	125	98	1	1	27.00	440.00
352	102	129	127	100	1	1	30.00	440.00
353	104	131	129	102	1	1	34.00	439.00
354	118	133	131	104	1	1	37.00	438.00
355	556	558	602	600	1	1	9.00	454.00
356	511	513	558	556	1	1	9.00	457.00
357	463	464	513	511	1	1	9.00	459.00
358	419	420	464	463	1	1	9.00	465.00
359	379	380	420	419	1	1	8.00	470.00
360	340	341	380	379	1	1	8.00	470.00
361	302	303	341	340	1	1	7.00	468.00
362	265	266	303	302	1	1	6.00	463.00
363	231	232	266	265	1	1	6.00	465.00
364	197	198	232	231	1	1	8.00	470.00
365	169	170	198	197	1	1	9.00	470.00
366	143	159	170	169	1	1	7.00	468.00
367	132	157	159	143	1	1	9.00	467.00
368	130	155	157	132	1	1	10.00	466.00
369	128	153	155	130	1	1	10.00	463.00
370	126	151	153	128	1	1	10.00	462.00
371	124	149	151	126	1	1	10.00	458.00
372	1147	1146	1176	1177	1	1	25.00	455.00
373	1122	1114	1146	1147	1	1	24.00	455.00
374	1101	1078	1114	1122	1	1	23.00	452.00
375	1052	1054	1078	1101	1	1	22.00	448.00
376	998	1000	1054	1052	1	1	21.00	446.00
377	944	946	1000	998	1	1	20.00	445.00
378	890	892	946	944	1	1	19.00	445.00
379	840	842	892	890	1	1	18.00	445.00
380	792	794	842	840	1	1	19.00	445.00
381	745	747	794	792	1	1	17.00	445.00
382	696	698	747	745	1	1	13.00	445.00
383	650	652	698	696	1	1	12.00	446.00
384	602	604	652	650	1	1	10.00	447.00
385	558	560	604	602	1	1	9.00	452.00
386	513	514	560	558	1	1	9.00	456.00
387	464	465	514	513	1	1	10.00	458.00
388	420	421	465	464	1	1	11.00	464.00
389	380	381	421	420	1	1	12.00	469.00
390	341	342	381	380	1	1	13.00	470.00
391	303	304	342	341	1	1	13.00	464.00
392	266	267	304	303	1	1	13.00	458.00
393	232	233	267	266	1	1	12.00	464.00
394	198	199	233	232	1	1	12.00	468.00
395	170	187	199	198	1	1	12.00	469.00
396	159	186	187	170	1	1	12.00	464.00
397	157	184	186	159	1	1	12.00	463.00
398	155	182	184	157	1	1	12.00	462.00
399	153	180	182	155	1	1	12.00	461.00
400	151	176	180	153	1	1	12.00	459.00
401	149	147	176	151	1	1	12.00	455.00
402	122	147	149	124	1	1	12.00	453.00
403	120	145	147	122	1	1	13.00	446.00
404	119	144	145	120	1	1	15.00	444.00
405	121	146	144	119	1	1	18.00	443.00
406	123	148	146	121	1	1	20.00	443.00
407	125	150	148	123	1	1	22.00	442.00
408	127	152	150	125	1	1	25.00	440.00
409	129	154	152	127	1	1	27.00	439.00
410	131	156	154	129	1	1	33.00	437.00
411	133	158	156	131	1	1	37.00	436.00
412	1146	1145	1175	1176	1	1	25.00	455.00
413	1114	1113	1145	1146	1	1	24.00	455.00
414	1078	1071	1113	1114	1	1	23.00	452.00
415	1054	1024	1071	1078	1	1	22.00	448.00
416	1000	1002	1024	1054	1	1	21.00	447.00
417	946	948	1002	1000	1	1	20.00	446.00
418	892	894	948	946	1	1	20.00	447.00
419	842	844	894	892	1	1	20.00	448.00
420	794	796	844	842	1	1	20.00	447.00

TABLE A.7-3
(Continued)

0***** ELEMENT DATA *****

ELEMENT NO.	NODE 1	2	3	4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
421	747	749	796	794	1	1	18.00	445.00
422	698	700	749	747	1	1	13.00	445.00
423	652	654	700	698	1	1	12.00	445.00
424	604	606	654	652	1	1	10.00	446.00
425	560	561	606	604	1	1	9.00	449.00
426	514	515	561	560	1	1	10.00	453.00
427	465	466	515	514	1	1	13.00	457.00
428	421	422	466	465	1	1	15.00	458.00
429	381	382	422	421	1	1	15.00	464.00
430	342	343	382	381	1	1	16.00	465.00
431	304	305	343	342	1	1	17.00	458.00
432	267	268	305	304	1	1	17.00	456.00
433	233	234	268	267	1	1	17.00	458.00
434	199	219	234	233	1	1	16.00	462.00
435	187	218	219	199	1	1	15.00	463.00
436	186	215	218	187	1	1	15.00	459.00
437	184	213	215	186	1	1	15.00	459.00
438	182	211	213	184	1	1	15.00	459.00
439	180	207	211	182	1	1	15.00	459.00
440	176	177	207	180	1	1	14.00	456.00
441	147	174	177	176	1	1	14.00	452.00
442	145	172	174	147	1	1	14.00	446.00
443	144	171	172	145	1	1	15.00	443.00
444	146	173	171	144	1	1	16.00	443.00
445	148	175	173	146	1	1	18.00	443.00
446	150	178	175	148	1	1	20.00	443.00
447	152	179	178	150	1	1	24.00	441.00
448	154	181	179	152	1	1	27.00	438.00
449	156	183	181	154	1	1	32.00	436.00
450	158	185	183	156	1	1	37.00	433.00
451	1145	1144	1174	1175	1	1	25.00	455.00
452	1113	1112	1144	1145	1	1	24.00	455.00
453	1071	1070	1112	1113	1	1	23.00	453.00
454	1024	1019	1070	1071	1	1	22.00	448.00
455	1002	968	1019	1024	1	1	21.00	448.00
456	948	950	968	1002	1	1	20.00	448.00
457	894	896	950	948	1	1	20.00	449.00
458	844	846	896	894	1	1	20.00	451.00
459	796	798	846	844	1	1	20.00	448.00
460	749	751	798	796	1	1	15.00	446.00
461	700	702	751	749	1	1	13.00	445.00
462	654	656	702	700	1	1	12.00	445.00
463	606	607	656	654	1	1	12.00	445.00
464	561	562	607	606	1	1	13.00	446.00
465	515	516	562	561	1	1	14.00	450.00
466	466	467	516	515	1	1	16.00	454.00
467	422	423	467	466	1	1	18.00	457.00
468	382	383	423	422	1	1	18.00	458.00
469	343	344	383	382	1	1	19.00	458.00
470	305	306	344	343	1	1	21.00	453.00
471	268	269	306	305	1	1	20.00	452.00
472	234	254	269	268	1	1	18.00	455.00
473	219	253	254	234	1	1	18.00	458.00
474	218	252	253	219	1	1	17.00	459.00
475	215	250	252	218	1	1	16.00	458.00
476	213	248	250	215	1	1	16.00	458.00
477	211	244	248	213	1	1	16.00	459.00
478	207	208	244	211	1	1	16.00	457.00
479	177	205	208	207	1	1	16.00	454.00
480	174	203	205	177	1	1	16.00	449.00
481	172	201	203	174	1	1	16.00	444.00
482	171	200	201	172	1	1	16.00	442.00
483	173	202	200	171	1	1	17.00	442.00
484	175	204	202	173	1	1	18.00	443.00
485	178	206	204	175	1	1	19.00	444.00
486	179	209	206	178	1	1	23.00	442.00
487	181	210	209	179	1	1	27.00	437.00
488	183	212	210	181	1	1	33.00	433.00
489	185	214	212	183	1	1	40.00	431.00
490	216	217	214	185	1	1	39.00	430.00

TABLE A.7-3
(Continued)

0***** ELEMENT DATA *****

ELEMENT NO.	NODE 1	2	3	4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
491	1144	1143	1173	1174	1	1	25.00	455.00
492	1112	1111	1143	1144	1	1	24.00	455.00
493	1070	1069	1111	1112	1	1	23.00	453.00
494	1019	1017	1069	1070	1	1	22.00	450.00
495	968	965	1017	1019	1	1	21.00	450.00
496	950	912	965	968	1	1	20.00	450.00
497	896	898	912	950	1	1	20.00	450.00
498	846	848	898	896	1	1	20.00	450.00
499	798	800	848	846	1	1	19.00	448.00
500	751	753	800	798	1	1	14.00	446.00
501	702	704	753	751	1	1	13.00	444.00
502	656	657	704	702	1	1	13.00	442.00
503	607	608	657	656	1	1	15.00	442.00
504	562	563	608	607	1	1	14.00	444.00
505	516	517	563	562	1	1	17.00	445.00
506	467	468	517	516	1	1	19.00	452.00
507	423	424	468	467	1	1	21.00	453.00
508	383	384	424	423	1	1	24.00	453.00
509	344	345	384	383	1	1	25.00	448.00
510	306	307	345	344	1	1	25.00	445.00
511	269	291	307	306	1	1	25.00	447.00
512	254	290	291	269	1	1	24.00	450.00
513	253	289	290	254	1	1	22.00	456.00
514	252	286	289	253	1	1	20.00	457.00
515	250	285	286	252	1	1	18.00	457.00
516	248	282	285	250	1	1	18.00	457.00
517	244	245	282	248	1	1	18.00	456.00
518	208	242	245	244	1	1	18.00	455.00
519	205	240	242	208	1	1	17.00	450.00
520	203	236	240	205	1	1	17.00	446.00
521	201	235	236	203	1	1	18.00	443.00
522	200	202	235	201	1	1	18.00	441.00
523	1143	1142	1172	1173	1	1	25.00	455.00
524	1111	1110	1142	1143	1	1	24.00	455.00
525	1069	1067	1110	1111	1	1	23.00	454.00
526	1017	1015	1067	1069	1	1	22.00	450.00
527	965	963	1015	1017	1	1	21.00	450.00
528	912	909	963	965	1	1	20.00	450.00
529	898	860	909	912	1	1	20.00	450.00
530	848	850	860	898	1	1	20.00	448.00
531	800	802	850	848	1	1	19.00	447.00
532	753	755	802	800	1	1	14.00	444.00
533	704	705	755	753	1	1	15.00	438.00
534	657	658	705	704	1	1	15.00	437.00
535	608	609	658	657	1	1	18.00	437.00
536	563	564	609	608	1	1	20.00	440.00
537	517	518	564	563	1	1	22.00	443.00
538	468	469	518	517	1	1	23.00	445.00
539	424	426	469	468	1	1	27.00	447.00
540	384	425	426	424	1	1	29.00	445.00
541	385	427	425	384	1	8	33.00	443.00
542	345	346	385	384	1	8	33.00	443.00
543	307	329	346	345	1	1	32.00	443.00
544	291	328	329	307	1	1	31.00	443.00
545	290	327	328	291	1	1	31.00	446.00
546	289	323	327	290	1	1	31.00	454.00
547	286	322	323	289	1	1	29.00	457.00
548	285	320	322	286	1	1	25.00	456.00
549	282	283	320	285	1	1	25.00	456.00
550	245	280	283	282	1	1	25.00	453.00
551	242	278	280	245	1	5	23.00	450.00
552	240	271	278	242	1	5	21.00	447.00
553	236	270	271	240	1	1	21.00	445.00
554	235	238	270	236	1	1	22.00	439.00
555	202	237	238	235	1	1	22.00	440.00
556	204	239	237	202	1	1	19.00	443.00
557	206	241	239	204	1	1	20.00	445.00
558	209	243	241	206	1	1	23.00	443.00
559	210	246	243	209	1	1	27.00	437.00
560	212	247	246	210	1	1	34.00	432.00

TABLE A.7-3
(Continued)

0***** ELEMENT DATA *****

ELEMENT NO.	NODE 1	NODE 2	NODE 3	NODE 4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
561	214	249	247	212	1	1	40.00	430.00
562	217	251	249	214	1	1	40.00	430.00
563	1142	1141	1171	1172	1	1	24.00	456.00
564	1110	1108	1141	1142	1	1	23.00	455.00
565	1067	1065	1108	1110	1	1	22.00	454.00
566	1015	1013	1065	1067	1	1	21.00	451.00
567	963	961	1013	1015	1	1	20.00	450.00
568	909	907	961	963	1	1	20.00	450.00
569	860	857	907	909	1	1	20.00	450.00
570	850	808	857	860	1	1	20.00	448.00
571	802	804	808	850	1	1	15.00	446.00
572	755	756	804	802	1	1	16.00	436.00
573	705	706	756	755	1	1	19.00	429.00
574	658	659	706	705	1	1	25.00	427.00
575	609	610	659	658	1	1	24.00	431.00
576	564	565	610	609	1	1	24.00	436.00
577	518	519	565	564	1	1	25.00	437.00
578	469	473	519	518	1	1	30.00	438.00
579	426	471	473	469	1	1	32.00	440.00
580	425	470	471	426	1	1	33.00	441.00
581	427	472	470	425	1	8	37.00	440.00
582	428	430	472	427	1	9	40.00	442.00
583	385	386	428	427	1	9	39.00	440.00
584	346	368	386	385	1	8	37.00	439.00
585	329	367	368	346	1	1	37.00	441.00
586	328	366	367	329	1	1	36.00	443.00
587	327	361	366	328	1	1	40.00	445.00
588	323	360	361	327	1	1	35.00	452.00
589	322	358	360	323	1	1	33.00	456.00
590	320	321	358	322	1	1	30.00	456.00
591	283	319	321	320	1	1	31.00	453.00
592	280	317	319	283	1	1	31.00	450.00
593	278	308	317	280	1	5	30.00	448.00
594	271	275	308	278	1	5	29.00	444.00
595	270	238	275	271	1	1	27.00	439.00
596	238	273	276	275	1	1	35.00	437.00
597	237	272	273	238	1	1	28.00	439.00
598	239	274	272	237	1	1	22.00	443.00
599	241	277	274	239	1	1	22.00	445.00
600	243	279	277	241	1	1	24.00	444.00
601	246	281	279	243	1	1	28.00	437.00
602	247	284	281	246	1	1	35.00	431.00
603	249	251	284	247	1	1	40.00	430.00
604	1141	1140	1155	1171	1	1	23.00	457.00
605	1108	1107	1140	1141	1	1	23.00	456.00
606	1065	1064	1107	1108	1	1	22.00	455.00
607	1013	1012	1064	1065	1	1	21.00	452.00
608	961	960	1012	1013	1	1	21.00	451.00
609	907	906	960	961	1	1	20.00	450.00
610	857	856	906	907	1	1	20.00	448.00
611	808	806	856	857	1	1	21.00	446.00
612	804	759	806	808	1	1	23.00	440.00
613	756	757	759	804	1	1	30.00	430.00
614	706	707	757	756	1	1	31.00	429.00
615	659	660	707	706	1	1	31.00	429.00
616	610	611	660	659	1	1	31.00	431.00
617	565	566	611	610	1	1	30.00	436.00
618	519	521	566	565	1	1	31.00	438.00
619	473	520	521	519	1	1	32.00	438.00
620	471	477	520	473	1	1	31.00	439.00
621	470	472	477	471	1	1	40.00	437.00
622	472	430	476	477	1	1	29.00	444.00
623	386	429	430	428	1	9	32.00	443.00
624	408	431	429	386	1	9	30.00	443.00
625	402	408	386	368	1	8	39.00	439.00
626	366	402	368	367	1	1	40.00	442.00
627	361	400	402	366	1	1	36.00	445.00
628	360	399	400	361	1	1	30.00	450.00
629	360	397	401	399	1	1	28.00	454.00
630	358	359	397	360	1	1	30.00	455.00

TABLE A.7-3
(Continued)

0***** ELEMENT DATA *****

0 ELEMENT NO.	NODE 1	2	3	4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
631	321	357	359	358	1	1	30.00	454.00
632	319	356	357	321	1	1	32.00	449.00
633	317	347	356	319	1	1	33.00	447.00
634	308	314	347	317	1	5	35.00	444.00
635	275	276	314	308	1	5	36.00	439.00
636	276	312	315	314	1	5	39.00	437.00
637	273	310	312	276	1	1	39.00	435.00
638	272	309	310	273	1	1	35.00	439.00
639	274	311	309	272	1	1	27.00	444.00
640	277	313	311	274	1	1	24.00	448.00
641	279	316	313	277	1	1	25.00	444.00
642	281	318	316	279	1	1	29.00	437.00
643	284	288	318	281	1	1	38.00	431.00
644	251	287	288	284	1	1	40.00	430.00
645	1140	1120	1153	1155	1	1	23.00	458.00
646	1107	1109	1120	1140	1	1	22.00	456.00
647	1064	1066	1109	1107	1	1	21.00	455.00
648	1012	1014	1066	1064	1	1	21.00	453.00
649	960	962	1014	1012	1	1	20.00	452.00
650	906	908	962	960	1	1	20.00	450.00
651	856	858	908	906	1	1	20.00	448.00
652	806	854	858	856	1	1	23.00	446.00
653	806	805	853	854	1	1	25.00	442.00
654	759	758	805	806	1	1	30.00	437.00
655	757	707	758	759	1	1	30.00	433.00
656	707	708	760	758	1	1	27.00	439.00
657	660	661	708	707	1	1	30.00	440.00
658	611	612	661	660	1	1	29.00	444.00
659	566	568	612	611	1	1	30.00	440.00
660	521	567	568	566	1	1	30.00	443.00
661	520	525	567	521	1	1	29.00	445.00
662	477	476	525	520	1	1	28.00	447.00
663	476	478	526	525	1	1	19.00	455.00
664	430	475	478	476	1	1	18.00	455.00
665	429	474	475	430	1	1	17.00	452.00
666	431	450	474	429	1	8	19.00	448.00
667	408	441	450	431	1	9	20.00	443.00
668	402	400	441	408	1	8	30.00	442.00
669	400	399	440	441	1	8	24.00	446.00
670	401	442	440	399	1	8	21.00	453.00
671	401	438	443	442	1	8	22.00	456.00
672	397	398	438	401	1	1	24.00	453.00
673	359	396	398	397	1	1	27.00	452.00
674	357	395	396	359	1	1	30.00	450.00
675	356	387	395	357	1	1	33.00	447.00
676	347	355	387	356	1	1	37.00	444.00
677	314	315	355	347	1	5	40.00	439.00
678	315	351	352	355	1	1	40.00	438.00
679	312	310	351	315	1	1	40.00	436.00
680	310	349	352	351	1	1	40.00	438.00
681	309	348	349	310	1	1	40.00	439.00
682	311	350	348	309	1	1	32.00	444.00
683	313	353	350	311	1	1	25.00	450.00
684	316	354	353	313	1	1	27.00	444.00
685	318	326	354	316	1	1	34.00	438.00
686	288	325	326	318	1	1	40.00	431.00
687	287	324	325	288	1	1	37.00	431.00
688	1214	1213	1223	1224	1	1	23.00	451.00
689	1201	1199	1213	1214	1	1	23.00	455.00
690	1184	1182	1199	1201	1	1	23.00	458.00
691	1153	1151	1182	1184	1	1	22.00	460.00
692	1120	1118	1151	1153	1	1	22.00	459.00
693	1109	1075	1118	1120	1	1	21.00	457.00
694	1066	1068	1075	1109	1	1	20.00	456.00
695	1014	1016	1068	1066	1	1	20.00	455.00
696	962	964	1016	1014	1	1	17.00	453.00
697	908	910	964	962	1	1	17.00	451.00
698	858	903	910	908	1	1	20.00	449.00
699	854	853	903	858	1	1	23.00	446.00
700	853	855	904	903	1	1	21.00	445.00

TABLE A.7-3
(Continued)

0***** ELEMENT DATA *****

0 ELEMENT NO.	NODE 1	2	3	4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
701	805	807	855	853	1	1	25.00	445.00
702	758	760	807	805	1	1	27.00	439.00
703	760	761	809	807	1	1	24.00	445.00
704	708	709	761	760	1	1	25.00	445.00
705	661	662	709	708	1	1	26.00	443.00
706	612	613	662	661	1	1	28.00	447.00
707	568	567	613	612	1	2	27.00	447.00
708	567	571	614	613	1	3	25.00	450.00
709	525	526	571	567	1	1	23.00	455.00
710	526	527	572	571	1	1	28.00	448.00
711	478	524	527	526	1	1	25.00	452.00
712	475	523	524	478	1	1	18.00	455.00
713	522	491	523	475	1	10	15.00	455.00
714	474	500	522	475	1	10	15.00	454.00
715	450	487	500	474	1	9	15.00	453.00
716	441	440	487	450	1	9	18.00	450.00
717	440	442	488	487	1	9	20.00	454.00
718	442	443	489	488	1	9	17.00	456.00
719	487	488	489	500	1	9	15.00	455.00
720	500	489	491	522	1	8	15.00	455.00
721	489	443	490	491	1	9	15.00	456.00
722	443	485	492	490	1	8	17.00	455.00
723	438	439	485	443	1	8	22.00	455.00
724	398	437	439	438	1	1	24.00	453.00
725	393	394	398	396	1	1	31.00	446.00
726	387	393	396	395	1	1	31.00	445.00
727	355	352	393	387	1	1	40.00	440.00
728	352	391	394	393	1	1	39.00	441.00
729	349	389	391	352	1	1	40.00	439.00
730	348	388	389	349	1	1	40.00	440.00
731	350	390	388	348	1	1	33.00	445.00
732	353	392	390	350	1	1	29.00	448.00
733	354	365	392	353	1	1	29.00	445.00
734	326	364	365	354	1	1	36.00	442.00
735	325	363	364	326	1	1	40.00	435.00
736	324	362	363	325	1	1	30.00	435.00
737	1223	1222	1226	1227	1	1	22.00	450.00
738	1213	1211	1222	1223	1	1	22.00	451.00
739	1199	1197	1211	1213	1	1	22.00	455.00
740	1182	1180	1197	1199	1	1	22.00	458.00
741	1151	1149	1180	1182	1	1	22.00	460.00
742	1118	1116	1149	1151	1	1	20.00	459.00
743	1075	1073	1116	1118	1	1	15.00	457.00
744	1068	1021	1073	1075	1	1	15.00	456.00
745	1016	1018	1021	1068	1	1	15.00	455.00
746	964	966	1018	1016	1	1	15.00	453.00
747	910	957	966	964	1	1	16.00	451.00
748	903	904	957	910	1	1	18.00	448.00
749	904	905	958	957	1	1	21.00	447.00
750	855	859	905	904	1	1	22.00	445.00
751	807	809	859	855	1	1	22.00	445.00
752	809	810	861	859	1	1	17.00	445.00
753	761	762	810	809	1	1	19.00	445.00
754	709	710	762	761	1	1	20.00	446.00
755	662	663	710	709	1	1	24.00	447.00
756	613	614	663	662	1	1	25.00	447.00
757	614	617	664	663	1	1	28.00	444.00
758	571	572	617	614	1	1	28.00	447.00
759	572	573	618	617	1	1	34.00	441.00
760	527	570	573	572	1	1	33.00	443.00
761	524	569	570	527	1	1	32.00	446.00
762	523	536	569	524	1	1	26.00	450.00
763	491	490	536	523	1	10	15.00	455.00
764	490	492	537	536	1	10	20.00	453.00
765	492	534	538	537	1	1	25.00	448.00
766	485	486	534	492	1	10	18.00	455.00
767	439	484	486	485	1	10	19.00	455.00
768	437	483	484	439	1	1	23.00	453.00
769	436	482	483	437	1	1	30.00	445.00
770	394	436	437	398	1	1	30.00	447.00

TABLE A.7-3
(Continued)

0***** ELEMENT DATA *****

0 ELEMENT NO.	NODE 1	2	3	4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
771	391	435	436	394	1	1	34.00	443.00
772	389	433	435	391	1	1	38.00	442.00
773	388	432	433	389	1	1	37.00	443.00
774	390	434	432	388	1	1	35.00	445.00
775	392	407	434	390	1	1	32.00	445.00
776	365	406	407	392	1	1	32.00	444.00
777	364	405	406	365	1	1	39.00	443.00
778	363	404	405	364	1	1	30.00	442.00
779	362	403	404	363	1	1	28.00	442.00
780	1222	1221	1225	1226	1	1	21.00	447.00
781	1211	1210	1221	1222	1	1	21.00	450.00
782	1197	1196	1210	1211	1	1	21.00	453.00
783	1180	1179	1196	1197	1	1	21.00	456.00
784	1149	1148	1179	1180	1	1	21.00	457.00
785	1116	1115	1148	1149	1	1	20.00	457.00
786	1073	1072	1115	1116	1	1	15.00	457.00
787	1021	1020	1072	1073	1	1	15.00	456.00
788	1018	966	1020	1021	1	1	15.00	453.00
789	966	1009	1022	1020	1	1	20.00	450.00
790	957	958	1009	966	1	1	21.00	448.00
791	958	959	1010	1009	1	1	18.00	448.00
792	905	911	959	958	1	1	18.00	449.00
793	859	861	911	905	1	1	17.00	447.00
794	861	862	913	911	1	1	15.00	445.00
795	810	811	862	861	1	1	17.00	447.00
796	762	763	811	810	1	1	20.00	448.00
797	710	712	763	762	1	1	21.00	448.00
798	663	711	712	710	1	1	24.00	448.00
799	664	713	711	663	1	1	29.00	443.00
800	664	667	714	713	1	1	36.00	437.00
801	617	618	667	664	1	1	34.00	436.00
802	618	619	668	667	1	6	45.00	435.00
803	573	616	619	618	1	1	40.00	437.00
804	570	615	616	573	1	1	40.00	440.00
805	569	580	615	570	1	1	37.00	442.00
806	536	537	580	569	1	1	34.00	446.00
807	537	538	581	580	1	1	37.00	443.00
808	538	578	582	581	1	1	40.00	439.00
809	534	535	578	538	1	1	30.00	445.00
810	486	533	535	534	1	1	20.00	450.00
811	484	532	533	486	1	1	20.00	454.00
812	483	531	532	484	1	1	23.00	454.00
813	482	530	531	483	1	1	25.00	448.00
814	481	529	530	482	1	1	26.00	446.00
815	435	481	482	436	1	1	33.00	445.00
816	433	480	481	435	1	1	35.00	444.00
817	432	479	480	433	1	1	36.00	445.00
818	434	449	479	432	1	1	34.00	445.00
819	407	448	449	434	1	1	33.00	445.00
820	406	447	448	407	1	1	31.00	443.00
821	405	446	447	406	1	1	33.00	445.00
822	404	445	446	405	1	1	29.00	444.00
823	403	444	445	404	1	1	28.00	444.00
824	1221	1219	1220	1225	1	1	15.00	445.00
825	1210	1212	1219	1221	1	1	15.00	447.00
826	1196	1198	1212	1210	1	1	15.00	452.00
827	1179	1181	1198	1196	1	1	15.00	454.00
828	1148	1150	1181	1179	1	1	15.00	455.00
829	1115	1117	1150	1148	1	1	15.00	454.00
830	1072	1074	1117	1115	1	1	15.00	453.00
831	1020	1022	1074	1072	1	1	15.00	451.00
832	1022	1061	1076	1074	1	1	16.00	447.00
833	1009	1010	1061	1022	1	1	15.00	447.00
834	1010	1011	1062	1061	1	1	23.00	437.00
835	959	967	1011	1010	1	1	22.00	438.00
836	911	913	967	959	1	1	17.00	443.00
837	913	914	969	967	1	1	27.00	437.00
838	862	863	914	913	1	1	25.00	436.00
839	811	812	863	862	1	1	24.00	437.00
840	763	767	812	811	1	1	24.00	438.00

TABLE A.7-3
(Continued)

0***** ELEMENT DATA *****

0 ELEMENT NO.	NODE 1	2	3	4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
841	712	765	767	763	1	1	24.00	438.00
842	711	764	765	712	1	1	28.00	440.00
843	711	713	766	764	1	1	33.00	437.00
844	713	714	768	766	1	1	37.00	430.00
845	714	717	769	768	1	6	45.00	432.00
846	667	668	717	714	1	6	45.00	434.00
847	668	669	718	717	1	7	37.00	435.00
848	619	665	669	668	1	6	44.00	435.00
849	616	615	665	619	1	1	45.00	435.00
850	615	626	666	665	1	1	45.00	436.00
851	580	581	626	615	1	1	45.00	437.00
852	581	582	627	626	1	1	45.00	439.00
853	582	624	628	627	1	1	44.00	443.00
854	578	579	624	582	1	1	43.00	440.00
855	535	577	579	578	1	1	35.00	443.00
856	533	576	577	535	1	1	24.00	448.00
857	531	576	533	532	1	1	20.00	453.00
858	530	575	576	531	1	1	19.00	450.00
859	529	574	575	530	1	1	20.00	445.00
860	528	546	574	529	1	1	23.00	445.00
861	480	528	529	481	1	1	27.00	445.00
862	479	499	528	480	1	1	29.00	445.00
863	449	498	499	479	1	1	29.00	445.00
864	448	497	498	449	1	1	31.00	445.00
865	447	496	497	448	1	1	29.00	445.00
866	446	495	496	447	1	1	28.00	445.00
867	445	494	495	446	1	1	26.00	445.00
868	444	493	494	445	1	1	26.00	445.00
869	1219	1209	1218	1220	1	1	17.00	440.00
870	1212	1208	1209	1219	1	1	17.00	444.00
871	1198	1200	1208	1212	1	1	17.00	448.00
872	1181	1183	1200	1198	1	1	17.00	450.00
873	1150	1152	1183	1181	1	1	18.00	451.00
874	1117	1119	1152	1150	1	1	18.00	449.00
875	1074	1076	1119	1117	1	1	15.00	448.00
876	1076	1104	1121	1119	1	1	24.00	438.00
877	1061	1062	1104	1076	1	1	23.00	437.00
878	1062	1063	1105	1104	1	1	27.00	437.00
879	1011	1023	1063	1062	1	1	29.00	437.00
880	967	969	1023	1011	1	1	27.00	437.00
881	969	970	1025	1023	1	1	45.00	435.00
882	914	915	970	969	1	1	45.00	435.00
883	863	864	915	914	1	1	42.00	435.00
884	812	816	864	863	1	1	33.00	435.00
885	767	813	816	812	1	1	29.00	435.00
886	765	764	813	767	1	1	30.00	436.00
887	764	766	814	813	1	1	33.00	433.00
888	766	768	815	814	1	1	37.00	431.00
889	768	769	817	815	1	1	45.00	432.00
890	769	772	818	817	1	1	39.00	435.00
891	717	718	772	769	1	6	38.00	435.00
892	718	719	773	772	1	6	33.00	439.00
893	669	715	719	718	1	6	35.00	438.00
894	665	666	715	669	1	6	38.00	437.00
895	666	676	716	715	1	1	37.00	443.00
896	626	627	676	666	1	1	42.00	440.00
897	627	628	677	676	1	1	40.00	444.00
898	628	674	678	677	1	1	37.00	445.00
899	624	625	674	628	1	1	41.00	443.00
900	579	623	625	624	1	1	41.00	441.00
901	577	621	623	579	1	1	40.00	441.00
902	575	621	577	576	1	1	26.00	445.00
903	574	620	621	575	1	1	27.00	443.00
904	591	622	620	574	1	1	26.00	443.00
905	546	590	591	574	1	1	20.00	445.00
906	545	589	590	546	1	1	22.00	445.00
907	499	545	546	528	1	1	24.00	445.00
908	498	544	545	499	1	1	25.00	445.00
909	497	543	544	498	1	1	26.00	445.00
910	496	542	543	497	1	1	26.00	445.00

TABLE A.7-3
(Continued)

0***** ELEMENT DATA *****

ELEMENT NO.	NODE 1	NODE 2	NODE 3	NODE 4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
911	495	541	542	496	1	1	25.00	445.00
912	494	540	541	495	1	1	24.00	445.00
913	493	539	540	494	1	1	24.00	445.00
914	1209	1207	1217	1218	1	1	24.00	437.00
915	1208	1195	1207	1209	1	1	24.00	437.00
916	1200	1194	1195	1208	1	1	24.00	438.00
917	1183	1185	1194	1200	1	1	24.00	441.00
918	1152	1154	1185	1183	1	1	24.00	441.00
919	1119	1121	1154	1152	1	1	24.00	439.00
920	1207	1206	1216	1217	1	1	29.00	425.00
921	1195	1191	1206	1207	1	1	29.00	428.00
922	1194	1169	1191	1195	1	1	29.00	429.00
923	1185	1168	1169	1194	1	1	29.00	430.00
924	1154	1156	1168	1185	1	1	30.00	433.00
925	1121	1139	1156	1154	1	1	30.00	434.00
926	1104	1105	1139	1121	1	1	30.00	437.00
927	1105	1106	1134	1139	1	1	45.00	433.00
928	1063	1077	1106	1105	1	1	45.00	434.00
929	1023	1025	1077	1063	1	1	42.00	435.00
930	1025	1026	1079	1077	1	1	47.00	433.00
931	970	971	1026	1025	1	1	43.00	433.00
932	915	916	971	970	1	1	45.00	433.00
933	864	868	916	915	1	1	40.00	435.00
934	816	865	868	864	1	1	38.00	435.00
935	813	814	865	816	1	1	37.00	435.00
936	814	815	866	865	1	1	40.00	434.00
937	815	817	867	866	1	1	45.00	434.00
938	817	818	869	867	1	1	45.00	435.00
939	818	819	830	869	1	1	44.00	436.00
940	772	773	819	818	1	1	38.00	436.00
941	773	771	781	819	1	1	36.00	443.00
942	719	770	771	773	1	1	33.00	443.00
943	715	716	770	719	1	1	34.00	443.00
944	716	726	771	770	1	1	30.00	448.00
945	676	677	726	716	1	1	33.00	447.00
946	677	678	727	726	1	1	30.00	449.00
947	678	724	728	727	1	1	28.00	449.00
948	674	675	724	678	1	1	33.00	447.00
949	625	673	675	674	1	1	36.00	443.00
950	623	670	673	625	1	1	38.00	440.00
951	621	620	670	623	1	1	37.00	440.00
952	620	622	671	670	1	1	32.00	440.00
953	622	638	672	671	1	1	30.00	440.00
954	591	637	638	622	1	1	28.00	443.00
955	590	636	637	591	1	1	24.00	445.00
956	589	635	636	590	1	1	23.00	445.00
957	588	634	635	589	1	1	21.00	445.00
958	544	588	589	545	1	1	22.00	445.00
959	543	587	588	544	1	1	22.00	445.00
960	542	586	587	543	1	1	22.00	445.00
961	541	585	586	542	1	1	21.00	445.00
962	540	584	585	541	1	1	22.00	445.00
963	539	583	584	540	1	1	22.00	445.00
964	583	629	585	584	1	1	20.00	445.00
965	1206	1205	1215	1216	1	1	45.00	417.00
966	1191	1190	1205	1206	1	1	45.00	417.00
967	1169	1163	1190	1191	1	1	45.00	425.00
968	1168	1136	1163	1169	1	1	45.00	426.00
969	1156	1135	1136	1168	1	1	45.00	428.00
970	1139	1134	1135	1156	1	1	45.00	430.00
971	1134	1099	1100	1135	1	1	50.00	428.00
972	1106	1098	1099	1134	1	1	46.00	428.00
973	1077	1079	1098	1106	1	1	47.00	432.00
974	1079	1048	1046	1098	1	1	51.00	430.00
975	1026	1027	1048	1079	1	1	50.00	427.00
976	971	972	1027	1026	1	1	49.00	430.00
977	916	920	972	971	1	1	47.00	432.00
978	868	917	920	916	1	1	46.00	435.00
979	865	866	917	868	1	1	42.00	435.00
980	866	867	918	917	1	1	46.00	435.00

TABLE A.7-3
(Continued)

0***** ELEMENT DATA *****

0 ELEMENT NO.	NODE 1	2	3	4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
981	867	869	919	918	1	1	46.00	435.00
982	869	881	921	919	1	1	48.00	433.00
983	869	830	879	881	1	1	47.00	437.00
984	830	828	877	879	1	1	45.00	438.00
985	819	781	828	830	1	1	42.00	438.00
986	781	780	827	828	1	1	37.00	445.00
987	771	726	780	781	1	1	30.00	448.00
988	726	727	782	780	1	1	27.00	453.00
989	727	728	783	782	1	1	24.00	453.00
990	728	778	784	783	1	1	22.00	452.00
991	724	725	778	728	1	1	26.00	448.00
992	675	723	725	724	1	1	30.00	444.00
993	673	720	723	675	1	1	32.00	442.00
994	670	671	720	673	1	1	33.00	440.00
995	671	672	721	720	1	1	30.00	441.00
996	672	686	722	721	1	1	27.00	442.00
997	638	685	686	672	1	1	28.00	440.00
998	637	684	685	638	1	1	25.00	443.00
999	635	684	637	636	1	1	23.00	445.00
1000	634	683	684	635	1	1	23.00	445.00
1001	633	682	683	634	1	1	22.00	445.00
1002	587	633	634	588	1	1	20.00	445.00
1003	586	631	633	587	1	1	20.00	445.00
1004	585	630	631	586	1	1	20.00	445.00
1005	629	632	630	585	1	1	20.00	445.00
1006	1190	1189	1204	1205	1	1	55.00	410.00
1007	1163	1162	1189	1190	1	1	55.00	415.00
1008	1136	1128	1162	1163	1	1	53.00	417.00
1009	1135	1100	1128	1136	1	1	50.00	422.00
1010	1100	1088	1127	1128	1	1	59.00	417.00
1011	1099	1047	1088	1100	1	1	56.00	423.00
1012	1098	1046	1047	1099	1	1	53.00	427.00
1013	1046	992	1038	1047	1	1	58.00	423.00
1014	1027	992	1046	1048	1	1	55.00	429.00
1015	972	974	992	1027	1	1	52.00	427.00
1016	920	973	974	972	1	1	48.00	429.00
1017	917	918	973	920	1	1	46.00	431.00
1018	918	919	921	973	1	1	48.00	430.00
1019	973	921	936	974	1	1	51.00	429.00
1020	921	881	932	936	1	1	52.00	433.00
1021	881	879	930	932	1	1	50.00	434.00
1022	879	877	928	930	1	1	46.00	437.00
1023	877	876	927	928	1	1	44.00	439.00
1024	828	827	876	877	1	1	40.00	441.00
1025	827	829	878	876	1	1	34.00	450.00
1026	780	782	829	827	1	1	28.00	453.00
1027	782	783	831	829	1	1	20.00	457.00
1028	783	784	832	831	1	1	20.00	456.00
1029	784	825	833	832	1	1	20.00	454.00
1030	778	779	825	784	1	1	21.00	452.00
1031	725	777	779	778	1	1	24.00	448.00
1032	723	774	777	725	1	1	26.00	444.00
1033	720	721	774	723	1	1	28.00	443.00
1034	721	722	775	774	1	1	25.00	443.00
1035	722	736	776	775	1	1	23.00	444.00
1036	686	735	736	722	1	1	25.00	443.00
1037	685	734	735	686	1	1	25.00	440.00
1038	684	733	734	685	1	1	23.00	443.00
1039	683	732	733	684	1	1	25.00	445.00
1040	682	731	732	683	1	1	23.00	445.00
1041	680	730	731	682	1	1	22.00	445.00
1042	631	680	682	633	1	1	20.00	445.00
1043	630	679	680	631	1	1	20.00	445.00
1044	632	681	679	630	1	1	20.00	445.00
1045	679	729	730	680	1	1	20.00	445.00
1046	1189	1188	1203	1204	1	1	65.00	408.00
1047	1162	1161	1188	1189	1	1	65.00	410.00
1048	1128	1127	1161	1162	1	1	63.00	413.00
1049	1127	1126	1160	1161	1	1	68.00	409.00
1050	1088	1087	1126	1127	1	1	65.00	414.00

TABLE A.7-3
(Continued)

0***** ELEMENT DATA *****

0 ELEMENT NO.	NODE 1	2	3	4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
1051	1047	1038	1087	1088	1	1	62.00	421.00
1052	1038	1037	1086	1087	1	1	63.00	420.00
1053	992	986	1037	1038	1	1	59.00	423.00
1054	974	936	986	992	1	1	55.00	427.00
1055	936	932	985	986	1	1	56.00	427.00
1056	932	930	984	985	1	1	56.00	432.00
1057	930	928	982	984	1	1	50.00	434.00
1058	928	927	981	982	1	1	45.00	436.00
1059	927	929	983	981	1	1	39.00	445.00
1060	876	878	929	927	1	1	35.00	447.00
1061	878	880	931	929	1	1	25.00	458.00
1062	829	831	880	878	1	1	24.00	458.00
1063	831	832	882	880	1	1	20.00	459.00
1064	832	833	883	882	1	1	20.00	455.00
1065	833	874	884	883	1	1	20.00	452.00
1066	825	826	874	833	1	1	20.00	451.00
1067	779	824	826	825	1	1	20.00	449.00
1068	777	820	824	779	1	1	22.00	448.00
1069	774	775	820	777	1	1	24.00	446.00
1070	775	776	821	820	1	1	23.00	444.00
1071	776	822	823	821	1	1	27.00	443.00
1072	1188	1187	1202	1203	1	1	70.00	406.00
1073	1161	1160	1187	1188	1	1	70.00	407.00
1074	1160	1159	1186	1187	1	1	68.00	414.00
1075	1126	1125	1159	1160	1	1	67.00	414.00
1076	1087	1086	1125	1126	1	1	65.00	417.00
1077	1086	1085	1124	1125	1	1	65.00	418.00
1078	1037	1036	1085	1086	1	1	65.00	422.00
1079	986	985	1036	1037	1	1	60.00	424.00
1080	985	984	1035	1036	1	1	60.00	427.00
1081	984	982	1034	1035	1	1	56.00	430.00
1082	982	981	1033	1034	1	1	48.00	437.00
1083	981	983	990	1033	1	1	42.00	445.00
1084	983	934	988	990	1	1	29.00	459.00
1085	929	931	934	983	1	1	30.00	459.00
1086	880	933	934	931	1	1	20.00	460.00
1087	880	882	935	933	1	1	20.00	460.00
1088	882	883	937	935	1	1	20.00	458.00
1089	883	884	938	937	1	1	21.00	452.00
1090	884	925	939	938	1	1	24.00	445.00
1091	874	875	925	884	1	1	23.00	445.00
1092	826	872	875	874	1	1	24.00	445.00
1093	824	823	872	826	1	1	23.00	445.00
1094	821	823	824	820	1	1	23.00	444.00
1095	823	871	873	872	1	1	26.00	442.00
1096	822	870	871	823	1	1	29.00	442.00
1097	1187	1186	1193	1202	1	1	70.00	414.00
1098	1186	1167	1192	1193	1	1	68.00	417.00
1099	1159	1158	1167	1186	1	1	67.00	417.00
1100	1125	1124	1158	1159	1	1	66.00	417.00
1101	1124	1123	1133	1158	1	1	65.00	420.00
1102	1085	1084	1123	1124	1	1	65.00	422.00
1103	1036	1035	1084	1085	1	1	63.00	423.00
1104	1035	1034	1083	1084	1	1	60.00	424.00
1105	1034	1033	1044	1083	1	1	52.00	435.00
1106	1033	990	1042	1044	1	1	45.00	444.00
1107	990	988	1040	1042	1	1	35.00	459.00
1108	988	987	1039	1040	1	1	28.00	460.00
1109	934	933	987	988	1	1	25.00	460.00
1110	933	935	989	987	1	1	20.00	460.00
1111	935	937	991	989	1	1	20.00	455.00
1112	937	938	993	991	1	1	22.00	450.00
1113	938	939	994	993	1	1	26.00	445.00
1114	939	979	995	994	1	1	30.00	441.00
1115	925	926	979	939	1	1	30.00	442.00
1116	875	924	926	925	1	1	27.00	442.00
1117	872	873	924	875	1	1	27.00	442.00
1118	871	923	924	873	1	1	29.00	440.00
1119	870	922	923	871	1	1	30.00	440.00
1120	1158	1133	1166	1167	1	1	66.00	419.00

TABLE A.7-3
(Continued)

0***** ELEMENT DATA *****

ELEMENT NO.	NODE 1	NODE 2	NODE 3	NODE 4	PROPERTY ZONE	RECHARGE ZONE	THICKNESS (m)	DATUM (m)
1121	1133	1132	1165	1166	1	1	65.00	422.00
1122	1123	1096	1132	1133	1	1	65.00	422.00
1123	1084	1083	1096	1123	1	1	62.00	423.00
1124	1083	1044	1094	1096	1	1	57.00	435.00
1125	1044	1042	1092	1094	1	1	45.00	443.00
1126	1042	1040	1090	1092	1	1	38.00	459.00
1127	1040	1039	1089	1090	1	1	32.00	460.00
1128	1039	1041	1091	1089	1	1	30.00	457.00
1129	987	989	1041	1039	1	1	24.00	459.00
1130	989	991	1043	1041	1	1	24.00	454.00
1131	991	993	1045	1043	1	1	26.00	444.00
1132	993	994	1049	1045	1	1	29.00	442.00
1133	994	995	1050	1049	1	1	30.00	440.00
1134	995	1031	1051	1050	1	1	30.00	440.00
1135	979	980	1031	995	1	1	30.00	440.00
1136	926	977	980	979	1	1	30.00	440.00
1137	923	977	926	924	1	1	30.00	440.00
1138	923	976	978	977	1	1	30.00	440.00
1139	922	975	976	923	1	1	30.00	440.00
1140	1132	1131	1164	1165	1	1	60.00	430.00
1141	1096	1094	1131	1132	1	1	58.00	433.00
1142	1094	1092	1130	1131	1	1	50.00	443.00
1143	1092	1090	1129	1130	1	1	40.00	460.00
1144	1041	1043	1093	1091	1	1	27.00	452.00
1145	1043	1045	1095	1093	1	1	30.00	444.00
1146	1045	1049	1097	1095	1	1	30.00	442.00
1147	1031	1032	1081	1051	1	1	30.00	440.00
1148	980	1030	1032	1031	1	1	30.00	440.00
1149	977	978	1030	980	1	1	30.00	440.00
1150	976	1029	1030	978	1	1	30.00	440.00
1151	975	1028	1029	976	1	1	30.00	440.00
1152	1029	1080	1032	1030	1	1	30.00	440.00
1153	1080	1082	1081	1032	1	1	30.00	440.00

TABLE A.7-4

LAKE ELEMENTS AND RECHARGE ZONES[a]

LAKE	ELEMENTS	LAKE BOTTOM THICKNESS (m)	RECHARGE ZONE
Duck	707	15	2
	708	10	3
Skunk	261	2	4
	262	2	4
	263	2	4
Oak[b]	551	5	5
	552	5	5
	593	5	5
	594	5	5
	634	5	5
	635	5	5
	636	5	5
	677	5	5
Deep Hole	802	6	6
	845	6	6
	846	6	6
	847	8	7
	848	6	6
	891	6	6
	892	6	6
	893	6	6
	894	6	6
Little Sand	541	7	8
	542	7	8
	581	7	8
	582	9	9
	583	9	9
	584	7	8
	623	9	9
	624	9	9
	625	7	8
	666	7	8
	667	9	9
	668	7	8
	669	7	8
	670	7	8
	671	7	8
	713	5	10
	714	5	10
	715	9	9
	716	9	9
	717	9	9
	718	9	9
	719	9	9
	720	7	8
	721	9	9
	722	7	8
	723	7	8
	723	7	8
	763	5	10
	764	5	10
	766	5	10
	767	5	10

[a]An average lake bottom permeability of $5x10^{-9}$ m/sec was used (STS Consultants, Inc., 1984b).

[b]The potentiometric surface is below the Oak Lake bottom.

TABLE A.7-5

POTENTIOMETRIC HEAD VALUES FOR SOUTHERN WETLANDS AREA

NODE NUMBER	CONSTANT POTENTIOMETRIC HEAD VALUE[a] (meters above MSL)
620	472.0
622	472.5
635	470.0
638	472.5
670	471.5
671	470.5
672	469.5
684	470.0
685	469.7
686	468.8

[a]Potentiometric head values were interpreted from Figure A-13.

TABLE A.7-6

POTENTIOMETRIC HEAD VALUES FOR CONSTANT HEAD BOUNDARY CONDITION

BOUNDARY NODE NUMBER	CONSTANT HEAD VALUE[a] (meters above MSL)
1	468.00
4	468.00
5	467.90
6	467.90
11	468.00
13	467.90
23	468.20
26	467.90
41	468.70
42	468.70
43	469.00
45	467.90
46	467.90
47	467.90
61	469.20
63	469.00
66	467.90
83	469.40
88	467.90
108	469.60
114	467.80
115	467.80
116	467.80
117	469.00
118	470.50
133	471.40

See footnote at end of table.

TABLE A.7-6
(Continued)

BOUNDARY NODE NUMBER	CONSTANT HEAD VALUE[a] (meters above MSL)
137	469.80
158	472.10
163	470.00
185	472.40
191	470.20
216	472.40
217	472.60
225	470.50
226	470.80
251	473.20
260	471.40
287	473.40
297	472.00
324	473.60
335	475.00
362	473.80
374	477.00
403	473.80
414	478.00
444	473.00
458	478.80
459	479.00
493	471.70
508	480.00
539	470.60
554	480.00
583	470.00

See footnote at end of table.

TABLE A.7-6
(Continued)

BOUNDARY NODE NUMBER	CONSTANT HEAD VALUE[a] (meters above MSL)
599	480.20
629	469.80
632	469.40
646	480.40
647	480.70
679	468.50
681	469.00
693	481.00
729	468.00
730	468.00
731	468.00
732	468.00
733	468.00
734	468.00
735	468.00
736	468.00
742	481.00
776	468.00
789	481.00
822	468.00
837	481.10
870	468.00
887	481.10
922	467.90
940	481.10
941	481.10
955	481.10

See footnote at end of table.

TABLE A.7-6
(Continued)

BOUNDARY NODE NUMBER	CONSTANT HEAD VALUE[a] (meters above MSL)
956	481.10
975	467.80
996	481.20
997	481.10
1007	481.20
1008	481.20
1028	467.70
1029	467.60
1049	467.60
1050	467.60
1051	467.60
1055	481.40
1056	481.40
1057	481.30
1058	481.30
1059	481.30
1060	481.20
1080	467.60
1081	467.70
1082	467.60
1089	481.60
1090	483.00
1091	479.50
1093	473.50
1095	469.00
1097	467.60
1103	481.40

See footnote at end of table.

TABLE A.7-6
(Continued)

BOUNDARY NODE NUMBER	CONSTANT HEAD VALUE[a] (meters above MSL)
1129	483.00
1130	484.00
1131	484.10
1138	481.40
1153	481.80
1155	481.70
1157	481.40
1164	484.20
1165	484.30
1166	484.50
1167	484.60
1170	481.40
1171	481.70
1172	481.60
1173	481.60
1174	481.60
1175	481.50
1176	481.50
1177	481.50
1178	481.40
1184	481.80
1192	484.70
1193	484.60
1201	481.90
1202	484.50
1203	484.30
1204	484.30

See footnote at end of table.

TABLE A.7-6
(Continued)

BOUNDARY NODE NUMBER	CONSTANT HEAD VALUE[a] (meters above MSL)
1205	484.20
1214	481.90
1215	484.20
1216	484.10
1217	483.80
1218	483.20
1220	482.80
1223	482.00
1224	482.00
1225	482.30
1226	482.00
1227	482.00

[a]Sources for potentiometric head values are as follows:

1. STS Consultants, Ltd., 1984, "Ground Water Potentiometric Contours" for April 1984, Dwg. No. 12959-9, Hydrologic Study Update for Exxon Minerals Company, Crandon Project.

2. Golder Associates, June 1982, "Regional Potentiometric Map," Dwg. No. 050-1-81121, Geohydrologic Characterization for Exxon Minerals Company, Crandon Project.

3. USGS topographic maps.

4. Exxon Minerals Company, Crandon Project, 1984, Crandon Hydrology Data Base, Water Levels for April 27, 1984, Rhinelander, Wisconsin.

TABLE A.7-7

COMBINED CONSTANT HEAD AND NO-FLOW BOUNDARY CONDITIONS[a,b]

NO-FLOW BOUNDARY NODE NUMBERS	
116	1129
117	1130
118	1131
133	1164
158	1165
185	1166
216	1167
217	1192
251	1193
1090	1202

[a]All other conditions are identical to the constant head boundary calibrated model; refer to Section A.7.1.

[b]Based on Golder Associates (1982).

TABLE A.7-8
SWAMP CREEK NO-FLOW BOUNDARY CONDITION[a]

NO-FLOW BOUNDARY NODE NUMBERS		
1	66	459
4	83	508
5	88	554
6	108	599
11	114	646
13	137	647
23	163	693
26	191	742
41	225	789
42	226	837
43	260	887
45	297	940
46	335	941
47	374	955
61	414	956
63	458	997

[a]All other conditions are identical to the constant head boundary calibrated model; refer to Section A.7.1.

TABLE A.7-9

SUMMARY OF INPUT DATA FOR CALIBRATED MODELS AND SENSITIVITY ANALYSES

SENSITIVITY ANALYSIS	BOUNDARY CONDITIONS	RECHARGE LAKE CONDITIONS	MIDDLE RECHARGE CASE MAIN AQUIFER PERMEABILITY[a] (m/s)	
			ZONE 1	ZONE 2
TWO PERMEABILITY ZONES:				
Constant Head Boundary Condition	Table A.7-6	Table A.7-4	1.22×10^{-4}	7.23×10^{-5}
Combined Constant Head and No-Flow Boundary Conditions	Table A.7-7[b]	Table A.7-4	1.22×10^{-4}	7.23×10^{-5}
Swamp Creek No-Flow Boundary Condition	Table A.7-8[b]	Table A.7-4	1.22×10^{-4}	7.23×10^{-5}
Increased Lake Bottom Permeability	Table A.7-6	Table A.7-4[c]	1.22×10^{-4}	7.23×10^{-5}
UNIFORM PERMEABILITY ZONE:				
Constant Head Boundary Condition	Table A.7-6	Table A.7-4	1.22×10^{-4}	1.22×10^{-4}

[a]Refer to Table A-15 for permeabilities corresponding to Low and High Recharge cases.

[b]All other boundary conditions are the same as those listed in Table A.7-6; all other input parameters were identical to the constant head boundary calibrated model.

[c]Lake bottom permeability was changed to 1×10^{-8} m/s from 5×10^{-9} m/s; all other input parameters were identical to the constant head boundary calibrated model.

TABLE A.7-10

POTENTIOMETRIC HEADS FOR MAXIMUM MINE INFLOW MODELING

NODE NUMBER	CALIBRATED POTENTIOMETRIC HEAD (m)	LOWERED POTENTIOMETRIC HEAD[a] (m)
143	479.6	469.0
159	480.0	468.0
169	480.2	470.0
170	480.5	469.0
186	480.2	464.0
187	480.7	466.0
197	481.1	468.0
198	481.3	469.0
199	481.5	465.0
215	480.4	459.0
218	480.8	463.0
219	481.5	462.0
232	482.1	464.0
233	482.2	461.0
234	482.2	458.0
266	482.9	460.0
267	482.8	457.0
268	482.8	456.0
303	483.5	466.0
304	483.4	461.0
381	484.4	466.0
382	484.3	464.0
421	484.8	469.0
422	484.7	464.0

[a]Potentiometric heads were lowered to the aquifer bottom elevation and held constant to simulate maximum mine inflow rate.

TABLE A.7-11

PREDICTED MAXIMUM MINE INFLOW RATE[a]

CALIBRATION CONDITION	MAXIMUM MINE INFLOW RATE MIDDLE RECHARGE CASE m^3/s	gpm
TWO PERMEABILITY ZONES:		
Constant Head Boundary Condition[b]	0.0972	1,540
Combined Constant Head and No-Flow Boundary Conditions[c]	0.0968	1,534
Swamp Creek No-Flow Boundary Condition	0.1121	1,777
Increased Lake Bottom Permeability	0.1020	1,617
UNIFORM PERMEABILITY ZONE		
Constant Head Boundary Condition	0.0944	1,496

[a]Maximum mine inflow rate represents a lowering of the calibrated potentiometric surface to the bottom of the aquifer for selected nodes representing the mine area.

[b]Predicted maximum mine inflow rates corresponding to the Low and High Recharge cases are 0.0709 m^3/s (1,124 gpm) and 0.1229 m^3/s (1,948 gpm), respectively.

[c]Based on Golder Associates (1982).

TABLE A.7-12

SUMMARY OF HYDROLOGIC ACTIONS FOR HORIZONTAL MODEL
MIDDLE RECHARGE CASE[a]

PROJECT TIME (year)	NATURAL RECHARGE	LAKES: DUCK	LAKES: SKUNK	LAKES: OAK	LAKES: DEEP HOLE	LAKES: LITTLE SAND	DRAINAGE AREA 1[b]	DRAINAGE AREA 2[b]	DRAINAGE BASIN 1[b]	DRAINAGE BASIN 2[b]	PREPRODUCTION ORE STORAGE PAD[b]	OILY RUNOFF AND WASTE ROCK AREA[b]	SANITARY ABSORPTION FIELD[b]	MINE WASTE DISPOSAL FACILITY[c]: T1	MINE WASTE DISPOSAL FACILITY[c]: T2	MINE WASTE DISPOSAL FACILITY[c]: T3	MINE WASTE DISPOSAL FACILITY[c]: T4	WATER RECLAIM PONDS[c]: R1	WATER RECLAIM PONDS[c]: R2	ZERO AQUIFER THICKNESS/ ZERO RECHARGE AREAS	POTABLE WATER WELL[b] m^3/y	MINE INFLOW[d]	RECLAMATION CAP RECHARGE RATE[c] ($m^3/y.m$): T1	T2	T3	T4
	RECHARGE/SEEPAGE RATE (m/y)																									
Recharge Zone:	1	2,3[e]	4[e]	5[e]	6,7[e]	8,9,10[e]	11[f]	12[f]	13[f]	14[f]	15[f]	16[f]	17[f]	18[f]	19[f]	20[f]	21[f]	22[f]	23[f]	24g			18	19	20	21
(Calibration)	0.216	0.0898[h]	0.0948[h]	0.406[i]	0.144[h]	0.0699[h]	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.0	0.0	0.0	--	--	--	--
1	0.216	--[j]	--	0.406	--[j]	--[j]	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.0	0.216	0.0	99,488	0.0	--	--	--	--
2	0.216	--	0.167	0.406	--	--	0.216	0.216	0.216	0.216	0.216	0.216	2.14	0.216	0.216	0.216	0.216	0.0	0.216	0.0	99,488	30%	--	--	--	--
3	0.216	--	0.320[k]	0.406	--	--	0.054	0.054	1.14	0.737	0.0	0.0	2.14	0.216	0.216	0.216	0.216	0.0	0.216	0.0	99,488	100%	--	--	--	--
4-9	0.216	--	0.320	0.406	--	--	0.054	0.054	1.14	0.737	0.0	0.0	2.14	0.0164	0.216	0.216	0.216	0.0	0.0	0.0	99,488	100%	--	--	--	--
10-11	0.216	--	0.320	0.406	--	--	0.054	0.054	1.14	0.737	0.0	0.0	2.14	0.0164	0.0178	0.216	0.216	0.0	0.0	0.0	99,488	100%	--	--	--	--
12-16	0.216	--	0.320	0.406	--	--	0.054	0.054	1.14	0.737	0.0	0.0	2.14	0.0164	0.0178	0.216	0.216	0.0	0.0	0.0	99,488	100%	32.27	--	--	--
17-18	0.216	--	0.320	0.406	--	--	0.054	0.054	1.14	0.737	0.0	0.0	2.14	0.0164	0.0178	0.0168	0.216	0.0	0.0	0.0	99,488	100%	32.27	--	--	--
19-22	0.216	--	0.320	0.406	--	--	0.054	0.054	1.14	0.737	0.0	0.0	2.14	0.0164	0.0178	0.0168	0.216	0.0	0.0	0.0	99,488	100%	32.27	27.64	--	--
23-24	0.216	--	0.320	0.406	--	--	0.054	0.054	1.14	0.737	0.0	0.0	2.14	0.0164	0.0178	0.0168	0.0151	0.0	0.0	0.0	99,488	100%	32.27	27.64	--	--
25-28	0.216	--	0.320	0.406	--	--	0.054	0.054	1.14	0.737	0.0	0.0	2.14	0.0164	0.0178	0.0168	0.0151	0.0	0.0	0.0	99,488	100%	32.27	27.64	33.17	--
29	0.216	--	0.320	0.406	--	--	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.0164	0.0178	0.0168	0.0151	0.216	0.216	0.0	99,488	50%	32.27	27.64	33.17	--
30	0.216	--	0.320	0.406	--	--	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.0164	0.0178	0.0168	0.0151	0.216	0.216	0.0	0.0	0.0	REFER TO TABLE A.7-18			
31-35	0.216	--	0.320	0.406	--	--	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.0164	0.0178	0.0168	0.0282	0.216	0.216	0.0	0.0	0.0	REFER TO TABLE A.7-18			
36-40	0.216	--	--[j]	0.406	--	--	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.00168	0.0178	0.0168	0.0282	0.216	0.216	0.0	0.0	0.0	REFER TO TABLE A.7-18			
41-50	0.216	--	--[j]	0.406	--	--	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.00168	0.00168	0.0168	0.0151	0.216	0.216	0.0	0.0	0.0	REFER TO TABLE A.7-18			
51-55	0.216	--	--[j]	0.406	--	--	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.00168	0.00168	0.00168	0.0151	0.216	0.216	0.0	0.0	0.0	REFER TO TABLE A.7-18			
56-60	0.216	--	--[j]	0.406	--	--	0.216	0.216	0.216	0.216	0.216	0.216	0.216	0.00168	0.00168	0.00168	0.00168	0.216	0.216	0.0	0.0	0.0	REFER TO TABLE A.7-18			

[a]Refer to Figure A-28 for locations of lakes, mine inflow points, and mine/mill surface facilities.

[b]Refer to Figure A-3a.

[c]Refer to Figure A-3b.

[d]Refer to Tables A-2, A.7-15, and A.7-16 for mine inflow rates.

[e]Refer to Table A.7-4 for elements and lake bottom (lacustrine) thicknesses corresponding to lake recharge zones.

[f]Refer to Table A.7-17 for elements and recharge rates associated with the mine/mill surface facilities.

[g]Refer to Figure A-28 for locations of zero aquifer saturated thickness/zero recharge areas.

[h]Lake recharge rates calculated by GEOFLOW.

[i]The Oak Lake bottom is above the preconstruction potentiometric surface; therefore, the recharge rate was set at maximum for all analyses.

[j]Computer generated recharge rates for Duck, Deep Hole, and Little Sand lakes are not listed because calculation of lake recharge rates during maximum mine inflow analysis showed that these lakes would not approach maximum recharge during the impact assessment.

[k]At Project Year 3, the predicted potentiometric surface was below the lake bottom; therefore, Skunk Lake recharge rate was set at its maximum rate until potentiometric surface rebound.

TABLE A.7-13

SUMMARY OF HYDROLOGIC ACTIONS FOR HORIZONTAL MODEL LOW RECHARGE CASE[a]

PROJECT TIME (year)	RECHARGE/SEEPAGE RATE (m/y): NATURAL RECHARGE	LAKES					DRAINAGE AREA 1[b]	DRAINAGE AREA 2[b]	DRAINAGE BASIN 1[b]	DRAINAGE BASIN 2[b]	PREPRODUCTION ORE STORAGE PAD[b]	OILY RUNOFF AND WASTE ROCK AREA[b]	SANITARY ABSORPTION FIELD[b]	MINE WASTE DISPOSAL FACILITY[c]				WATER RECLAIM PONDS[c]		ZERO AQUIFER THICKNESS/ ZERO RECHARGE AREAS	POTABLE WATER WELL[b]	MINE INFLOW[d]	RECLAMATION CAP RECHARGE RATE[c] ($m^3/y.m$)			
		DUCK	SKUNK	OAK	DEEP HOLE	LITTLE SAND								T1	T2	T3	T4	R1	R2		m^3/y		T1	T2	T3	T4
Recharge Zone:	1	2,3[e]	4[e]	5[e]	6,7[e]	8,9,10[e]	11[f]	12[f]	13[f]	14[f]	15[f]	16[f]	17[f]	18[f]	19[f]	20[f]	21[f]	22[f]	23[f]	24[g]			18	19	20	21
(Calibration)	0.152	0.0898[h]	0.0948[h]	0.406[i]	0.144[h]	0.0699[h]	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.0	0.0	0.0	--	--	--	--
1	0.152	--[j]	--	0.406	--[j]	--[j]	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.0	0.152	0.0	99,488	0.0	--	--	--	--
2	0.152	--	0.167	0.406	--	--	0.152	0.152	0.152	0.152	0.152	0.152	2.08	0.152	0.152	0.152	0.152	0.0	0.152	0.0	99,488	30%	--	--	--	--
3	0.152	--	0.320[k]	0.406	--	--	0.038	0.038	0.803	0.519	0.0	0.0	2.08	0.152	0.152	0.152	0.152	0.0	0.152	0.0	99,488	100%	--	--	--	--
28[l]	0.152	--	0.320	0.406	--	--	0.038	0.038	0.803	0.519	0.0	0.0	2.08	0.0164	0.0178	0.0168	0.0151	0.0	0.0	0.0	99,488	100%	32.27	27.64	33.17	52.48

[a]Refer to Figure A-28 for locations of lakes, mine inflow points, and mine/mill surface facilities.

[b]Refer to Figure A-3a.

[c]Refer to Figure A-3b.

[d]Refer to Tables A-2, A.7-15, and A.7-16 for mine inflow rates.

[e]Refer to Table A.7-4 for elements and lake bottom (lacustrine) thicknesses corresponding to lake recharge zones.

[f]Refer to Table A.7-17 for elements and recharge rates associated with the mine/mill surface facilities.

[g]Refer to Figure A-28 for locations of zero aquifer saturated thickness/zero recharge areas.

[h]Lake recharge rates calculated by GEOFLOW.

[i]The Oak Lake bottom is above the preconstruction potentiometric surface; therefore, the recharge rate was set at maximum for all analyses.

[j]Computer generated recharge rates for Duck, Deep Hole, and Little Sand lakes are not listed because calculation of lake recharge rates during maximum mine inflow analysis showed that these lakes would not approach maximum recharge during the impact assessment.

[k]At Project Year 3, the predicted potentiometric surface was below the lake bottom; therefore, Skunk Lake recharge rate was set at its maximum rate until potentiometric surface rebound.

[l]All hydrologic actions were applied (Year 28) to simulate maximum potentiometric drawdown; ten time steps were performed to achieve steady-state solution.

TABLE A.7-14

SUMMARY OF HYDROLOGIC ACTIONS FOR HORIZONTAL MODEL
HIGH RECHARGE CASE[a]

PROJECT TIME (year)	RECHARGE/SEEPAGE RATE (m/y): NATURAL RECHARGE	LAKES: DUCK	LAKES: SKUNK	LAKES: OAK	LAKES: DEEP HOLE	LAKES: LITTLE SAND	DRAINAGE AREA 1[b]	DRAINAGE AREA 2[b]	DRAINAGE BASIN 1[b]	DRAINAGE BASIN 2[b]	PREPRODUCTION ORE STORAGE PAD[b]	OILY RUNOFF AND WASTE ROCK AREA[b]	SANITARY ABSORPTION FIELD[b]	MINE WASTE DISPOSAL FACILITY[c]: T1	MINE WASTE DISPOSAL FACILITY[c]: T2	MINE WASTE DISPOSAL FACILITY[c]: T3	MINE WASTE DISPOSAL FACILITY[c]: T4	WATER RECLAIM PONDS[c]: R1	WATER RECLAIM PONDS[c]: R2	ZERO AQUIFER THICKNESS/ ZERO RECHARGE AREAS	POTABLE WATER WELL[b] m^3/y	MINE INFLOW[d]	RECLAMATION CAP RECHARGE RATE[c] ($m^3/y.m$): T1	T2	T3	T4
Recharge Zone:	1	2,3[e]	4[e]	5[e]	6,7[e]	8,9,10[e]	11[f]	12[f]	13[f]	14[f]	15[f]	16[f]	17[f]	18[f]	19[f]	20[f]	21[f]	22[f]	23[f]	24[g]			18	19	20	21
(Calibration)	0.279	0.098[h]	0.0948[h]	0.406[i]	0.144[h]	0.0699[h]	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.0	0.0	0.0	--	--	--	--
1	0.279	--[j]	--	0.406	--[j]	--[j]	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.0	0.279	0.0	99,488	0.0	--	--	--	--
2	0.279	--	0.167	0.406	--	--	0.279	0.279	0.279	0.279	0.279	0.279	2.21	0.279	0.279	0.279	0.279	0.0	0.279	0.0	99,488	30%	--	--	--	--
3	0.279	--	0.320[k]	0.406	--	--	0.070	0.070	1.47	0.952	0.0	0.0	2.21	0.279	0.279	0.279	0.279	0.0	0.279	0.0	99,488	100%	--	--	--	--
28[l]	0.279	--	0.320	0.406	--	--	0.070	0.070	1.47	0.952	0.0	0.0	2.21	0.0164	0.0178	0.0168	0.0151	0.0	0.0	0.0	99,488	100%	32.27	27.64	33.17	52.48

[a]Refer to Figure A-28 for locations of lakes, mine inflow points, and mine/mill surface facilities.

[b]Refer to Figure A-3a.

[c]Refer to Figure A-3b.

[d]Refer to Tables A-2, A.7-15, and A.7-16 for mine inflow rates.

[e]Refer to Table A.7-4 for elements and lake bottom (lacustrine) thicknesses corresponding to lake recharge zones.

[f]Refer to Table A.7-17 for elements and recharge rates associated with the mine/mill surface facilities.

[g]Refer to Figure A-28 for locations of zero aquifer saturated thickness/zero recharge areas.

[h]Lake recharge rates calculated by GEOFLOW.

[i]The Oak Lake bottom is above the preconstruction potentiometric surface; therefore, the recharge rate was set at maximum for all analyses.

[j]Computer generated recharage rates for Duck, Deep Hole, and Little Sand lakes are not listed because calculation of lake seepage rates during maximum mine inflow modeling showed that these lakes would not approach maximum seepage during the impact assessment.

[k]At Project Year 3, the predicted potentiometric surface was below the lake bottom; therefore, Skunk Lake recharge rate was set at its maximum rate until potentiometric surface rebound.

[l]All hydrologic actions were applied (Year 28) to simulate maximum potentiometric drawdown; ten time steps were performed to achieve steady-state solution.

TABLE A.7-15

MINE INFLOW RATE DISTRIBUTION - YEAR 2[a]

COMPUTER MODEL MINE INFLOW POINT NO.[b]	COMPUTER MODEL NODE NO.	MINE INFLOW RATE LOW RECHARGE CASE $m^3/s \times 10^{-4}$	MIDDLE RECHARGE CASE $m^3/s \times 10^{-4}$	HIGH RECHARGE CASE $m^3/s \times 10^{-4}$
1	142	0.43	0.48	0.51
2	168	0.57	0.66	0.72
3	196	1.12	1.31	1.44
4	230	1.55	1.79	1.96
5	264	1.02	1.27	1.41
6	301	0.15	0.21	0.29
7	339	0	0	0
8	378	0.23	0.25	0.26
9	418	1.21	1.29	1.38
10	143	0.49	0.72	1.12
11	169	0.47	0.78	1.18
12	197	0.38	0.62	0.94
13	231	0.55	0.82	0.98
14	265	0.85	1.21	1.39
15	302	0.18	0.26	0.39
16	340	0.12	0.13	0.18
17	379	0.47	0.53	0.60
18	419	1.08	1.18	1.29
19	159	0.40	0.63	0.84
20	170	0.18	0.31	0.37
21	198	0.19	0.33	0.45
22	232	0.33	0.62	0.95
23	266	0.71	1.35	1.96
24	303	0.15	0.39	0.53
25	341	0.10	0.13	0.18
26	380	0.47	0.52	0.64
27	420	1.45	1.58	1.73
28	186	2.21	3.76	2.97
29	187	0	0	0
30	199	0	0	0
31	233	0.46	1.04	0.63
32	267	7.44	12.0	12.1
33	304	12.8	18.5	21.7
34	342	0.47	0.52	0.56
34	381	0.82	1.50	2.19
36	421	2.58	2.72	2.91
37	215	12.2	15.4	24.8
38	218	11.5	15.9	20.1
39	219	11.3	16.5	18.3
40	234	17.2	23.2	30.3
41	268	21.3	26.6	42.0
42	305	2.15	2.21	2.19
43	343	1.77	1.82	1.86
44	382	23.6	32.4	40.1
45	422	34.1	46.9	54.8
TOTAL		177	240	301

[a]The mine inflow rate for Year 2 is 30 percent of the steady-state rate (TAP Associates, 1984).

[b]Refer to Figure A-2 for location of mine inflow points and Figure A-3a for mine inflow schedule.

TABLE A.7-16

MINE INFLOW RATE DISTRIBUTION - YEAR 29[a]

COMPUTER MODEL MINE INFLOW POINT NO.[b]	COMPUTER MODEL NODE NO.	MINE INFLOW RATE LOW RECHARGE CASE $m^3/s \times 10^{-4}$	MIDDLE RECHARGE CASE $m^3/s \times 10^{-4}$	HIGH RECHARGE CASE $m^3/s \times 10^{-4}$
1	142	0.72	0.80	0.85
2	168	0.95	1.10	1.21
3	196	1.87	2.18	2.40
4	230	2.58	2.99	3.26
5	264	1.70	2.11	2.35
6	301	0.26	0.35	0.49
7	339	0	0	0
8	378	0.38	0.41	0.44
9	418	2.02	2.15	2.30
10	143	0.82	1.19	1.87
11	169	0.79	1.30	1.96
12	197	0.62	1.03	1.56
13	231	0.92	1.37	1.64
14	265	1.42	2.01	2.32
15	302	0.30	0.43	0.65
16	340	0.20	0.21	0.30
17	379	0.78	0.88	1.00
18	419	1.80	1.97	2.16
19	159	0.67	1.04	1.40
20	170	0.30	0.51	0.62
21	198	0.32	0.55	0.75
22	232	0.56	1.03	1.59
23	266	1.19	2.25	3.26
24	303	0.24	0.65	0.88
25	341	0.16	0.22	0.30
26	380	0.78	0.87	1.06
27	420	2.42	2.63	2.89
28	186	3.68	6.27	4.94
29	187	0	0	0
30	199	0	0	0
31	233	0.76	1.74	1.06
32	267	12.4	20.0	20.2
33	304	21.4	30.9	36.2
34	342	0.78	0.87	0.94
35	381	1.36	2.51	3.66
36	421	4.30	4.53	4.85
37	215	20.3	25.7	41.3
38	218	19.2	26.6	33.5
39	219	18.9	27.4	30.4
40	234	28.6	38.7	50.5
41	268	35.5	44.4	70.0
42	305	3.58	3.69	3.64
43	343	2.95	3.04	3.10
44	382	39.4	54.0	67.0
45	422	57.0	78.1	91.5
TOTAL		295	401	502

[a]The mine inflow rate for Year 29 is 50 percent of the steady-state rate (TAP Associates, 1984).
[b]Refer to Figure A-2 for location of mine inflow points and Figure A-3a for mine inflow schedule.

TABLE A.7-17

RECHARGE/SEEPAGE RATES FOR MODELING OF MINE/MILL SURFACE FACILITIES[a]

LOCATION	RECHARGE ZONE	ELEMENTS	RECHARGE/SEEPAGE RATE (m/year) LOW RECHARGE CASE	MIDDLE RECHARGE CASE	HIGH RECHARGE CASE
Mill Site Drainage Area No. 1[b]	11	335-337 362-364	0.038	0.054	0.070
Mill Site Drainage Area No. 2[b]	12	269-271 311, 313	0.038	0.054	0.070
Drainage Basin No. 1	13	392	0.803	1.14	1.47
Drainage Basin No. 2	14	230	0.519	0.737	0.952
Preproduction Ore Storage Pad[c]	15	228	0	0	0
Oily Runoff Collection and Waste Rock Storage Area[c]	16	312	0	0	0
Sanitary Absorption Field	17	433	2.08	2.14	2.21
Tailings Pond No. T1[d]	18	656 702-704 753, 754 796, 797 840, 841	1.64×10^{-2}	1.64×10^{-2}	1.64×10^{-2}
Tailings Pond No. T2[d]	19	457-460 497-500 529-532 571, 572 612, 613 654, 655	1.78×10^{-2}	1.78×10^{-2}	1.78×10^{-2}
Tailings Pond No. T3[d]	20	752 791-795 833-839 879, 880	1.68×10^{-2}	1.68×10^{-2}	1.68×10^{-2}
Tailings Pond No. T4[d]	21	569, 570 610, 611 651-653 698-701 748-751	1.51×10^{-2} [f] 2.82×10^{-2}	1.51×10^{-2} [f] 2.82×10^{-2}	1.51×10^{-2} [f] 2.82×10^{-2}
Reclaim Pond No. R1[e]	22	464, 465 504, 505 536, 537	0	0	0
Reclaim Pond No. R2[e]	23	462, 463 502, 503 534, 535 574, 575	0	0	0

[a]Source: Exxon (1984).

[b]75% of surface runoff redirected to drainage basins.

[c]All precipitation collected for water treatment.

[d]Rates adjusted for model grid areas.

[e]Water reclaim ponds will be double lined with synthetic and bentonite modified soil liners; therefore, no seepage is expected.

[f]Infiltration rate following underdrain pump shutdown.

TABLE A.7-18A

RECLAMATION CAP RECHARGE RATES AT MWDF PERIMETER

TAILINGS POND NO.	MWDF PERIMETER NODE NUMBERS	RECLAMATION CAP RECHARGE RATE DURING MWDF OPERATION[a] (m^3/y.m)	RECLAMATION CAP RECHARGE RATE AFTER MWDF OPERATION[b] (m^3/y.m)
T1	707,708	32.27	39.80
	708,709	32.27	39.80
	709,710	32.27	43.40
	710,712	32.27	43.40
	712,765	32.27	43.40
	765,767	32.27	43.40
	767,812	32.27	43.40
T2	707,757	27.64	72.04
	757,756	27.64	72.04
	756,755	27.64	72.04
	755,753	27.64	72.04
	753,751	27.64	24.71
	751,749	27.64	24.71
	749,796	27.64	24.71
	796,844	27.64	24.71
	844,894	27.64	24.71
	894,948	27.64	24.71
	948,950	27.64	24.71
	950,912	27.64	19.01
	912,909	27.64	19.01
T3	812,863	33.17	34.53
	863,914	33.17	34.53
	914,969	33.17	34.53
	969,1023	33.17	34.53
	1023,1063	33.17	34.53
	1063,1062	33.17	29.93
	1062,1061	33.17	29.93
	1061,1022	33.17	29.93
	1022,1009	33.17	29.93
	1009,958	33.17	29.93
T4	909,907	52.48	19.01
	907,906	52.48	19.01
	906,908	52.48	19.01
	908,910	52.48	19.01
	910,957	52.48	29.93
	957,958	52.48	29.93

[a] As each tailings pond is closed during the operation phase, total annual recharge volume (area of tailings pond multiplied by the annual infiltration rate of 118.7 mm/y) is distributed along the MWDF perimeter of the corresponding tailings pond.

[b] After final closure of the MWDF, the total annual watershed recharge volume (area of each reclamation cap watershed multiplied by the annual infiltration rate of 118.7 mm/y) is distributed along the perimeter of the corresponding reclamation cap watershed area (Ayres Associates, 1984).

TABLE A.7-18B

PARAMETERS FOR COMPUTATION OF RECLAMATION CAP RECHARGE RATES AT MWDF PERIMETER DURING MWDF OPERATION

TAILING POND NUMBER	AREA OF GEOFLOW ELEMENTS (m^2)	RECHARGE RATE[a] (in/yr)	RECHARGE RATE[a] (m/yr)	YEARLY RECHARGE (m^3/yr)	PERIMETER LENGTH (m)	RECHARGE PER UNIT LENGTH OF PERIMETER (m^3/yr/m)
1	349,800	4.67	0.119	41,626	1,290	32.27
2	427,420	4.67	0.119	50,863	1,840	27.64
3	415,320	4.67	0.199	49,423	1,490	33.17
4	458,670	4.67	0.119	54,581	,1040	52.48

[a]Recharge is that due to excess surface water runoff from the MWDF. This is added to recharge from outside the MWDF.

TABLE A.7-18C

PARAMETERS FOR COMPUTATION OF RECLAMATION CAP RECHARGE RATES AT MWDF PERIMETER AFTER MWDF OPERATION

DRAINAGE BASIN NUMBER	AREA OF WATERSHED (m^2)	RECHARGE RATE[a] (in/yr)	(m/yr)	YEARLY RECHARGE (m^3/yr)	PERIMETER LENGTH (m)	RECHARGE PER UNIT LENGTH OF PERIMETER (m^3/yr/m)
1	122,980	4.67	0.119	14,635	770	19.01
2	218,040	4.67	0.119	25,947	1,050	24.71
3	332,960	4.67	0.119	39,623	550	72.04
4	150,500	4.67	0.119	17,910	450	39.80
5	311,790	4.67	0.119	37,103	855	43.40
6	174,090	4.67	0.119	20,717	600	34.53
7	355,850	4.67	0.119	42,346	1,415	29.93

[a] Recharge is that due to excess surface water runoff from the MWDF. This is added to recharge from outside the MWDF.

TABLE A.7-19

INPUT PARAMETERS FOR ONE-DIMENSIONAL VERTICAL MODEL

MATERIAL	SEEPAGE RATE CATEGORY	MWDF SEEPAGE RATE[a] m/s	MWDF SEEPAGE RATE[a] ft/day	PERCENT SATURATION (%)	MOISTURE[b] CONTENT (%)	PORE VELOCITY[c] m/s	PORE VELOCITY[c] ft/day	DISPERSION COEFFICIENT m^2/s	DISPERSION COEFFICIENT ft^2/day
Glacial Till	Operation Phase	5.49×10^{-10}	1.56×10^{-4}	40.5	12.4	4.42×10^{-9}	1.25×10^{-3}	7.8×10^{-10}	7.3×10^{-4}
	Maximum	1.02×10^{-9}	2.89×10^{-4}	43.5	13.4	7.64×10^{-9}	2.17×10^{-3}	8.6×10^{-10}	8.0×10^{-4}
	Steady State	5.39×10^{-11}	1.53×10^{-5}	30.0	9.2	5.87×10^{-10}	1.66×10^{-4}	7.0×10^{-10}	6.5×10^{-4}
Berea Sandstone	Operation Phase	5.49×10^{-10}	1.56×10^{-4}	32.5	6.5	8.45×10^{-9}	2.40×10^{-3}	8.8×10^{-10}	8.2×10^{-4}
	Maximum	1.02×10^{-9}	2.89×10^{-4}	33.5	6.7	1.52×10^{-8}	4.31×10^{-3}	1.0×10^{-9}	9.3×10^{-4}
	Steady State	5.39×10^{-11}	1.53×10^{-5}	30.0	6.0	8.98×10^{-10}	2.55×10^{-4}	7.1×10^{-10}	6.6×10^{-4}

[a]Source: Exxon (1984).

[b]Degree of saturation times porosity.

[c]Seepage velocity divided by moisture content.

TABLE A.7-20

SUMMARY OF INPUT PARAMETERS FOR VERTICAL MODEL CALIBRATION

PARAMETER	ZONE	INPUT VALUES AND UNITS					
		LOW RECHARGE CASE		MIDDLE RECHARGE CASE		HIGH RECHARGE CASE	
		m/s	ft/day	m/s	ft/day	m/s	ft/day
Horizontal Permeability	Coarse Drift	8.9×10^{-5}	25.2	1.2×10^{-4}	34.5	1.6×10^{-4}	45.4
	Fine Drift	4.4×10^{-5}	12.6	6.1×10^{-5}	17.3	7.8×10^{-5}	22.0
	Till	4×10^{-6}	1.2	6×10^{-6}	1.7	8×10^{-6}	2.2
Vertical Permeability	Coarse Drift	1.8×10^{-6}	5.0×10^{-1}	2.4×10^{-6}	6.9×10^{-1}	3.1×10^{-6}	8.8×10^{-1}
	Fine Drift	8.9×10^{-7}	2.5×10^{-1}	1.2×10^{-6}	3.4×10^{-1}	1.6×10^{-6}	4.4×10^{-1}
	Till	4×10^{-6}	1.2	6×10^{-6}	1.7	8×10^{-6}	2.2
Lake Seepage Rate[a]				mm/y	in/y		
	Deep Hole Lake			144	5.65		
Precipitation Recharge Rate		mm/y	in/y	mm/y	in/y	mm/y	in/y
	Entire Section	152	6	216	8.5	279	11
Storage Coefficient[a]				Dimensionless			
	Coarse Drift			0.050			
	Fine Drift			0.050			
	Till			0.054			

[a]Input values are the same for the three recharge rates.

TABLE A.7-21

PARAMETERS FOR SENSITIVITY ANALYSIS
STEADY-STATE VERTICAL TWO-DIMENSIONAL MODEL

VARIABLE PARAMETER	K_V/K_H[a] TILL	DRIFT	a_L[b] m	ft	a_L/a_T[c]	RECHARGE	MWDF SEEPAGE mm/y	in/y	ATTACHMENT A.4 FIGURE NUMBER
Permeability Ratio	1/1	1/10	20	66	30	Middle	1.68	0.066	A.4-2
	1/1	1/20							
	1/1	1/50							
	1/3	1/50							
Longitudinal Dispersivity	1/1	1/50	5	16	30	Middle	1.68	0.066	A.4-3
			20	66					
			30	98					
			60	197					
Dispersivity Ratio	1/1	1/50	60	197	5	Middle	1.68	0.066	A.4-4
					20				
					50				
					1000				
MWDF Seepage Rate	1/1	1/50	60	197	50	Middle	1.68	0.066	A.4-5
							16.8	0.66	
Recharge Rate	1/1	1/50	60	197	50	Low	1.68	0.066	A.4-6
						Middle			
						High			

[a] K_V/K_H is defined as the ratio of vertical to horizontal permeability.

[b] a_L is defined as longitudinal dispersivity.

[c] a_L/a_T is defined as the ratio of longitudinal to transverse dispersivity.

TABLE A.7-22

NODAL MASS FLUX FOR INPUT TO TRANSIENT VERTICAL MODEL

TIME (yr)	NORMALIZED CONCENTRATION c/co		CONCENTRATION GRADIENT - (d (c/co)/dx) (1/meter)		TOTAL NODAL FLUX[1] (m^3/day x 10^{-4})	
	POND T4	POND T2	POND T4	POND T2	POND T4	POND T2
0-50	0.0	0.0	0.008	0.006	0.060	0.044
50-100	0.110	0.090	0.103	0.075	0.968	0.724
100-150	0.305	0.240	0.158	0.127	1.74	1.39
150-200	0.480	0.390	0.150	0.137	2.01	1.74
200-250	0.600	0.520	0.128	0.126	2.07	1.90
250-300	0.690	0.625	0.106	0.110	2.07	1.98
300-350	0.765	0.700	0.084	0.093	2.05	2.00
350-400	0.820	0.760	0.068	0.076	2.03	1.98
400-450	0.855	0.815	0.054	0.063	1.99	1.99
450-500	0.880	0.855	0.044	0.051	1.97	1.97
500-550	0.900	0.880	0.036	0.041	1.94	1.95
550-600	0.920	0.920	0.028	0.033	1.92	1.95
600-650	0.940	0.940	0.023	0.026	1.92	1.94
650-700	0.960	0.960	0.018	0.019	1.92	1.93
700-750	0.980	0.980	0.013	0.012	1.93	1.92
750 on	1.000	1.000	0.008	0.005	1.86	1.86

[1] Total Nodal Flux = $A \left(V \frac{C}{Co} - ND \frac{d(C/Co)}{dx}\right)$

V = Darcy Velocity = 0.0017 m/yr = 4.66×10^{-6} m/day

C/Co = normalized concentration

d(C/Co)/dx = concentration gradient

N = porosity = 0.307

D = Diffusion coefficient = 7×10^{-10} m/sec = 6.048×10^{-5} m/day

A = Area assigned to each node = 40 M^2. (This value applies to each node. Each end node is assigned one-half the value).

For example, for Pond T4 at 50-100 years:

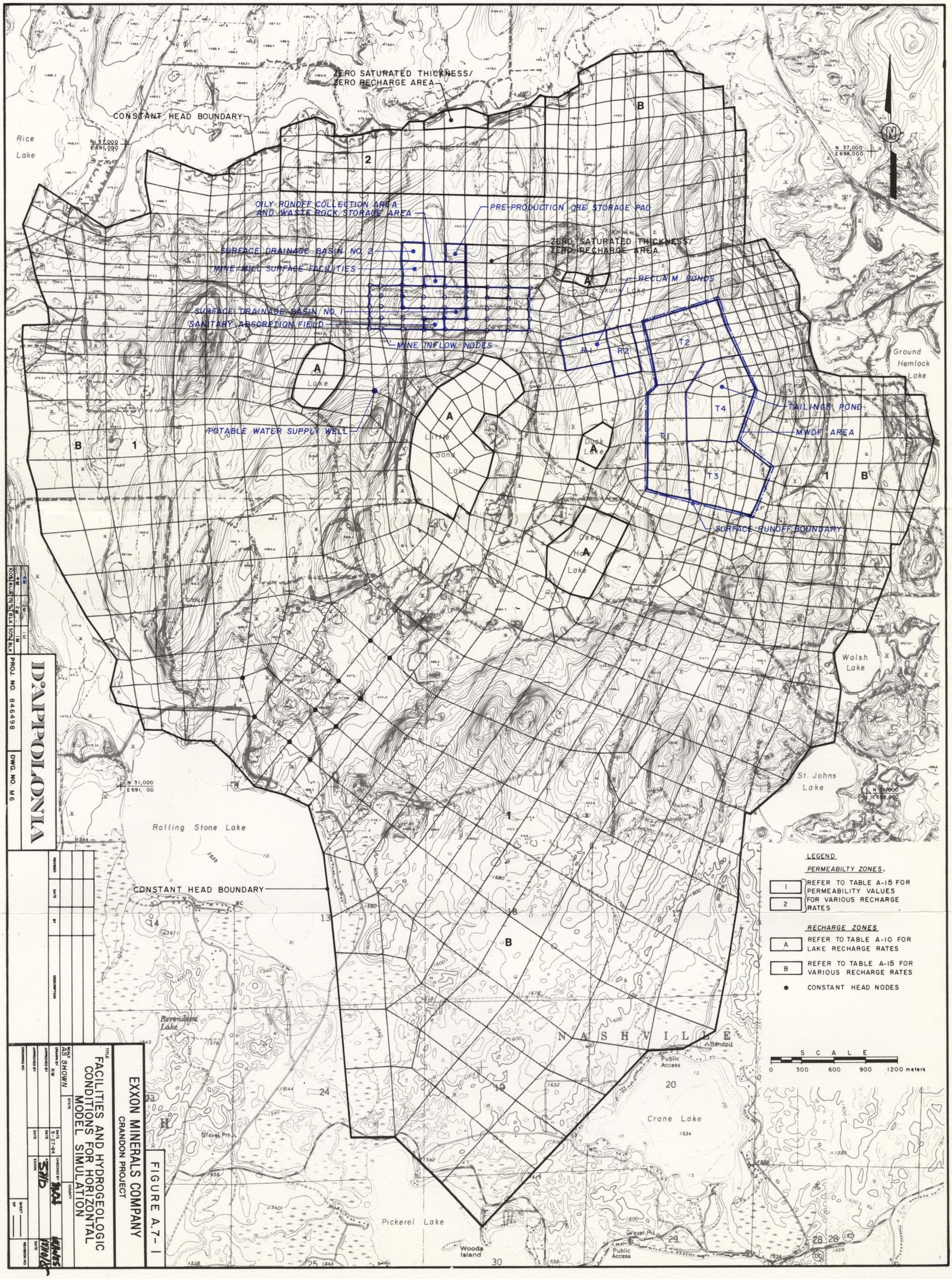
$$C/Co = 0.110, \quad \frac{d(C/Co)}{dx} = -0.103$$

$$\text{Total Nodal Flux} = 40 \quad [4.66 \times 10^{-6} (0.110) - 0.307 (6.048 \times 10^{-5}) (-0.103)]$$

$$\text{Total Nodal Flux} = 40 \quad [0.5126 \times 10^{-6} + 1.912 \times 10^{-6}]$$

$$\text{Total Nodal Flux} = 40 \quad [2.42 \times 10^{-6}] = 0.968 \times 10^{-4} \ m^3/day$$

FIGURES



ZERO SATURATED THICKNESS/
ZERO RECHARGE AREA
CONSTANT HEAD BOUNDARY
Rice Lake
N 37,000
E 691,000
N 37,000
E 698,000
OILY RUNOFF COLLECTION AREA
AND WASTE ROCK STORAGE AREA
PRE-PRODUCTION ORE STORAGE PAD
SURFACE DRAINAGE BASIN NO. 2
MINE/MILL SURFACE FACILITIES
ZERO SATURATED THICKNESS/
ZERO RECHARGE AREA
RECLAIM PONDS
Skunk Lake
SURFACE DRAINAGE BASIN NO. 1
SANITARY ABSORPTION FIELD
MINE INFLOW NODES
R1
R2
T1
T2
T3
T4
Ground Hemlock Lake
TAILINGS POND
MWDF AREA
POTABLE WATER SUPPLY WELL
Little Sand Lake
Duck Lake
Deep Hole Lake
SURFACE RUNOFF BOUNDARY
Walsh Lake
St. Johns Lake
N 31,000
E 691,00
N 31,000
E 698,000
Rolling Stone Lake
CONSTANT HEAD BOUNDARY
LEGEND
PERMEABILTY ZONES.
REFER TO TABLE A-15 FOR PERMEABILITY VALUES FOR VARIOUS RECHARGE RATES
RECHARGE ZONES
REFER TO TABLE A-10 FOR LAKE RECHARGE RATES
REFER TO TABLE A-15 FOR VARIOUS RECHARGE RATES
CONSTANT HEAD NODES
NASHVILLE
SCALE
0 300 600 900 1200 meters
Crane Lake
Pickerel Lake
Woods Island
Public Access
Gravel Pit
D'APPOLONIA
PROJ. NO. 846498
DWG. NO. M6
FIGURE A.7-1
EXXON MINERALS COMPANY
CRANDON PROJECT
FACILITIES AND HYDROGEOLOGIC CONDITIONS FOR HORIZONTAL MODEL SIMULATION

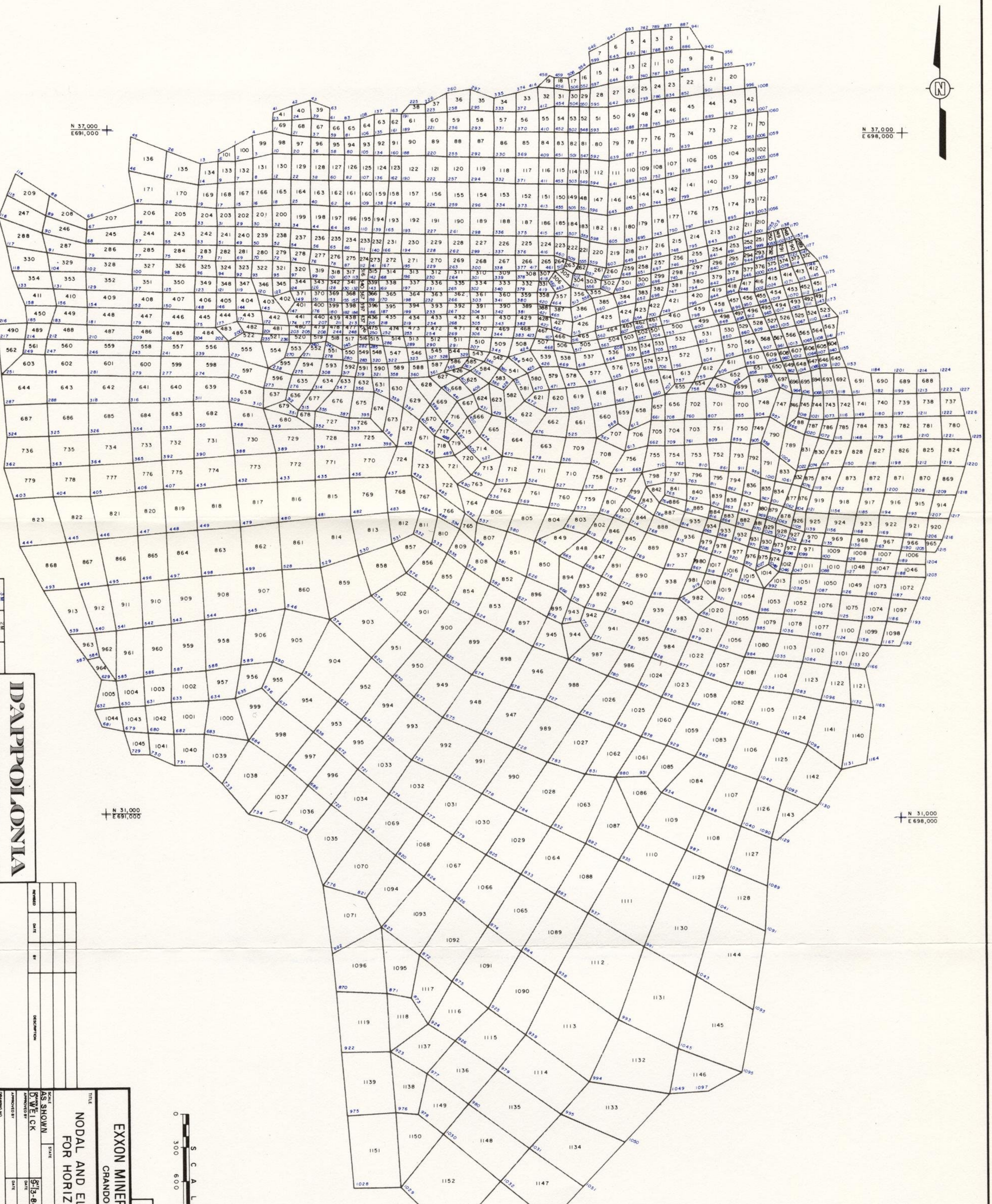


FIGURE A.7-2

EXXON MINERALS COMPANY

CRANDON PROJECT

NODAL AND ELEMENT SYSTEM FOR HORIZONTAL MODEL

SCALE: AS SHOWN

DRAWN BY: D. WEICK

DATE: 8-13-84

D'APPOLONIA

PROJ. NO. 846498

DWG. NO. M1

ATTACHMENT A.8

EVALUATION OF MODEL ACCURACY

ATTACHMENT A.8

TABLE OF CONTENTS

ATTACHMENT A.8

LIST OF TABLES

ATTACHMENT A.8

EVALUATION OF MODEL ACCURACY

A.8.1 INTRODUCTION

The numerical accuracy of the impact modeling has been verified by the use of the Mass Balance Analysis described in Section A.8.2 and evaluation of the Peclet and Courant numbers described in Section A.8.3.

A.8.2 MASS BALANCE ANALYSIS

Mass balance analyses were performed for both flow and mass transport computer simulations (runs). The GEOFLOW program prints the mass balance analysis for each element and total mass in and out for the entire grid system. The computer listings contain the necessary program mass balance outputs. Several key computer runs have been selected to show the degree of accuracy of the mass balance analysis. These runs include both transient and steady-state simulations for the Middle Recharge case as follows:

1. Calibrated horizontal model
2. Horizontal hydrologic impact assessment at Year 3
3. Horizontal hydrologic impact assessment at Year 28
4. Horizontal hydrologic impact assessment at Year 60
5. Horizontal dispersion run
6. Two-dimensional vertical calibration
7. Two-dimensional vertical dispersion at Year 800
8. Two-dimensional vertical dispersion at steady-state conditions

Summaries of the mass balance for each run are shown in Tables A.8-1 through A.8-4. Each of Tables A.8-1 through A.8-4 shows the difference between storage rate and net flow rate into the model. This difference includes model created water or mass. For the flow model, the model created water may be defined as the water added to the model by resetting the saturated thickness and corresponding potentiometric head to represent a minimum thickness where dewatering has lowered the head below an input value. Since the solution before resetting the head is the solution of the governing equation of mass conservation, resetting heads to other values results in an imbalance in the corresponding mass flow rates and storage rate. For the contaminant transport model, the model created mass is usually caused by a similar alteration of the solution. In this case, the solution often includes oscillating errors in the spacial distribution of concentration. It is typical to observe small meaningless negative concentrations. The GEOFLOW program resets these negative concentrations to zero and hence a model created mass is introduced. The significance of model created water or mass is expressed as a percentage of total flow into the model which is identified as percent error in each of Tables A.8-1 through A-8.4. This error also includes truncation and roundoff errors in the process of forming and solving the governing equations. As can be seen from these tables, the percent error in the flow and mass transport simulations is less than two percent, indicating good model accuracy and numerical performance.

A.8.3 EVALUATION OF PECLET AND COURANT NUMBERS

For flow and mass transport solutions, numerical errors have been minimized by the selection of appropriate grid size and time step. For steady-state dispersion problems, the numerical solution is characterized by the nondimensional Peclet number; for transient dispersion, the numerical solution is characterized by the nondimensional Peclet and Courant numbers.

The Peclet number represents the relative ratio of convective terms to dispersive terms. The Peclet number, Pe, is defined as

$$Pe = \frac{VL}{D}$$

where

V = pore velocity

L = grid spacing

D = dispersion coefficient

For an irregular finite element grid consisting of arbitrary quadrilaterals, the Peclet number has been evaluated for each side of each element by equating the grid spacing to the side length and pore velocity equal to the velocity component in the direction of the element side. The appropriate dispersion coefficient for the irregular grid is the direct component of the dispersion tensor in the direction of the element side. This definition of the Peclet number for the two-dimensional irregular grid then reduces to the usual definition for a one-dimensional regularly spaced grid.

For high values of Peclet numbers, the solution is dominated by the convective terms and numerical errors associated with approximation of the convective term can result in a meaningless oscillation imposed on the correct analytical solution. This oscillation is generally insignificant for values of Peclet numbers less than 1.0 with increasing deterioration in the solution with increasing Peclet number until the solution may be dominated by oscillatory errors for a Peclet number equal to 10.0. In general, the numerical oscillation which occurs for high Peclet numbers is easily observed by plotting the spatial variation of concentration. The degree to which the problem exists is problem dependent; however, in general, a practical limit of the Peclet number is in the range of 2.0 to 5.0. Higher values of Peclet number may be justified by observing the spatial variations of the concentrations. High values for the Peclet number are of no consequence when they occur for elements outside the contamination plume. In general, higher values of Peclet numbers are critical only near the contaminant source. Ranges of Peclet numbers for key computer runs are given in Table A-8.5. The high values in the range reported in Table A-8.5 occur for large elements outside the contaminant plume and do not adversely affect the solution.

For the vertical simulation with longitudinal dispersivity equal to 60 m, no deterioration was observed in the solution. For the longitudinal dispersivity value of 5.0 meters, some minor oscillation was observed in the solution near the perimeter of the MWDF (area of reclamation cap recharge). The horizontal modeling oscillations were not severe for a longitudinal dispersivity of 60 meters. The quality of the horizontal dispersion solution was observed to deteriorate for dispersivity less than 20 meters.

As mentioned above, the accuracy of the transient dispersion simulations is also influenced by the Courant number. The Courant number determines the ability of the finite element model to propagate a concentration front accurately. High values of the Courant number may result in "undershoot" and "overshoot" near a concentration front along with increased numerical dispersion. For the transient two-dimensional vertical dispersion model, a backward difference scheme was used for the time integration. This reduces or minimizes the problems of oscillation near the concentration front. Effects of numerical dispersion are generally less for small values of the Courant number. The Courant number, Co, is defined as:

$$Co = \frac{V \Delta t}{L}$$

where V and L are defined above and Δt is the time step. For the transient 2-D vertical dispersion simulation, a time step equal to 2.0 years was used for the first 800 years. This resulted in Courant numbers ranging from approximately 0.1 beneath the MWDF to 17.0 at Hemlock Creek. The high value at a single element near Hemlock Creek is of no consequence because a sharp concentration front is not present at this location. No overshoot or undershoot was observed in the solution at the concentration front. For years 800-8800, the time step was increased to 20.0 years resulting in a Courant number of approximately 1.0 beneath the MWDF, and again the solution was stable.

TABLES

TABLE A.8-1

SUMMARY OF MASS BALANCE FOR HORIZONTAL MODEL SIMULATION
MIDDLE RECHARGE CASE

RUN DESCRIPTION[a]	FIGURE NO.	MASS INTO MODEL (m^3/y)			MASS OUT OF MODEL (m^3/y)						
		PRECIPITATION RECHARGE	LAKE RECHARGE	TOTAL IN	BOUNDARY[b]	MINE INFLOW	TOTAL OUT	TOTAL IN-TOTAL OUT (m^3/y)	STORAGE (m^3/y)	DIFFERENCE	PERCENT ERROR[c]
Calibrated Horizontal Model	A-23	$1.192x10^7$	$0.014x17^7$	$1.206x10^7$	$1.206x10^7$	0	$1.206x10^7$	0	0	0	0
Horizontal Simulation at Year 3	A-29	$1.192x10^7$	$0.025x10^7$	$1.217x10^7$	$1.124x10^7$	$0.252x10^7$	$1.376x10^7$	$-0.156x10^7$	$-0.156x10^7$	0	0
Horizontal Simulation at Year 28	A-31	$1.157x10^7$	$0.031x10^7$	$1.188x10^7$	$0.936x10^7$	$0.252x10^7$	$1.188x10^7$	0	570	570	0.005
Horizontal Simulation at Year 60	A-33	$1.157x10^7$	$0.014x10^7$	$1.171x10^7$	$1.170x10^7$	0	$1.170x10^7$	$1x10^4$	-90	$1x10^4$	0.085

[a]Refer to Attachment A.7 for discussion of input data.

[b]Boundary flow includes southern wetlands area.

[c]Percent error = (Difference/Total In) x 100%.

TABLE A.8-2

SUMMARY OF MASS BALANCE
FOR HORIZONTAL DISPERSION SIMULATION

			MASS FLOW RATE[a]
Mass In:			
	Total Mass In		2,809
Mass Out:			
	Hemlock Creek - Node:	1057[b]	0.02
		1056	0.84
		1055	22.11
		1103	14.76
		1138	11.28
		1170	12.54
		1157	49.51
		1178	23.68
		1177	68.36
		1176	100.8
		1175	128.2
		1174	131.9
		1173	362.7
		1172	331.7
		1171	549.1
		1155	454.3
		1153	218.4
		1184	23.95
		1201	1.05
		1214	0.12
		TOTAL TO HEMLOCK CREEK	2,505.3
	Southern Wetlands Area - Node:	620	64.2
		670	241.4
		622	-8.36[c]
		671	36.17
		638	-2.66
		672	3.45
		685	0.31
		686	0.50
		684	0.25
		635	0.78
		734	0.00
		735	0.78
		TOTAL TO SOUTHERN WETLANDS AREA	336.1

TOTAL MASS OUT = 2,505.3 + 336.1 = 2,841.4
TOTAL MASS IN - TOTAL MASS OUT = 32.4
PERCENT ERROR[d] = 1.2%

---

[a]Units are mass per year. Normalized mass input is a concentration equal to 1 mass unit per cubic meter.

[b]The mass flow rate for boundary nodes north of Node 1057 is equal to zero. Refer to Attachment A.7 for node locations.

[c]Weak numerical oscillations resulted in a small mass flux into the system at Nodes 622 and 638. These fluxes are reported as negative rates in the summary of mass out at the wetlands.

[d]Percent error = $\frac{\text{(Total Mass In - Total Mass Out)}}{\text{Total Mass In}}$ X 100%.

TABLE A.8-3

SUMMARY OF MASS BALANCE FOR
TWO-DIMENSIONAL VERTICAL FLOW CALIBRATION[a]
MIDDLE RECHARGE CASE

	MASS FLOW RATE[b]
Mass In	
Recharge	3.463
Deep Hole Lake Recharge	0.217
	3.680
Mass Out	
Southwest Boundary of Model	1.963
Northeast Boundary of Model	0.242
Hemlock Creek	1.475
	3.680
Difference	0.000
Percent Error[c]	0.000

[a]Refer to Figure A-27.

[b]Units are cubic meter per day.

[c]Percent Error = (Difference/Total In) x 100%.

TABLE A.8-4

SUMMARY OF MASS BALANCE
FOR TWO-DIMENSIONAL VERTICAL DISPERSION MODELS
MIDDLE RECHARGE CASE

RUN DESCRIPTION	FIGURE NO.	MASS INTO MODEL[a]	MASS OUT OF MODEL HEMLOCK CREEK	MASS OUT OF SOUTHWEST BOUNDARY OF MODEL	TOTAL OUT	TOTAL IN-TOTAL OUT	STORAGE	DIFFERENCE	PERCENT ERROR[b]
Vertical Dispersion at Steady State	A.4-6	6.802×10^{-3}	6.382×10^{-3}	0.426×10^{-3}	6.807×10^{-3}	-5×10^{-6}	0.0	-5×10^{-6}	0.074
Vertical Dispersion at 800 Years	A-40	6.882×10^{-3}	0.612×10^{-3}	0.325×10^{-3}	0.937×10^{-3}	5.945×10^{-3}	5.953×10^{-3}	0.008×10^{-3}	0.135

[a]Units are mass units per day. Normalized mass input is a concentration equal to 1.0 mass units per cubic meter.

[b]Percent error = (Difference/Total In) x 100%.

TABLE A.8-5

PECLET NUMBERS FOR KEY COMPUTER RUNS

RUN DESCRIPTION	RANGE OF PECLET NUMBER FOR ENTIRE MODEL	TYPICAL PECLET NUMBER AT MWDF
Two-Dimensional Vertical Dispersion $a_L = 60$ m	0.7 - 4.2	0.7
Two-Dimensional Vertical Dispersion $a_L = 5$ m	7.0 - 45.0	8.0
Two-Dimensional Horizontal Dispersion $a_L = 60$ m	1.6 - 14	3.0

ATTACHMENT A.9

GEOFLOW MODEL VERIFICATION USING PUMPING TEST DATA

ATTACHMENT A.9

TABLE OF CONTENTS

ATTACHMENT A.9

LIST OF TABLES

LIST OF FIGURES

ATTACHMENT A.9

GEOFLOW MODEL VERIFICATION USING PUMPING TEST DATA

A.9.1 PURPOSE

To further evaluate the validity of the input parameters used in the hydrologic impact assessment, the calibrated horizontal flow model was used to simulate results of pumping test data from Well TW-41 (Golder Associates, 1981). In order to more fully verify the site recharge rate the simulation was performed for low and middle recharge rates.

A.9.2 PUMPING TEST

A pumping test of Well TW-41 was conducted by Golder Associates (1981) during the period June 6, 1980 to September 10, 1980. The well (Wisconsin Plane State Coordinates of N 34787 m and E 696267 m) was pumped at an average rate of 0.090 m^3/s (1,420 gpm) for 24 days, starting on June 27, 1980.

In the analysis of the pumping test data, the stratified drift was assumed to have a uniform thickness of 20 m (66 feet) and infinite areal extent. In addition, the permeability of the stratified drift was assumed to be homogeneous and isotropic, and Well TW-41 was assumed to fully penetrate the aquifer. The aquifer includes, in descending order, a 25-m-thick layer of till, a 20-m-thick stratified drift formation, and a 20-m-thick layer of till. The mean value of the horizontal permeability in the stratified drift was determined to be 1.3×10^{-4} m/s (37 feet/day) using Boulton's method and the assumptions discussed above.

The potentiometric drawdown distribution around Well TW-41, measured between July 17 and July 21, 1980, was presented by Golder Associates (1981). In addition, Golder Associates (1981) extrapolated the measured potentiometric drawdown in the stratified drift to other locations in the study area by assuming homogeneous and isotropic conditions.

A.9.3 SIMULATION OF THE PUMPING TEST USING GEOFLOW

The calibrated horizontal flow model was tested for compatibility with the pumping test as follows. The finite element grid system for this model is shown in Figure A.7-2 of Attachment A.7. Node 805 in the grid system represents Well TW-41 and its location was accordingly adjusted to (E 696267 m, N 34787 m) from (E 696271 m, N 34727 m) to agree with the coordinates used by Golder Associates (1981). The pumping test model consists of the similar hydrologic input data used in the calibrated models for the Middle and Low Recharge rates. With a pumping rate of 0.090 m^3/s (1,420 gpm) assigned to Node 805, the pumping test was simulated for 24 days, and the computed results at the 24th day were compared with pumping test results to determine the accuracy of the model. The simulation was performed using low and middle recharge rates as defined in Table A-15.

A comparison of the calculated potentiometric heads at selected nodes with the pumping test measured potentiometric drawdown distribution is shown in Figure A.9-1. A tabular listing of the computed potentiometric drawdowns and their associated nodal points are given in Table A.9-1 and Table A.9-2 for middle and low recharge rates, respectively. The majority of these nodes are located either south or east of Node 574 and are consistent with the locations of the observation wells used for the Well TW-41 pumping test.

For the middle recharge rate, agreement between GEOFLOW calculated results and measured data occurs at distances greater than 152 m (500 feet) from the pumped well. Within 152 m (500 feet) of the pumped well, the simulated potentiometric heads are less than those measured. For low recharge rates the difference between simulated and measured heads is slightly greater. This difference occurs primarily because the amount of flow released from the saturated till during pumping was not incorporated in the model. In addition, the vertical recharge decreases with distance from the pumping well due to reductions in the vertical hydraulic gradient between the till and drift formation. This explanation is also supported by the measured data shown in Figure A.9-1 which indicates a small difference in potentiometric drawdown between the till and the stratified drift layer beyond a distance of 152 m (500 feet) from the pumped well. Furthermore, the results of this analyses show that the middle recharge rate is more representative of the site.

In Figures A.9-2 and A.9-3, the model-calculated potentiometric drawdown contours are compared with Golder Associates' estimated drawdown pattern for middle and low recharge values. Both contour plots show good agreement of simulated and observed results. Because the horizontal model has nonuniform thickness, the simulated drawdown contours are not circular as would be for the ideal conditions assumed in Golder Associates' estimation approach. The model-calculated potentiometric drawdown contour of 0.1 foot does not extend to Hemlock Creek because the thickness of stratified drift decreases in that area. The agreement of the 5- and 10-foot drawdown contours for the simulated and Golder Associates' estimated case is very good.

These results further substantiate the reliability of the horizontal flow model used in the hydrologic impact assessment of the site area. The close agreement between model-calculated and measured potentiometric drawdowns for the Well TW-41 pumping test adds confidence to the data base and predicted impacts.

ATTACHMENT A.9

REFERENCE

Golder Associates, 1981, Pump Test and Analyses, Project Report No. 4, Exxon Minerals Company, Crandon Project, Golder Associates, Atlanta, Georgia.

TABLES

TABLE A.9-1

COMPUTED DRAWDOWNS AT SELECTED NODES
MIDDLE RECHARGE RATE

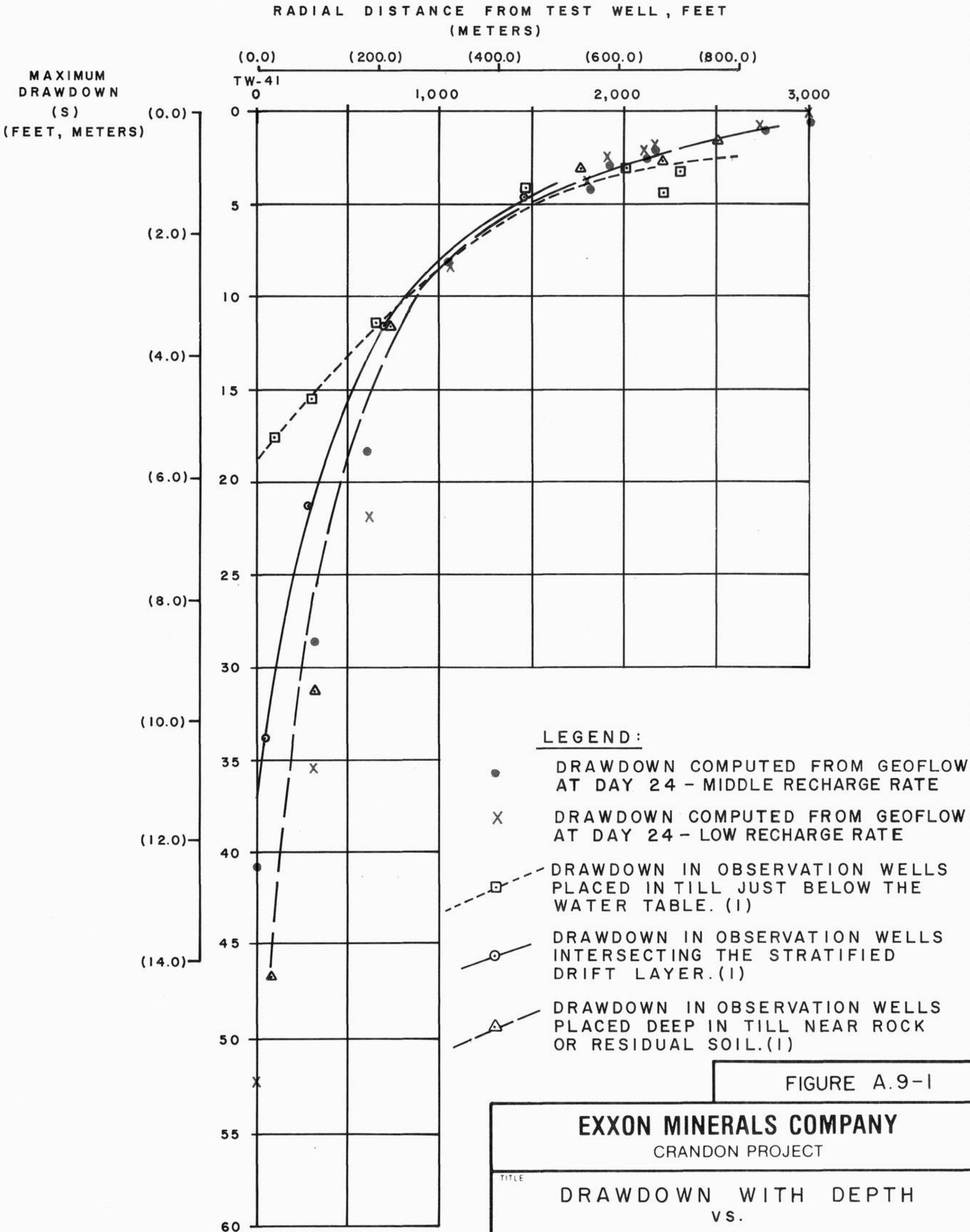
NODE NUMBER	RADIAL DISTANCE FROM WELL TW-41 m	DRAWDOWN m
805	0	485.05 - 472.521 = 12.53
806	100	484.95 - 476.206 = 8.74
758	180	485.13 - 479.553 = 5.58
807	310	485.11 - 482.594 = 2.51
659	550	485.19 - 483.924 = 1.27
906	585	484.03 - 483.178 = 0.85
709	645	485.02 - 484.272 = 0.75
905	655	485.02 - 484.346 = 0.67
568	840	484.86 - 484.534 = 0.33
1009	920	484.90 - 484.763 = 0.14
1120	1125	482.41 - 482.387 = 0.02

TABLE A.9-2

COMPUTED DRAWDOWNS AT SELECTED NODES
LOW RECHARGE RATE

NODE NUMBER	RADIAL DISTANCE FROM WELL TW-41 m	DRAWDOWN m
805	0	484.956 - 468.406 = 16.050
806	100	484.856 - 473.993 = 10.863
758	180	485.032 - 478.409 = 6.623
807	310	485.014 - 482.481 = 2.533
659	550	485.093 - 483.933 = 1.160
906	585	483.964 - 483.280 = 0.684
709	645	484.935 - 484.366 = 0.569
905	655	484.928 - 484.419 = 0.509
568	840	484.778 - 484.563 = 0.215
1009	920	484.823 - 484.762 = 0.061
1120	1125	482.387 - 482.385 = 0.0002

FIGURES



NOTE:

1. WATER LEVEL MEASUREMENTS MADE BETWEEN JULY 17 AND JULY 21, 1980 AS REPORTED IN GOLDER ASSOCIATES (1981).

FIGURE A.9-1

EXXON MINERALS COMPANY
CRANDON PROJECT

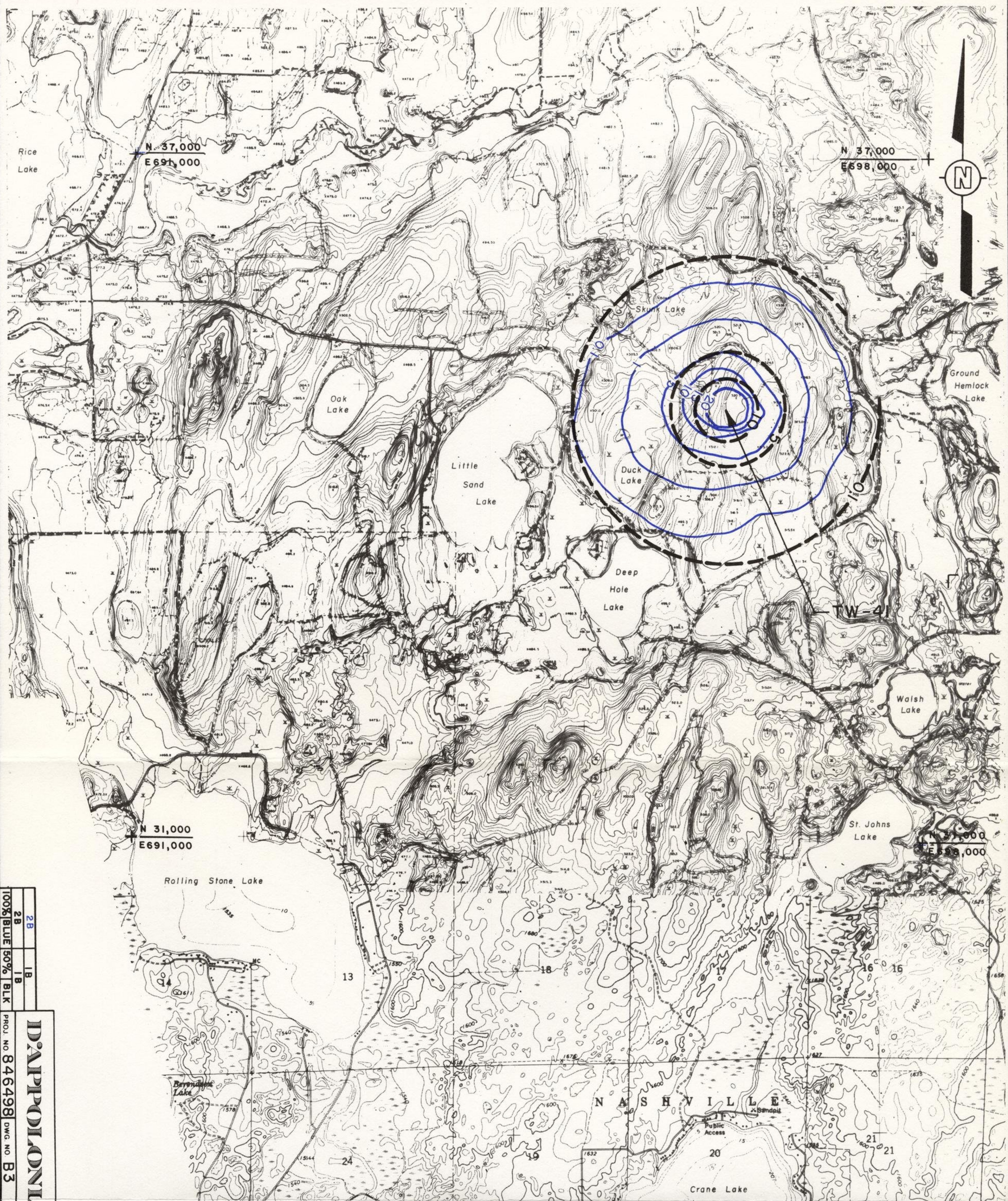
TITLE
DRAWDOWN WITH DEPTH VS. DISTANCE FROM TEST WELL

SCALE AS SHOWN	STATE		COUNTY	
DRAWN B J. LOGRECO	DATE 8-30-84	CHECKED BY MDL		DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD		12/10/85
APPROVED BY	DATE	EXXON		DATE
DRAWING NO			SHEET ___ OF ___	REVISION NO.

IA	
IA	
100%	BLUE

D'APPOLONIA

PROJ NO 846498 DWG NO A3



SCALE

0 600 1200 1800 meters

LEGEND

- - - - ESTIMATED DRAWDOWN (FEET) FROM GOLDER PUMP TEST OF WELL TW-41 (GOLDER ASSOCIATES, 1981)

——— GEOFLOW SIMULATED DRAWDOWN (FEET)

FIGURE A.9-2

EXXON MINERALS COMPANY

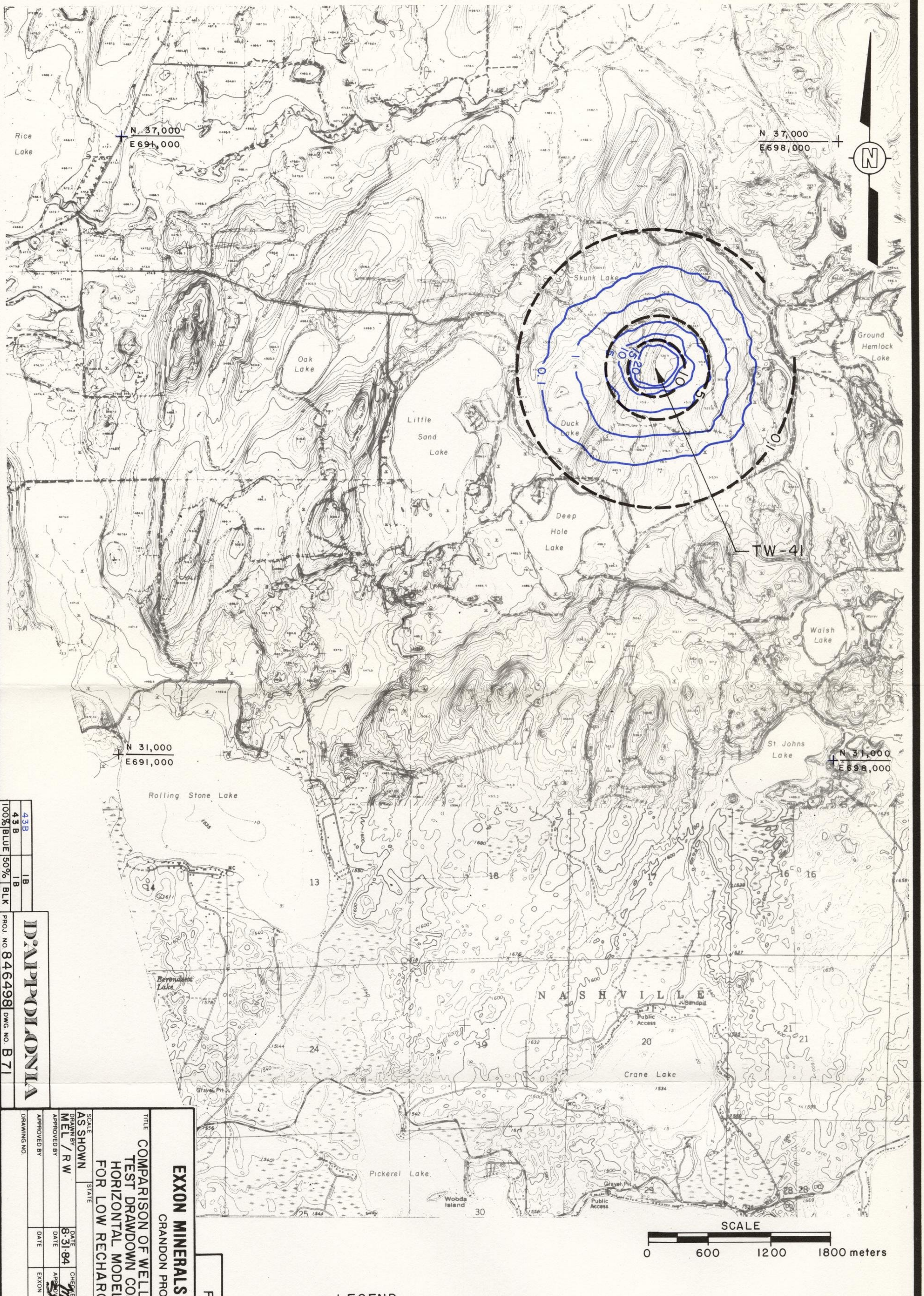
CRANDON PROJECT

TITLE COMPARISON OF WELL TW-41 PUMPING TEST DRAWDOWN CONTOURS WITH HORIZONTAL MODEL RESULTS FOR MIDDLE RECHARGE RATE

SCALE AS SHOWN	STATE	COUNTY	
DRAWN BY MEL / RW	DATE 8-31-84	CHECKED BY	DATE
APPROVED BY	DATE	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	
DRAWING NO		SHEET OF	REVISION NO

2B		
2B	1B	
100% BLUE	50%	BLK

D'APPOLONIA PROJ. NO 846498 DWG NO B3



LEGEND

- - - - ESTIMATED DRAWDOWN (FEET) FROM GOLDER PUMP TEST OF WELL TW-41 (GOLDER ASSOCIATES, 1981)

GEOFLOW SIMULATED DRAWDOWN (FEET)

FIGURE A.9-3

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE: COMPARISON OF WELL TW-41 PUMPING TEST DRAWDOWN CONTOURS WITH HORIZONTAL MODEL RESULTS FOR LOW RECHARGE VALUES

SCALE: AS SHOWN	STATE	COUNTY	
DRAWN BY: MEL / RW	DATE: 8-31-84	CHECKED	DATE
APPROVED BY	DATE	APPROVED	DATE
APPROVED BY	DATE	EXXON	DATE
DRAWING NO.		SHEET OF	REVISION NO.

D'APPOLONIA

PROJ. NO 846498 DWG. NO B71

43B 1B
100% BLUE 50% BLK

ATTACHMENT A.10

LAKE IMPACT ANALYSIS AND RELATED HYDROLOGICAL ASSESSMENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ATTACHMENT A.10

LAKE IMPACT ANALYSIS AND RELATED HYDROLOGICAL ASSESSMENTS

A.10.1.0 INTRODUCTION

Exxon Minerals Company (Exxon) has proposed to construct and operate an underground zinc, copper, and lead mine and mill complex near Crandon, Wisconsin. Ground water drainage into the mine and its subsequent dewatering will lower ground water levels in the site area during the operation phase. The decline of the ground water potentiometric surface is predicted to extend under five lakes near the mine--Duck, Deep Hole, Little Sand, Skunk, and Oak lakes (see Figure A-2). This attachment describes the evaluation of the potential effects of the predicted decline of the potentiometric surface on the five lakes in the site area.

A.10.1.1 OBJECTIVES

To assess the impacts on the five lakes, changes in lake hydrologic conditions during the operation phase were calculated and compared to preconstruction lake conditions. The following potential changes in lake conditions were evaluated:

1) Water surface elevation;
2) Inflows and outflows;
3) Seepage with respect to lake level; and
4) Surface area with respect to lake level.

These changes were determined using a water balance analysis that accounts for monthly lake water budget components on an annual basis. Detailed preconstruction annual water balances for each of the five lakes have previously been developed for average (mean of Water Years 1942 to 1981 for Rhinelander, Wisconsin) and dry (mean of five driest water years in the same period) regional climatic conditions (Dames and Moore, 1985). The preconstruction water balances presented in the 1985 Dames and Moore report were used in conjunction with lake hydrologic data to determine the effects of potentiometric surface decline on the lake water budget components for average climatic conditions and for two successive years of dry climatic conditions.

In addition, to determine if the lake seepage rates calculated by Dames and Moore (1985) are compatible with the calibrated ground water flow model parameters and observed preconstruction potentiometric heads in the vicinity of the lakes, the effect of the lake seepage values on the previously calibrated GEOFLOW model (see Section 5.0) was evaluated.

A.10.1.2 APPROACH

To determine changes in lake hydrologic conditions during the operation phase, the preconstruction hydrologic conditions of the lakes were established by determining the hydrologic parameters for each lake which resulted in the preconstruction seepage rates. Increased seepage rates resulting from lowered ground water levels were then determined as a function of lake level. The relationships between lake level and increased seepage were incorporated into the water balance analyses to determine the effects of lowered ground water levels on lake water budgets. This analysis determined steady-state impacts on lake conditions; a brief discussion of transient effects is included in the summary of results. Subsequent to the lake impact analysis, the GEOFLOW model calibration check was performed using the preconstruction lake seepage rates. Brief descriptions of the major tasks of the study are presented in the following subsections.

A.10.1.2.1 Preconstruction Lake Hydrologic Conditions

To adequately characterize and establish the preconstruction hydrologic conditions of the lakes, each lake was subdivided into different zones of lacustrine sediment thickness (Exxon, 1985a and 1985b) and vertical hydraulic gradients. Seepage for each zone was calculated using Darcy's law. Utilizing the different seepage rates and corresponding zone areas, overall preconstruction lake seepage rates were calculated to correspond to the water budget values determined by Dames and Moore (1985). This procedure established the geohydrologic parameters for each lake which were subsequently used in the impact analysis.

A.10.1.2.2 Lake Impact Analysis

To determine the effects of mine dewatering on the five lakes, the predicted decline of the ground water potentiometric surface under each lake was incorporated into the hydrologic lake conditions previously established. This caused increased computed lake seepage rates because the lowered ground water levels created larger vertical hydraulic gradients. Because lake levels fall in response to increased seepage, relationships between lake levels and seepage rates were determined. These relationships were then incorporated into the water balance analyses to determine equilibrated lake conditions for an average climatic year [based on regional (Rhinelander, Wisconsin) data]. After determining equilibrated lake levels for an average climatic year, water balance analyses were performed using lake budget components for dry climatic years to determine the effects of two successive dry years on lake levels during the operation phase. Recovery from these lake levels was then analyzed using average climatic conditions.

Lake seepage may increase with potentiometric surface decline as described above, thereby affecting lake conditions during the operation phase. However, seepage rates at Oak Lake and portions of Duck Lake are independent of potentiometric surface decline because the preconstruction ground water levels are below the bottom of the lake bed lacustrine sediments.

A.10.1.2.3 GEOFLOW Model Calibration Check

To evaluate the effect of the lake seepage values determined by Dames and Moore (1985) on the calibrated GEOFLOW model, a simulation using the Dames and Moore values was made. The simulated lake seepage rates were adjusted according to the elemental area of each lake in the GEOFLOW model grid to provide a volumetric seepage rate equal to that resulting from the Dames and Moore short-term water balance seepage values and total lake area.

A.10.1.3 SUMMARY OF RESULTS

Using average regional climatic data as input, the water balance analyses indicate that average or equilibrium lake levels are likely to decline by between 0.5 and 0.6 foot at Skunk Lake because of lowered ground water levels during the operation phase under average climatic conditions. Average or equilibrium lake levels at Duck, Deep Hole, and Little Sand lakes are expected to decline by between 0.1 and 0.4 foot during the operation phase. Oak Lake does not show a decline during the operation phase because the potentiometric surface is presently below the bottom of the lacustrine sediments and an increase in the separation does not result in increased hydraulic gradients.

Water balance analyses were performed to estimate lake levels which may result from two successive years of dry climatic conditions; equilibrium operation phase lake levels for average conditions were used as starting points. These analyses provide estimated lake levels resulting from the combined effects of mine dewatering and dry climatic conditions.

The analyses indicate that, for the operation phase, two successive dry years may cause additional lake level declines (from equilibrium operation phase lake levels) on the order of 1.7 feet at Duck Lake, 0.3 foot at Deep Hole Lake, and 0.5 foot at Little Sand Lake. The Skunk Lake level following one dry year is computed to be 0.5 foot lower than the equilibrium operation phase level. Analysis of dry conditions for Skunk Lake was limited to one dry year because declining lake levels and the resulting reduction in lake area caused numerical instability in the water balance iteration process. The decline at Oak Lake after two successive dry years is estimated to be approximately 0.1 foot, resulting solely from the drier climatic conditions.

The computed water levels resulting from two successive dry years during the operation phase show declines from equilibrium operation phase lake levels for average climatic conditions. Declining lake levels are also computed for dry climatic conditions during the preconstruction phase. The computed operation phase declines are similar to the estimated declines from preconstruction lake levels calculated using two successive dry years of climatic data and preconstruction phase ground water levels. This indicates that lake impacts associated with mine dewatering, when compared to preconstruction lake levels for the equivalent climatic conditions, will be similar for both average and dry conditions.

The analyses used potentiometric levels beneath the lakes derived from the predicted potentiometric surface at Project Year 28. However, development of potentiometric levels approximately equal to those for Year 28 occurs after approximately 6 years of mine dewatering. Therefore, the actual lake seepage rates will begin to increase when mine dewatering lowers potentiometric elevations, and are expected to approach the calculated seepage rates when the cone of depression is nearly fully developed, approximately 6 years after mine dewatering begins.

The GEOFLOW calibration check performed using lake seepage rates computed by Dames and Moore (1985) indicates that these seepage rates are generally compatible with calibrated model parameters and observed potentiometric levels. Computed heads near Skunk Lake, however, are higher than observed heads, indicating that the actual seepage rate may be less than the calculated rate of approximately 40 inches per year.

A.10.2.0 LAKE HYDROLOGIC DESCRIPTION

The Crandon Project site area is located entirely within the Wolf River drainage basin in northern Wisconsin. There are five lakes located within the site area where ground water levels are expected to decline from mine operation: Duck Lake, Deep Hole Lake, Little Sand Lake, Skunk Lake, and Oak Lake (see Figure A-2). All the lakes are located within approximately 1.5 miles of the proposed mine site, with Little Sand, Skunk, and Oak lakes located closer to the mine site than Duck and Deep Hole lakes.

Annual water balance analyses for the five lakes are described in detail in a study of preconstruction lake conditions (Dames and Moore, 1985). Hydrologic characteristics pertinent to the analysis of lake impacts resulting from mine dewatering are summarized below:

1) Water levels in all five lakes within the study area are consistently higher than nearby measured ground water levels (Dames and Moore, 1985), indicating that water seeps from the lakes downward into the ground water system.

2) The downward seepage rate at Deep Hole, Little Sand, and Skunk lakes, and at portions of Duck Lake, is controlled by the hydraulic gradient between the lake level and the underlying ground water level and by the thickness and permeability of the fine-grained lacustrine (lake bottom) sediments. At Oak Lake and at portions of Duck Lake, the seepage rate is independent of ground water level because the bottom of the lacustrine sediments is located above the water table, creating a partially saturated zone beneath the lacustrine sediments (Dames and Moore, 1985; Exxon, 1985a).

3) The configurations of the lacustrine sediments at the five lakes are indicated in geologic cross sections presented in Figures A.10-1 through A.10-5. Based on recent field investigations by Exxon (Exxon, 1985a), the geologic cross sections have been revised to include the lakeside wetlands at Duck, Deep Hole, Skunk, and Oak lakes. In addition, the lacustrine layer has been distinguished from the overlying organic silt layer. The data on the thickness of the lacustrine sediments indicate that the thickness is greatest near the center of each lake, decreasing toward the lake shores. Maximum lacustrine sediment thickness ranges from approximately 1 foot at Skunk Lake to 30 feet at Duck Lake, and measured permeabilities (STS

Consultants, Ltd., 1984b) are on the order of 10^{-7} to 10^{-6} centimeter per second (0.1 to 1.0 foot per year).

4) At each lake, water may be lost through evaporation and surface outflows in addition to outward seepage through the lacustrine sediments. Water is gained through precipitation on the lake and through surface inflows. The net difference between these gains and losses over a discrete time period results in a change in the volume of water in lake storage and a corresponding change in lake level.

5) At Duck, Deep Hole, Skunk, and Oak lakes, lakeside wetlands are integral components of the lake system. These wetlands have water elevations equal to that of the adjacent lake (IEP, Inc., 1985). Therefore, the wetlands were assumed to function largely as extensions of the lakes themselves (Dames and Moore, 1985).

For the five lakes, the open water and lakeside wetlands areas are indicated below (IEP, Inc., 1985):

LAKE	OPEN WATER (acres)	LAKESIDE WETLANDS (acres)	TOTAL (acres)
Duck	26.2	52.5	78.7
Deep Hole	100.5	28.4	128.9
Little Sand	244.1	0.0	244.1
Skunk	8.8	6.9	15.7
Oak	52.3	17.6	69.9

A.10.3.0 METHODOLOGY

In order to determine lake impacts during the operation phase, the following analyses were performed:

1) Determination of lake hydrologic parameters for the preconstruction phase;

2) Determination of lake level versus seepage relationships for lowered ground water levels during the operation phase;

3) Calculation of annual lake water balances for average and dry climatic conditions during the operation phase; and

4) GEOFLOW model calibration check.

This subsection presents the methodologies used for these analyses.

A.10.3.1 SELECTION OF LAKE HYDROLOGIC PARAMETERS

To properly determine changes in lake hydrologic conditions during mine dewatering, the preconstruction lake hydrologic conditions must first be established. Preconstruction conditions were established by determining which combinations of hydrologic parameters could result in the seepage rate estimated for each lake by Dames and Moore (1985). These seepage rates were computed as residuals based on field measurements of the lake water budget components.

For establishing preconstruction lake hydrologic conditions, seepage was calculated using Darcy's law, lacustrine sediment permeability and thickness data, computed hydraulic gradients between the lakes and the underlying potentiometric surface, and lake areas. After defining discrete zones of lacustrine sediment thickness and hydraulic gradient, lacustrine sediment permeability values were varied within realistic ranges to produce computed lake seepage rates similar to those calculated by Dames and Moore (1985). Permeability values were varied because they are of greater uncertainty than the other parameters in the calculations. By computing seepage rates similar to the 1985 Dames and Moore seepage rates using Darcy's law, lake hydrologic parameters (specifically lacustrine sediment permeabilities) were established for use in the lake impact analyses.

A.10.3.1.1 Lake Zones

Seepage rates through lake beds will vary spatially depending upon variations in lake bed characteristics and variations in hydraulic gradients. Therefore, the lake areas used in the 1985 Dames and Moore study (including lakeside wetlands) were subdivided into zones based on underlying ground water elevations and lacustrine sediment thickness. In addition, water depth contours were used as a basis for delineating lake zones to establish lake level versus seepage relationships during the lake impact analyses.

Lakes were initially divided into zones of discrete water depths based on open-water depth contour maps (Inman-Foltz, 1985) and on lakeside wetlands cross sections (Exxon, 1985a). These zones were further subdivided by delineating areas of approximately equal underlying ground water elevation. Each of the areas was then assigned a lacustrine sediment thickness value based on isopach contours provided by Exxon (1985b). Areas were further divided into regions of different lacustrine sediment thicknesses when necessary.

The configurations of the zones for each lake are presented in Figures A.10-6 through A.10-10. Parameter values for each zone are listed in Tables A.10-1 through A.10-5.

A.10.3.1.2 Calculations

A volumetric flow rate for each lake zone was computed using Darcy's law:

$$Q_i = K_i I_i A_i$$

where

Q_i = volumetric flow rate across Zone i (L^3/T),

K_i = permeability of Zone i lacustrine sediments (L/T),

I_i = hydraulic gradient for Zone i (lake level minus ground water elevation divided by lacustrine sediment thickness), and

A_i = area of Zone i (L^2).

(L and T in parentheses denote length and time dimensions, respectively.)

An overall seepage rate for each lake was then calculated using a computer program to sum the volumetric flows:

$$q_{lake} = \frac{\sum_{i=1}^{n} Q_i}{A_{lake}}$$

where

q_{lake} = lake seepage rate (L/T),
n = number of lake zones, and
A_{lake} = total lake area (L^2).

For each lake, lacustrine sediment thicknesses, lake levels, and underlying ground water levels were assigned to each lake zone. A permeability value was then selected for each lake to correspond to measured values or ranges of measured values (STS Consultants, Ltd., 1984a) and adjusted slightly as required to yield a lake seepage rate approximately equal to the rate computed by Dames and Moore (1985). The uniform permeability values and resultant seepage rates are indicated in Table A.10-6. These permeability values fall within realistic ranges and are similar to actual measured values for the lake sediments (Table A.10-6).

Additional cases of higher permeability zones near the lake shores were also considered because, in many cases, the largest volume of lake seepage occurs in nearshore areas (McBride and Pfannkuch, 1975). Combinations of relatively low permeability values in the central sediments, approximately corresponding to measured values, and higher permeabilities in the 0- to 2-foot depth zones were selected to produce lake seepage rates similar to the preconstruction phase values (Dames and Moore, 1985). These permeability combinations and resultant seepage rates are also indicated in Table A.10-6.

A.10.3.2 OPERATION PHASE LAKE SEEPAGE ANALYSIS

During mine dewatering, ground water levels underlying the lakes will be lowered. These lowered ground water levels may increase lake seepage rates by creating larger downward hydraulic gradients. Increased seepage rates out of the lakes during mine operation will cause lake levels to fall until one of the following occurs:

1) Reduced surface outflow (i.e., outlet streamflow) equals the increased seepage flow;

2) Seepage rate decreases to the original value due to reduced driving head and thicker lacustrine sediments in the center of the lake;

3) Lake area is reduced to the point that volumetric seepage is equal to the original value (i.e., a higher flow rate but over a smaller area);

4) Lake level decline is balanced by increases in other water balance components; or

5) A combination of the above factors.

When the increased seepage rate is balanced by changes in other components of a lake's water budget, the lake level will stop falling and reach a new equilibrium level. To calculate the equilibrium lake levels for the operation phase, relationships between lake levels and increased seepage rates were determined, along with relationships between lake levels and lake areas. These relationships were then incorporated in the annual water balances prepared by Dames and Moore (1985) to calculate new equilibrium lake levels. The following subsections describe the methodologies used.

A.10.3.2.1 Lake Level Versus Seepage Calculations

The maximum impact of mine dewatering on potentiometric surface decline is expected to occur at Project Year 28. To predict increased lake seepage rates resulting from the lowered potentiometric surface, ground water elevations computed by the GEOFLOW model for Year 28 (see Figure A-31) were input into the seepage calculations described in Subsection A.10.3.1.2. These lowered ground water elevations are shown in Figures A.10-6 through A.10-10 and are listed by lake zone in Tables A.10-1 through A.10-5.

The analyses used potentiometric levels beneath the lakes derived from the predicted potentiometric surface at Project Year 28. However, development of potentiometric levels approximately equal to those for Year 28 occurs after about 6 years of mine dewatering. Therefore, the actual lake seepage rates will begin to increase when mine dewatering lowers potentiometric elevations, and are expected to approach the calculated seepage rates when the cone of depression is nearly fully developed, approximately 6 years after mine dewatering begins.

Increased seepage rates were initially calculated for the Year 28 potentiometric surface using preconstruction lake levels. Because lake levels are expected to fall in response to the increased seepage rates, they were also calculated for lake levels lower than preconstruction values. Seepage rates were computed for lake levels lowered at 0.5-foot intervals using the formula presented in Subsection A.10.3.1.2. Areas of the shallower (near shoreline) lake zones were reduced proportionately to the lake level decline to represent the reduction of lake areas with lowered lake levels. Seepage rates therefore decrease as lake levels fall because of thicker lacustrine sediments toward the lake center and decreasing hydraulic gradients.

The calculations for increased seepage rate versus lake level were performed for two lacustrine sediment permeability cases for each lake, one for uniform permeability and one for a combination of low permeability central sediments and higher permeability nearshore sediments (Subsection A.10.3.1.2). The results of lake level versus increased seepage rate calculations for both cases for each lake are plotted in Figure A.10-11. The uniform lacustrine sediment permeability case may be considered the most conservative case because the decrease in seepage rate as lake level declines results primarily from decreasing hydraulic gradients. In addition, the uniform permeability case may be more appropriate for lakes with lakeside wetlands which trap fine-grained sediments. The higher nearshore permeability case results in a larger reduction of seepage rate because, as the lake level declines, the higher permeability area decreases while the lower permeability area remains constant.

A.10.3.2.2 Annual Water Balances for Operation Phase

Preconstruction annual water balances for each lake have been prepared by Dames and Moore (1985). These water balances are in LOTUS 123® spreadsheet format and account for monthly variations in precipitation, runoff, evaporation, and outflow to determine lake level fluctuations. Results of the Dames and Moore study (1985) include preconstruction equilibrium lake levels for average regional climatic conditions and changes in lake levels for wet and dry climatic conditions. For all three water balances, lake seepage rates were held constant at values determined in the short-term water balance field study.

These water balances, with appropriate modifications, were used to predict new equilibrium lake levels during the operation phase. In using the Dames and Moore water balances for lake impact analyses, the following assumptions were made:

1) The parameter values used in the water balances, such as monthly precipitation, surface water runoff, and evaporation, are representative of actual conditions;

2) Lakeside wetlands function as extensions of the lake area;

3) Evaporation rates are uniform over the lake surface; and

4) The relationships between lake level and surface outflow incorporated in the water balance analyses are appropriate through the range of lake levels considered.

The Dames and Moore preconstruction water balance analyses have been modified to allow computation of new equilibrium lake levels during the operation phase. Seepage rates, rather than being held constant, were computed as a function of lake level. The equations used to compute the increased seepage rates were straight-line approximations of the plots presented in Figure A.10-11 and are listed in Table A.10-7.

In addition, equations of lake area versus lake level were incorporated in the modified water balance analyses to account for reduced lake areas as lake water levels fall. These equations were based on depth contours and lake zone areas indicated in Figures A.10-6 through A.10-10 and are listed in Table A.10-7. As lake area decreases, the number of inches gained or lost by the lake for a given volume of surface runoff or outflow will increase. The effective watershed areas were held constant, independent of lake areas, because variations in lake areas were small relative to the watershed areas.

The water balance for Little Sand Lake was further modified to account for reduced outflows from Duck and Deep Hole lakes. Outlet streams from Duck and Deep Hole lakes flow into Little Sand Lake and surface outflows from these two lakes are reduced during the operation phase because of lowered lake levels. This reduction is accounted for by subtracting the monthly total reductions in

Duck and Deep Hole lakes outflow from the surface water runoff gains to Little Sand Lake.

Following the above modifications, equilibrium lake levels for average climatic conditions were determined using the water balance analyses as described in the Dames and Moore report (1985). Lakes were assumed to be full in May and the May lake level was adjusted until the net change in lake water storage for the year was zero. May lake levels, therefore, represent the start and end of each annual analysis. The numerous mathematical functions incorporated in the analyses required the calculations to be iterated until a stable solution was achieved, but these iterations represent numerical steps rather than steps through time.

Dry climatic conditions (annual precipitation of 22.8 inches per year versus average of 30.7 inches per year) cause lowered lake levels under preconstruction conditions (Dames and Moore, 1985) and may have differing effects during mine dewatering. Therefore, following the determination of equilibrium lake levels for average climatic conditions, input values for two successive dry years were used in the analyses to determine potential additional lake level declines. This dry climatic condition was considered for analysis based on agreement with the Wisconsin Department of Natural Resources. Average climatic conditions were then incorporated to indicate lake level recovery characteristics.

The water balance analyses were performed for each lake using the seepage/lake level relationship established for the uniform permeability case described in Subsection A.10.3.1.2. The uniform permeability case was used because it produces maximum calculated lake level declines and because it does not require assumptions about the extent of high permeability zones. However, in order to assess the effects of higher permeabilities in the nearshore areas, water balance analyses for the high perimeter permeability case were performed for Little Sand Lake. Little Sand Lake was selected because it does not have significant lakeside wetlands areas and therefore is more likely to have higher permeability zones nearshore than lakes surrounded by sediment-filled wetlands.

To permit evaluation of dry climatic conditions and recovery lake levels for the operation phase, the Dames and Moore (1985) preconstruction water balances were extended beyond the first dry year using the end of first dry year lake levels as starting points. For Deep Hole, Little Sand, and Oak lakes, this procedure was performed using the original Dames and Moore water balances and therefore did not account for changing lake areas or seepage rates. However, these lakes show relatively minor reductions in lake level and area, so associated changes in seepage and inflow/outflow rates would also be minor relative to other water balance components. The results provide a basis for comparing predicted operation phase lake levels to preconstruction lake levels under equivalent conditions.

For Duck and Skunk lakes, lake areas and/or levels are reduced significantly for the analysis of dry climatic conditions. Therefore, the Dames and Moore (1985) preconstruction water balances for these lakes were modified to account for changes in seepage and inflow/outflow rates associated with lake level and area variation. The seepage equations were obtained using preconstruction ground water levels and the procedure outlined above, and are presented in Table A.10-7.

A.10.3.3 GEOFLOW MODEL CALIBRATION CHECK

The seepage rates calculated by Dames and Moore (1985) and reproduced using the detailed analysis presented in Subsection A.10.3.1 differ somewhat from the values used in the horizontal GEOFLOW model of the study area's hydrogeologic system (Table A-10). To test the effect of the different seepage rates on the model's calibration status, a simulation was performed using parameters equal to those in the calibrated model but with lake seepage rates changed to those presented in Table A.10-6.

The lake seepage rates specified for the model calibration check were adjusted according to the elemental area of each lake in the model grid (see Figure A-22) to provide a volumetric seepage rate equal to that resulting from the seepage rates in Table A.10-6 and total lake areas indicated in Figures A.10-6 through A.10-10.

A.10.4.0 RESULTS AND DISCUSSION

The objective of this study was to determine the effects of mine dewatering on five nearby lakes and the potential impact on lake water surface elevation and area, lake inflows and outflows, and lake seepage rates. Results are presented for each lake, including:

1) Lake hydrologic parameter values;

2) Operation phase seepage rates as a function of lake level;

3) Equilibrated lake levels for average climatic conditions during the operation phase;

4) Lake levels for two successive years of dry climatic conditions during the operation phase; and

5) Lake level recovery under average climatic conditions for the operation phase.

Following the individual lake impact discussions, the results of the GEOFLOW model calibration check are presented.

A.10.4.1 DUCK LAKE

Duck Lake and its adjacent wetlands are approximately 78.7 acres in area, of which 52.5 acres are wetlands. The lake has a maximum depth of about 9 feet. The fine-grained lacustrine deposits underlying the lake range in thickness from approximately 30 feet in the center to less than 1 foot along the perimeter and their permeability has been measured at 1.0×10^{-7} and 1.3×10^{-6} centimeter per second (0.10 and 1.35 feet per year).

The preconstruction seepage rate at Duck Lake has been estimated to be 21.3 inches per year (Dames and Moore, 1985). For the lake bed model, this seepage rate is reproduced using Darcy's law calculations for two permeability cases: a uniform permeability of 0.86 foot per year, and an interior permeability of 0.37 foot per year with a perimeter permeability of 4.1 feet per year (Table A.10-6).

Incorporating maximum decline ground water elevations in the seepage calculations results in an initial seepage rate of approximately 24 inches per year for both permeability cases. The seepage rates decrease with lowered lake levels, the reduction more pronounced for the combined permeability case (Figure A.10-11).

The relationship between seepage and lake level for the uniform permeability case was used in the water balance analyses to predict operation phase lake levels at equilibrium under average climatic conditions (lake levels for all the lakes are summarized in Table A.10-8). The water balance is shown in Table A.10-9 and the monthly water levels are plotted in Figure A.10-12. The analysis indicates a drop of approximately 0.2 to 0.3 foot in the lake levels because of increased seepage; lake area is not significantly reduced. Surface outflow is reduced to between zero and 0.01 cubic foot per second from preconstruction values of 0.01 to 0.04 cubic foot per second.

The analysis of the effects of two years of dry climatic conditions on operation phase lake levels (Table A.10-10) indicates an additional 1.7-foot drop in May lake level (Table A.10-8). This decline is similar to the estimated lake level decline for the preconstruction phase under the same dry climatic conditions. The monthly lake level fluctuations for the average, two dry, and following average years are shown in Figure A.10-12. Duck Lake levels will decline less in the second dry year than in the first, and lake levels may recover the majority of the total decline after approximately two years of average climatic conditions. Recovery characteristics are similar for both preconstruction and operation phases.

A.10.4.2 DEEP HOLE LAKE

Deep Hole Lake is approximately 129 acres in area, 28 acres of which are wetlands, and has a maximum depth of about 18 feet. The fine-grained lacustrine deposits underlying the lake range from approximately 1 to 15 feet in thickness, and measured permeabilities range from 6.8×10^{-8} to 6.8×10^{-7} centimeter per second (0.07 to 0.70 foot per year).

The preconstruction seepage rate at Deep Hole Lake has been estimated (by analogy to the estimated rate for Little Sand Lake) to be approximately 8 inches per year (Dames and Moore, 1985). For the lake bed model, this seepage rate is reproduced using Darcy's law calculations for two permeability cases:

a uniform permeability of 0.13 foot per year, and an interior permeability of 0.07 foot per year with a perimeter permeability of 0.20 foot per year (Table A.10-6).

Using operation phase ground water elevations in the seepage calculations results in an initial seepage rate of approximately 11 inches per year for both permeability cases. The seepage rates decrease with lowered lake levels, the reduction more pronounced for the combined permeability case (Figure A.10-11).

The relationship between seepage and lake level for the uniform permeability case was used in the water balance analyses to predict operation phase lake levels at equilibrium under average climatic conditions. The water balance is shown in Table A.10-11 and the monthly water levels are plotted in Figure A.10-13. The analysis indicates a drop of up to 0.1 foot in lake levels because of increased seepage (Table A.10-8); lake area is not greatly reduced. Surface outflows are reduced by 0.02 to 0.08 cubic foot per second. These results indicate that the major portion of increased seepage volume due to lowered ground water levels can be accounted for by reduced surface outflow at Deep Hole Lake; this is because seepage is calculated to increase from 8 inches per year to a maximum of 11 inches per year, a moderate increase.

Following two successive dry years (Table A.10-12), May lake levels are computed to be 0.3 foot lower than equilibrium operation phase lake levels (Table A.10-8). This decline is similar to the estimated lake level decline for the preconstruction phase under the same dry climatic conditions. The plot of lake levels versus time (Figure A.10-13) indicates that equilibrium levels may be attained following one year of average climatic conditions.

A.10.4.3 LITTLE SAND LAKE

Little Sand Lake is the largest of the five study area lakes. It is approximately 244 acres in area, all of which are open water, and has a maximum depth of about 20 feet. The fine-grained lacustrine deposits range between 1 and 20 feet in thickness and the range of measured permeabilities is 1.1×10^{-7} to 1.6×10^{-6} centimeter per second (0.11 to 1.66 feet per year).

The preconstruction seepage rate at Little Sand Lake has been estimated to be approximately 8 inches per year (Dames and Moore, 1985). For the lake bed model, this seepage rate is reproduced using Darcy's law calculations for two permeability cases: a uniform permeability of 0.60 foot per year, and an interior permeability of 0.15 foot per year with a perimeter permeability of 2.0 feet per year (Table A.10-6).

Using operation phase ground water elevations in the seepage calculations results in an initial seepage rate of approximately 23 inches per year for both permeability cases. The seepage rates decrease with lowered lake levels, the reduction more pronounced for the combined permeability case (Figure A.10-11).

The relationships between seepage and lake level for both the uniform permeability case and the combined permeability case were used in the water balance analyses to predict operation phase lake levels at equilibrium under average climatic conditions. The water balances are shown in Tables A.10-13 and A.10-14 and the monthly water levels are plotted in Figures A.10-14 and A.10-15. The analyses are very similar for both permeability cases although the high perimeter permeability case indicates lake levels approximately 0.1 foot higher than the uniform case for several months. The May lake levels are reduced by 0.2 foot from preconstruction conditions for both cases (Table A.10-8), with maximum declines of 0.3 foot for the uniform case and 0.2 foot for the combined case. Surface outflows are reduced by 0.28 to 0.75 cubic foot per second for the uniform case and by 0.23 to 0.63 cubic foot per second for the combined case.

The analyses of the effects of two successive dry impact years during the operation phase (Tables A.10-15 and A.10-16) indicate additional May lake level declines of 0.5 foot for the uniform permeability case and 0.4 foot for the high perimeter permeability case (Table A.10-8). These declines are approximately 0.1 to 0.2 foot greater than the estimated lake level decline for the preconstruction phase under the same climatic conditions. For both cases, recovery to equilibrium operation phase levels should occur within approximately two years of average climatic conditions (Figures A.10-14 and A.10-15).

A.10.4.4 SKUNK LAKE

Skunk Lake is the smallest of the five study area lakes. It is approximately 15.7 acres in area, 6.9 acres of which are wetlands, and has a maximum depth of about 5 feet. The fine-grained lacustrine deposits underlying the lake are on the order of 1 foot in thickness and their permeability has been measured at 4.3×10^{-8} centimeter per second (0.04 foot per year).

The preconstruction seepage rate at Skunk Lake has been estimated to be approximately 40 inches per year (Dames and Moore, 1985). For the lake bed model, this seepage rate is reproduced using Darcy's law calculations for two permeability cases: a uniform permeability of 0.47 foot per year, or an interior permeability of 0.04 foot per year and a perimeter permeability of 0.65 foot per year (Table A.10-6).

Using operation phase ground water elevations in the seepage calculations results in an initial seepage rate of approximately 66 inches per year for both permeability cases. The seepage rates decrease with lowered lake levels, the reduction more pronounced for the combined permeability case (Figure A.10-11).

The relationship between seepage and lake level for the uniform permeability case was used in the water balance analysis to predict operation phase lake levels at equilibrium under average meteorologic conditions. The water balance is shown in Table A.10-17 and the monthly water levels are plotted in Figure A.10-16. The analysis indicates drops of approximately 0.5 to 0.6 foot in lake levels because of increased seepage (Table A.10-8); lake area is reduced from 15.7 acres to approximately 6 to 10 acres. These results indicate that most of the current wetlands area of Skunk Lake may be dewatered during the operation phase.

The analysis of the effects of dry climatic conditions on operation phase lake levels was limited to one dry year at Skunk Lake because the greatly reduced lake area created numerical instability in the water balance solution during the second dry year. Slight changes in these reduced areas from month to month created large percentage changes in the functions dependent upon lake area; the second dry year for Skunk Lake was the only water balance to exhibit this instability. The results for one dry year (Table A.10-18) indicate an additional drop of approximately 0.5 foot in May lake level compared to equilibrium operation phase conditions (Table A.10-8). For the preconstruction phase analysis using the same dry climatic conditions, lake level declines from equilibrium values are similar to the declines calculated for the operation phase. The monthly fluctuations in lake level for the dry year are shown in Figure A.10-16.

Impacts during the second dry year, along with the time required for lake recovery, can be inferred by comparison to results from the other study area lakes. This comparison indicates that Skunk Lake levels will decline less in the second dry year than in the first, and that lake levels may recover the majority of the total decline after approximately two years of average climatic conditions. Recovery characteristics should be similar for both preconstruction and operation phases.

A.10.4.5 OAK LAKE

Oak Lake and its adjacent wetlands are approximately 69.9 acres in area, of which 17.6 acres are wetlands. The lake has a maximum depth of about 47 feet. The fine-grained lacustrine deposits underlying the lake range in thickness from approximately 12 feet in the center to 3 feet at the perimeter and their permeability has been measured at 3.5×10^{7} and 2.3×10^{-6} centimeter per second (0.36 and 2.38 feet per year).

The preconstruction seepage rate at Oak Lake has been estimated to be approximately 9.1 inches per year (Dames and Moore, 1985). For the lake bed model, this seepage rate is reproduced using Darcy's law calculations for two permeability cases: a uniform permeability of 0.21 foot per year, or an interior permeability of 0.10 foot per year and a perimeter permeability of 0.55 foot per year (Table A.10-17).

The water balance for Oak Lake is shown in Table A.10-19. Oak Lake does not show a decline under operation phase conditions (Figure A.10-17) because the potentiometric surface is currently below the bottom of the lacustrine sediments. The water balance for two dry years (Table A.10-20) indicates a drop of 0.1 foot in May lake levels (Table A.10-8), due solely to the dry climatic conditions. This decline is lower than those computed for the other lakes under preconstruction phase dry climatic conditions, probably because of the greater reduction in surface water outflow at Oak Lake.

A.10.4.6 GEOFLOW MODEL CALIBRATION CHECK

To test the effect of the different seepage rates on the model's calibration status, a simulation was performed using parameters from the calibrated model but with lake seepage rates specified as those presented in Table A.10-6.

The computed potentiometric surface using revised lake seepage rates is shown in Figure A.10-18. The model continues to produce a good simulation of observed potentiometric heads, except for calculated heads in the vicinity of Skunk Lake which are higher than observed ground water levels. This indicates that the calculated seepage rate of approximately 40 inches per year for Skunk Lake may be somewhat higher than that which actually occurs.

A.10.5.0 SUMMARY

An average annual water balance method was used to analyze lake impacts resulting from lowered ground water levels during the operation phase. The water balance approach permitted the integration of numerous interrelated hydrologic variables and, despite simplifying assumptions, provides realistic and pertinent qualitative and quantitative results.

Using average regional (Rhinelander, Wisconsin) climatic data as input, the water balance analyses indicate that lake levels are likely to decline by between 0.5 and 0.6 foot at Skunk Lake because of lowered ground water levels during the operation phase. Lake levels at Duck, Deep Hole, and Little Sand lakes are expected to decline by between 0.1 and 0.4 foot during the operation phase. Oak Lake does not show a decline during the operation phase because the potentiometric surface is below the bottom of the lacustrine sediments in the preconstruction phase.

Water balance analyses were also performed to estimate lake levels which may result from two successive years of dry climatic conditions; equilibrium operation phase lake levels for average conditions were used as starting points. These analyses provide estimated lake levels resulting from the combined effects of mine dewatering and dry climatic conditions.

The analyses indicate that, for operation phase ground water elevations, two successive dry years may cause additional lake level declines (from equilibrium operation phase lake levels) on the order of 1.7 feet at Duck Lake, 0.3 foot at Deep Hole Lake, and 0.5 foot at Little Sand Lake. The Skunk Lake level following one dry year is computed to be 0.5 foot lower than the equilibrium operation phase level. Analysis of dry conditions for Skunk Lake was limited to one dry year because declining lake levels and the resulting reduction in lake area caused numerical instability in the water balance iteration process. The decline at Oak Lake after two successive dry years is estimated to be approximately 0.1 foot, resulting solely from the drier climatic conditions.

For all the lakes, water level declines resulting from two successive dry years during the operation phase are estimated. The resulting lake impacts, when compared to estimated lake levels for two successive dry years during the preconstruction phase, are similar to the impacts compared using average climatic data.

Analysis of Little Sand Lake using the seepage/lake level relationship established for the higher perimeter lake bed permeability case produces results very similar to those for the uniform permeability case; operation phase lake levels are up to 0.1 foot higher for the high perimeter permeability case. Using high perimeter permeability cases in the water balance analyses for Duck and Skunk lakes would reduce the calculated lake level declines for the operation phase; however, the presence of extensive lakeside wetlands at both lakes makes it unclear whether high perimeter permeabilities would be appropriate.

The GEOFLOW calibration check performed using lake seepage rates computed by Dames and Moore (1985) indicates that these seepage rates are generally compatible with calibrated model parameters and observed potentiometric levels. Computed ground water potentiometric heads near Skunk Lake, however, are higher than observed heads, indicating that the actual seepage rate may be less than the calculated rate of approximately 40 inches per year.

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TABLES

TABLE A.10-1

DUCK LAKE AND ADJACENT WETLANDS
LAKE ZONE PARAMETERS(a)

LAKE ZONE NUMBER	ZONE AREA ($feet^2$)	WATER DEPTH(b) (feet)	LAKE BED THICKNESS(c) (feet)	GROUND WATER POTENTIOMETRIC LEVEL	
				PRECONSTRUCTION(d) (feet above MSL)	MAXIMUM DECLINE(e) (feet above MSL)
1	62,400	0-2	0.7	1,608	1,608
2	25,600	0-2	0.7	1,608	1,608
3	144,000	0-2	1.0	1,608	1,608
4	38,400	0-2	6.6	1,592	1,577
5	254,400	2-5	1.3	1,607	1,607
6	608,000	2-5	1.6	1,606	1,606
7	219,200	2-5	5.9	1,604	1,604
8	280,000	2-5	1.6	1,607	1,607
9	409,600	5+	3.3	1,605	1,605
10	158,400	5+	2.0	1,606	1,606
11	308,800	5+	6.6	1,600	1,600
12	244,800	2-5	15	1,592	1,576
13	488,000	5+	26	1,592	1,575
14	300,800	5+	20	1,590	1,575
15	22,400	2-5	10	1,590	1,576

(a) Refer to Figure A.10-6 for lake zone map.

(b) Depths inferred from Inman-Foltz (1985) and wetlands depth data provided by Exxon (1985a).

(c) Lake bed thicknesses inferred from lacustrine isopach contours provided by Exxon (1985b).

(d) For Zones 4, 12, 13, 14, and 15, preconstruction potentiometric levels are based on ground water potentiometric contours shown in Figure A-13; for other (perched) zones, elevation of bottom of lacustrine sediments is used (Exxon, 1985a).

(e) For Zones 4, 12, 13, 14, and 15, maximum decline represents the predicted potentiometric level at Year 28 based on potentiometric contours shown in Figure A-31; for other (perched) zones, elevation of bottom of lacustrine sediments (Exxon, 1985a) represents maximum decline conditions.

TABLE A.10-2

DEEP HOLE LAKE AND ADJACENT WETLANDS
LAKE ZONE PARAMETERS(a)

LAKE ZONE NUMBER	ZONE AREA (feet^2)	WATER DEPTH(b) (feet)	LAKE BED THICKNESS(c) (feet)	GROUND WATER POTENTIOMETRIC LEVEL PRECONSTRUCTION(d) (feet above MSL)	GROUND WATER POTENTIOMETRIC LEVEL MAXIMUM DECLINE(e) (feet above MSL)
1	355,200	0-2	1	1,583	1,575
2	49,600	0-2	3	1,585	1,577
3	62,400	0-2	1	1,587	1,577
4	216,000	0-2	2	1,589	1,580
5	48,000	0-2	1	1,587	1,580
6	65,600	0-2	1	1,585	1,578
7	771,200	2-5	3	1,583	1,576
8	59,200	2-5	6	1,585	1,577
9	118,400	2-5	6	1,587	1,577
10	459,200	2-5	8	1,589	1,580
11	51,200	2-5	3	1,587	1,580
12	233,600	2-5	3	1,585	1,579
13	585,600	5+	9	1,583	1,576
14	1,444,800	5+	13	1,585	1,578
15	838,400	5+	13	1,587	1,579
16	297,600	5+	13	1,589	1,580

(a)Refer to Figure A.10-7 for lake zone map.

(b)Depths inferred from Inman-Foltz (1985) and wetlands depth data provided by Exxon (1985a).

(c)Lake bed thicknesses inferred from lacustrine isopach contours provided by Exxon (1985b).

(d)Preconstruction potentiometric level based on ground water potentiometric contours shown in Figure A-13.

(e)Maximum decline represents the predicted potentiometric level at Year 28 based on potentiometric contours shown in Figure A-31.

TABLE A.10-3

LITTLE SAND LAKE
LAKE ZONE PARAMETERS(a)

LAKE ZONE NUMBER	ZONE AREA ($feet^2$)	WATER DEPTH(b) (feet)	LAKE BED THICKNESS(c) (feet)	GROUND WATER POTENTIOMETRIC LEVEL	
				PRECONSTRUCTION(d) (feet above MSL)	MAXIMUM DECLINE(e) (feet above MSL)
1	99,200	0-2	4	1,578	1,566
2	144,000	0-2	2	1,578	1,561
3	62,400	0-2	2	1,580	1,556
4	60,800	0-2	8	1,582	1,552
5	64,000	0-2	12	1,584	1,549
6	54,400	0-2	4	1,586	1,547
7	83,200	0-2	9	1,586	1,554
8	49,600	0-2	14	1,586	1,560
9	22,400	0-2	8	1,586	1,560
10	20,800	0-2	3	1,584	1,559
11	19,200	0-2	12	1,584	1,560
12	78,400	0-2	3	1,584	1,565
13	40,000	0-2	1	1,582	1,569
14	64,000	0-2	4	1,580	1,568
15	100,800	2-5	7	1,578	1,566
16	142,400	2-5	3	1,578	1,561
17	88,000	2-5	4	1,580	1,557
18	99,200	2-5	10	1,582	1,552
19	84,800	2-5	14	1,584	1,549
20	67,200	2-5	8	1,586	1,548
21	259,200	2-5	14	1,586	1,556
22	54,400	2-5	9	1,586	1,559
23	30,400	2-5	5	1,584	1,559
24	60,800	2-5	12	1,584	1,562
25	86,400	2-5	4	1,584	1,566

TABLE A.10-3
(continued)

LAKE ZONE NUMBER	ZONE AREA (feet^2)	WATER DEPTH(b) (feet)	LAKE BED THICKNESS(c) (feet)	GROUND WATER POTENTIOMETRIC LEVEL PRECONSTRUCTION(d) (feet above MSL)	MAXIMUM DECLINE(e) (feet above MSL)
26	76,800	2-5	4	1,582	1,569
27	1,116,800	5+	9	1,578	1,563
28	643,200	5+	10	1,580	1,558
29	371,200	5+	13	1,582	1,554
30	156,800	5+	16	1,584	1,550
31	190,400	5+	14	1,586	1,550
32	192,000	5+	14	1,586	1,558
33	294,400	5+	11	1,584	1,558
34	224,000	5+	12	1,584	1,563
35	950,400	5+	14	1,582	1,564
36	763,200	5+	17	1,580	1,561
37	1,060,800	5+	20	1,582	1,558
38	1,132,800	5+	17	1,584	1,555
39	721,600	5+	20	1,586	1,555
40	512,000	5+	12	1,580	1,565
41	236,800	2-5	7	1,580	1,568

(a) Refer to Figure A.10-8 for lake zone map.

(b) Depths inferred from Inman-Foltz (1985).

(c) Lake bed thicknesses inferred from lacustrine isopach contours provided by Exxon (1985b).

(d) Preconstruction potentiometric level based on ground water potentiometric contours shown in Figure A-13.

(e) Maximum decline represents the predicted potentiometric level at Year 28 based on potentiometric contours shown in Figure A-31.

TABLE A.10-4

**SKUNK LAKE AND ADJACENT WETLANDS
LAKE ZONE PARAMETERS(a)**

LAKE ZONE NUMBER	ZONE AREA (feet^2)	WATER DEPTH(b) (feet)	LAKE BED THICKNESS(c) (feet)	GROUND WATER POTENTIOMETRIC LEVEL	
				PRECONSTRUCTION(d) (feet above MSL)	MAXIMUM DECLINE 28(e) (feet above MSL)
1	474,700	0-1	1	1,591	1,586.3
2	92,200	1-2	1	1,591	1,586.3
3	67,800	2-3	1	1,591	1,586.3
4	19,200	3-4	1	1,591	1,586.3
5	9,600	4-5	1	1,591	1,586.3
6	8,500	5+	1	1,591	1,586.3

(a)Refer to Figure A.10-9 for lake zone map.

(b)Depths inferred from Inman-Foltz (1985) and wetlands depth data provided by Exxon (1985a).

(c)Lake bed thicknesses inferred from lacustrine isopach contours provided by Exxon (1985b).

(d)Preconstruction potentiometric level based on ground water potentiometric contours shown in Figure A-13.

(e)Predicted potentiometric level at Year 28 is approximately 1,571 feet above MSL (Figure A-31). This level is below bottom of lake bed lacustrine sediments; therefore, the bottom of lacustrine elevation (1586.3 feet above MSL) represents maximum decline conditions.

TABLE A.10-5

OAK LAKE AND ADJACENT WETLANDS
LAKE ZONE PARAMETERS(a)

LAKE ZONE NUMBER	ZONE AREA ($feet^2$)	WATER DEPTH(b) (feet)	LAKE BED THICKNESS(c) (feet)	GROUND WATER POTENTIOMETRIC LEVEL	
				PRECONSTRUCTION(d) (feet above MSL)	MAXIMUM DECLINE(e) (feet above MSL)
1	804,800	0-2	3	1,623	1,623
2	702,900	2-5	7	1,611	1,611
3	1,535,500	5+	12	1,586	1,586

(a)Refer to Figure A.10-10 for lake bed zone map.

(b)Depths inferred from Inman-Foltz (1985) and wetlands depth data provided by Exxon (1985a).

(c)Lake bed thicknesses inferred from lacustrine isopach contours provided by Exxon (1985b).

(d)Preconstruction potentiometric level is below bottom of lake bed lacustrine sediments; therefore, bottom of lacustrine sediment elevation represents preconstruction conditions.

(e)Predicted potentiometric surface at Year 28 is approximately 1551 feet above MSL (Figure A-31). This level is below bottom of lake bed lacustrine sediments; therefore, bottom of lacustrine sediment elevation represents maximum decline conditions.

TABLE A.10-6

SUMMARY OF LAKE BED PERMEABILITY AND CALCULATED SEEPAGE

LAKE	MEASURED PERMEABILITY RANGE(a) (cm/s)	MEASURED PERMEABILITY RANGE(a) (ft/yr)	UNIFORM PERMEABILITY CASE(b) PERMEABILITY VALUE (ft/yr)	UNIFORM PERMEABILITY CASE(b) CALCULATED SEEPAGE (in/yr)	COMBINED PERMEABILITY CASE(c) PERIMETER PERMEABILITY VALUE (ft/yr)	COMBINED PERMEABILITY CASE(c) INTERIOR PERMEABILITY VALUE (ft/yr)	COMBINED PERMEABILITY CASE(c) CALCULATED SEEPAGE (in/yr)
Duck	1.0×10^{-7} 1.3×10^{-6}	0.10-1.35	0.86	21.4	4.1	0.37	21.1
Deep Hole	6.8×10^{-8} 6.8×10^{-7}	0.07-0.70	0.13	8.1	0.20	0.07	8.3
Little Sand	1.1×10^{-7} 1.6×10^{-6}	0.11-1.66	0.60	7.8	2.0	0.15	7.9
Skunk	4.3×10^{-8}	0.04	0.47	40.0	0.65	0.04	40.1
Oak	3.5×10^{-7} 2.3×10^{-6}	0.36-2.38	0.21	9.1	0.55	0.10	9.2

(a)Source: STS Consultants, Ltd., 1982 and 1984b.

(b)Same permeability value assigned to the entire lake bed.

(c)Higher permeability value assigned to the perimeter (0- to 2-foot water depth) lake zones.

TABLE A.10-7

SEEPAGE AND AREA EQUATIONS USED IN WATER BALANCE ANALYSES

LAKE	RANGE OF LAKE LEVELS	SEEPAGE EQUATION(a)	AREA EQUATION(b)
Duck	LL>1609.1 ft	S = (LL-1605.15)/0.247	A = (LL-1584.71)/0.323
	LL<1609.1 ft	S = (LL-1602.04)/0.442	A = (LL-1603.04)/0.080
Deep Hole	LL>1604.5 ft	S = (LL-1602.02)/0.407	A = (LL-1592.30)/0.109
	LL<1604.5 ft	S = (LL-1598.47)/0.990	A = (LL-1595.90)/0.077
Little Sand, Uniform Permeability Case	LL>1589.8 ft	S = (LL-1582.53)/0.397	A = (LL-1567.24)/0.101
	LL<1589.8 ft	S = (LL-1575.66)/0.773	A = (LL-1568.77)/0.094
Little Sand, High Perimeter Permeabiilty Case	LL>1589.8 ft	S = (LL-1589.27)/0.112	A = (LL-1567.24)/0.101
	LL<1589.8 ft	S = (LL-1575.79)/3.061	A = (LL-1568.77)/0.094
Skunk	LL>1597.09 ft	S = (LL-1586.30)/0.177	A = (LL-1596.68)/0.092
	1597.09>LL>1595.09 ft	S = (LL-1586.30)/0.177	A = (LL-1594.62)/0.549
	LL<1595.09 ft	S = (LL-1586.30)/0.177	A = (LL-1592.48)/3.03
Oak	LL>1631.19	S = (LL-1576.25)/6.25	A = (LL-1625.63)/0.108
	LL<1631.19	S = (LL-2007.90)/-42.86	A = (LL-1621.61)/0.186
Duck, Preconstruction Phase	LL>1609.1 ft	S = (LL-1605.78)/0.249	A = (LL-1584.71)/0.323
	LL<1609.1 ft	S = (LL-1603.79)/0.398	A = (LL-1603.04)/0.080
Skunk, Preconstruction Phase	LL>1597.09 ft	S = (LL-1591.00)/0.177	A = (LL-1596.68)/0.092
	1597.09>LL>1595.09 ft	S = (LL-1591.00)/0.177	A = (LL-1594.62)/0.549
	LL<1595.09 ft	S = (LL-1591.00)/0.177	A = (LL-1592.48)/3.03

(a)S = seepage in inches per year, LL = lake level in feet above MSL; equations are straight line approximations of the curves shown in Figure A.10-11; seepage equations for uniform permeability case and operation phase conditions except as noted.

(b)A = area in acres, LL = lake level in feet MSL.

TABLE A.10-8

LAKE LEVEL FLUCTUATIONS
PRECONSTRUCTION AND OPERATION PHASE CONDITIONS

LAKE	PRECONSTRUCTION CONDITIONS(a)		OPERATION PHASE				
			AVERAGE CLIMATIC YEAR			SECOND DRY CLIMATIC YEAR	
	MAY(b) LAKE LEVEL (ft above MSL)	ANNUAL FLUCTUATION (ft)	MAY LAKE LEVEL (ft above MSL)	ANNUAL FLUCTUATION (ft)	AVERAGE LAKE LEVEL DECLINE(c) (ft)	MAY LAKE LEVEL (ft above MSL)	ANNUAL FLUCTUATION (ft)
Duck	1,611.1	0.3	1,610.8	0.3	0.21	1,609.1	0.7
Deep Hole	1,606.5	0.4	1,606.5	0.3	0.04	1,606.2	0.4
Little Sand							
Uniform Permeability Case	1,591.8	0.3	1,591.6	0.4	0.23	1,591.1	0.4
High Perimeter Permeability Case	1,591.8	0.3	1,591.6	0.3	0.19	1,591.2	0.4
Skunk	1,598.1	0.4	1,597.6	0.3	0.58	1,597.1(d)	0.5
Oak	1,633.2	0.3	1,633.2	0.3	0.00	1,633.1	0.5

(a)Source: Dames and Moore, 1985.
(b)May level used as reference point; see Tables A.10-8 through A.10-19 for monthly fluctuations.
(c)Average decline is the mean value of the monthly differences between computed preconstruction and operation phase lake levels.
(d)May lake level after one dry climatic year.

TABLE A.10-9

DUCK LAKE
ANNUAL WATER BALANCE
OPERATION PHASE
AVERAGE YEAR
UNIFORM PERMEABILITY CASE

ESTIMATED WATER BALANCE COMPONENTS

GAINS	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	YEAR
Precipitation (in)	2.27	1.92	1.19	1.07	0.86	1.59	2.33	3.49	4.42	3.57	4.27	3.73	30.71
Runoff coeff.	0.15	0.24	0.24	0.24	0.24	0.24	0.24	0.16	0.12	0.13	0.09	0.12	
Runoff (in)	1.28	1.73	1.08	0.97	0.78	1.45	2.11	2.11	2.00	1.76	1.46	1.69	18.43
TOTAL (in)	3.55	3.65	2.27	2.04	1.64	3.04	4.44	5.60	6.42	5.33	5.73	5.42	49.14
LOSSES													
Evaporation (in)	1.67	0.98	0.98	0.98	0.98	0.98	0.98	3.74	4.21	4.41	3.52	2.23	25.69
Outflow (cfs)	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	
Outflow (in)	0.00	0.06	0.10	0.06	0.03	0.01	0.01	0.04	0.04	0.05	0.02	0.03	0.44
TOTAL (in)	1.67	1.05	1.08	1.04	1.01	1.00	1.00	3.78	4.25	4.46	3.54	2.26	26.13
LAKE STORAGE (in)	-0.06	0.65	-0.75	-0.91	-1.25	0.16	1.52	-0.10	0.25	-1.03	0.28	1.22	.00
LAKE LEVEL (ft)	1610.9	1611.0	1610.9	1610.8	1610.7	1610.7	1610.9	1610.8	1610.9	1610.8	1610.8	1610.9	
SEEPAGE (in)	-1.94	-1.96	-1.94	-1.91	-1.88	-1.88	-1.92	-1.92	-1.93	-1.90	-1.91	-1.94	-23.02
LAKE AREA (ac)	81.09	81.26	81.07	80.83	80.51	80.55	80.95	80.92	80.98	80.72	80.79	81.11	
SEEPAGE RATE (gpm)	97.5	98.7	97.5	95.7	93.8	93.9	96.4	96.3	96.9	95.1	95.7	97.5	96.2

GENERAL NOTES

(1) Original lake area (ac) = 78.7
(2) Watershed area (ac) = 330
(3) Effective area (ac) = 305.9
(4) Units are inches of lake level unless otherwise specified.
(5) Runoff=Precip (in) * Runoff Coeff. * Effective watershed area (ac) / Lake area (ac).
(6) Negative lake storage values indicate fall in water level.
(7) Negative seepage values indicate outward seepage.
(8) Ordinary High Water Mark = 1611.09 feet.
(9) Outflow (cfs)= $[0.579\ (L-1610)]^{7.69}$ where L = Lake level in feet.
(10) Seepage rate = monthly seepage * lake area. Annual seepage is an average of the monthly values.

TABLE A.10-10

DUCK LAKE
ANNUAL WATER BALANCE
OPERATION PHASE
TWO DRY YEARS AFTER AVERAGE YEAR
UNIFORM PERMEABILITY CASE

ESTIMATED WATER BALANCE COMPONENTS

GAINS	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	YEAR
Precipitation (in)	1.44	2.22	1.18	1.11	0.72	1.23	1.65	2.35	3.03	2.52	2.87	2.48	22.80
Runoff coeff.	0.15	0.24	0.24	0.24	0.24	0.24	0.24	0.16	0.12	0.13	0.09	0.12	
Runoff (in)	0.87	2.14	1.14	1.07	0.70	1.19	1.59	1.48	1.44	1.31	1.04	1.20	15.15
TOTAL (in)	2.31	4.36	2.32	2.18	1.42	2.42	3.24	3.83	4.47	3.83	3.91	3.68	37.95
LOSSES													
Evaporation (in)	1.94	1.11	1.11	1.11	1.11	1.11	1.11	3.91	4.77	5.21	4.02	2.53	29.06
Outflow (cfs)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Outflow (in)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	1.94	1.11	1.11	1.11	1.11	1.11	1.11	3.91	4.77	5.21	4.02	2.53	29.06
LAKE STORAGE (in)	-1.00	1.82	-0.21	-0.34	-1.07	-0.07	0.74	-1.66	-1.83	-2.83	-1.52	-0.25	-8.21
LAKE LEVEL (ft)	1609.2	1609.4	1609.3	1609.3	1609.2	1609.2	1609.3	1609.8	1609.7	1609.4	1609.3	1609.3	
SEEPAGE (in)	-1.37	-1.42	-1.41	-1.40	-1.37	-1.37	-1.39	-1.58	-1.53	-1.45	-1.40	-1.40	-17.09
LAKE AREA (ac)	75.85	76.32	76.26	76.18	75.90	75.88	76.07	77.76	77.29	76.56	76.17	76.11	
SEEPAGE RATE (gpm)	64.4	67.2	66.7	66.1	64.5	64.4	65.5	76.2	73.3	68.8	66.1	66.1	67.4

GENERAL NOTES

(1) Original lake area (ac) = 78.7
(2) Watershed area (ac) = 330
(3) Effective area (ac) = 305.9
(4) Units are inches of lake level unless otherwise specified.
(5) Runoff=Precip (in) * Runoff Coeff. * Effective watershed area (ac) / Lake area (ac).
(6) Negative lake storage values indicate fall in water level.
(7) Negative seepage values indicate outward seepage.
(8) Ordinary High Water Mark = 1611.09 feet.
(9) Outflow (cfs)= $[0.579 (L-1610)]^{7.69}$ where L = Lake level in feet.
(10) Seepage rate = monthly seepage * lake area. Annual seepage rate is an average of the monthly values.

TABLE A.10-11

DEEP HOLE LAKE
ANNUAL WATER BALANCE
OPERATION PHASE
AVERAGE YEAR
UNIFORM PERMEABILITY CASE

ESTIMATED WATER BALANCE COMPONENTS

GAINS	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	YEAR
Precipitation (in)	2.27	1.92	1.19	1.07	0.86	1.59	2.33	3.49	4.42	3.57	4.27	3.73	30.71
Runoff coeff.	0.15	0.24	0.24	0.24	0.24	0.24	0.24	0.16	0.12	0.13	0.09	0.12	
Runoff (in)	2.32	3.13	1.96	1.77	1.43	2.63	3.79	3.80	3.61	3.18	2.63	3.03	33.28
TOTAL (in)	4.59	5.05	3.15	2.84	2.29	4.22	6.12	7.29	8.03	6.75	6.90	6.76	63.99
LOSSES													
Evaporation (in)	1.67	0.98	0.98	0.98	0.98	0.98	0.98	3.74	4.21	4.41	3.52	2.23	25.69
Outflow (cfs)	0.58	0.42	0.52	0.33	0.25	0.19	0.28	0.59	0.50	0.52	0.35	0.40	
Outflow (in)	3.25	2.33	2.93	1.86	1.44	1.04	1.55	3.26	2.76	2.89	1.94	2.24	27.50
TOTAL (in)	4.92	3.32	3.92	2.85	2.43	2.03	2.53	7.00	6.97	7.30	5.46	4.47	53.19
LAKE STORAGE (in)	-1.23	0.82	-1.66	-0.88	-0.99	1.31	2.66	-0.62	0.13	-1.44	0.54	1.37	.00
LAKE LEVEL (ft)	1606.4	1606.5	1606.4	1606.3	1606.2	1606.3	1606.5	1606.5	1606.5	1606.4	1606.4	1606.5	
SEEPAGE (in)	-0.90	-0.92	-0.89	-0.87	-0.86	-0.88	-0.93	-0.92	-0.92	-0.89	-0.90	-0.93	-10.80
LAKE AREA (ac)	129.69	130.32	129.05	128.38	127.62	128.62	130.65	130.17	130.28	129.18	129.59	130.64	
SEEPAGE RATE (gpm)	72.4	74.3	71.2	69.2	68.0	70.2	75.3	74.2	74.3	71.3	72.3	75.3	72.3

GENERAL NOTES

(1) Original lake area (ac) = 128.9
(2) Watershed area (ac) = 885.5
(3) Effective area (ac) = 885.5
(4) Units are inches of lake level unless otherwise specified.
(5) Runoff=Precip (in) * Runoff Coeff. * Effective watershed area (ac)/Lake area (ac.).
(6) Negative lake storage values indicate fall in water level.
(7) Negative seepage values indicate outward seepage.
(8) Ordinary High Water Mark = 1605.83 feet.
(9) Outflow (cfs)= $[0.58\ (L-1605)]^{4.76}$ where L = Lake level in feet.
(10) Seepage rate monthly seepage * lake area. Annual seepage rate is an average of the monthly values.

TABLE A.10-12

DEEP HOLE LAKE
ANNUAL WATER BALANCE
OPERATION PHASE
TWO DRY YEARS AFTER AVERAGE YEAR
UNIFORM PERMEABILITY CASE

ESTIMATED WATER BALANCE COMPONENTS

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	YEAR
GAINS													
Precipitation (in)	1.44	2.22	1.18	1.11	0.72	1.23	1.65	2.35	3.03	2.52	2.87	2.48	22.80
Runoff coeff.	0.15	0.24	0.24	0.24	0.24	0.24	0.24	0.16	0.12	0.13	0.09	0.12	
Runoff (in)	1.52	3.68	1.96	1.85	1.21	2.05	2.73	2.61	2.54	2.32	1.83	2.10	26.40
TOTAL (in)	2.96	5.90	3.14	2.96	1.93	3.28	4.38	4.96	5.57	4.84	4.70	4.58	49.20
LOSSES													
Evaporation	1.94	1.11	1.11	1.11	1.11	1.11	1.11	3.91	4.77	5.21	4.02	2.53	29.06
Outflow (cfs)	0.07	0.07	0.23	0.22	0.20	0.14	0.16	0.26	0.17	0.12	0.06	0.05	
Outflow (in)	0.41	0.37	1.32	1.25	1.16	0.77	0.92	1.49	0.97	0.70	0.34	0.28	9.99
TOTAL	2.35	1.49	2.43	2.37	2.27	1.89	2.04	5.40	5.74	5.91	4.36	2.81	39.05
LAKE STORAGE (in)	-0.20	3.54	-0.16	-0.28	-1.19	0.54	1.46	-1.29	-1.01	-1.87	-0.45	0.96	0.06
LAKE LEVEL (ft)	1606.0	1606.3	1606.3	1606.2	1606.1	1606.2	1606.3	1606.2	1606.1	1605.9	1605.9	1606.0	
SEEPAGE (in)	-0.81	-0.87	-0.87	-0.86	-0.84	-0.85	-0.88	-0.85	-0.84	-0.80	-0.80	-0.81	-10.08
LAKE AREA (ac)	125.45	128.16	128.04	127.83	126.92	127.34	128.45	127.42	126.65	125.22	124.87	125.61	
SEEPAGE RATE (gpm)	63.0	69.1	69.1	68.1	66.1	67.1	70.1	67.1	66.0	62.1	61.9	63.1	66.07

GENERAL NOTES

(1) Original lake area (ac) = 128.9
(2) Watershed area (ac) = 885.5
(3) Effective area (ac) = 885.5
(4) Units are inches of lake level unless otherwise specified.
(5) Runoff=Precip (in) * Runoff Coeff. * Effective watershed area (ac)/Lake area (ac).
(6) Negative lake storage values indicate fall in water level.
(7) Negative seepage values indicate outward seepage.
(8) Ordinary High Water Mark = 1605.83 feet.
(9) Outflow (cfs)= $[0.58 (L-1605)]^{4.76}$ where L = Lake level in feet.
(10) Seepage rate = monthly seepage * lake ara. Annual seepage rate is an average of the monthly values.

TABLE A.10-13

LITTLE SAND LAKE
ANNUAL WATER BALANCE
OPERATION PHASE
AVERAGE YEAR
UNIFORM PERMEABILITY CASE

ESTIMATED WATER BALANCE COMPONENTS

GAINS	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	YEAR
Precipitation (in)	2.27	1.92	1.19	1.07	0.86	1.59	2.33	3.49	4.42	3.57	4.27	3.73	30.71
Runoff coeff.	0.15	0.24	0.24	0.24	0.24	0.24	0.24	0.16	0.12	0.13	0.09	0.12	
Runoff (in)	2.64	3.57	2.23	2.01	1.62	2.99	4.34	4.33	4.11	3.61	2.99	3.46	37.89
Delta Outflow (in)	-0.30	-0.20	-0.30	-0.18	-0.13	-0.09	-0.15	-0.32	-0.20	-0.22	-0.13	-0.18	-2.40
TOTAL (in)	4.61	5.29	3.11	2.90	2.35	4.48	6.52	7.50	8.33	6.96	7.12	7.01	66.19
LOSSES													
Evaporation (in)	1.67	0.98	0.98	0.98	0.98	0.98	0.98	3.74	4.21	4.41	3.52	2.23	25.69
Outflow (cfs)	0.72	0.54	0.66	0.42	0.30	0.19	0.27	0.60	0.61	0.67	0.47	0.51	
Outflow (in)	2.17	1.63	2.00	1.27	0.90	0.59	0.82	1.79	1.82	2.02	1.42	1.53	17.97
TOTAL (in)	3.84	2.61	2.98	2.25	1.89	1.57	1.80	5.53	6.03	6.43	4.94	3.76	43.65
LAKE STORAGE (in)	-1.11	0.77	-1.74	-1.20	-1.37	1.07	2.83	0.07	0.40	-1.36	0.30	1.34	0.00
LAKE LEVEL (ft)	1591.5	1591.6	1591.4	1591.3	1591.2	1591.3	1591.5	1591.6	1591.6	1591.5	1591.5	1591.6	
SEEPAGE (in)	-1.89	-1.90	-1.87	-1.85	-1.83	-1.84	-1.89	-1.89	-1.90	-1.88	-1.88	-1.91	-22.54
LAKE AREA (ac)	240.36	241.00	239.56	238.57	237.45	238.33	240.66	240.72	241.05	239.93	240.17	241.28	
SEEPAGE RATE (gpm)	281.6	283.9	277.7	273.6	269.4	271.9	282.0	282.0	283.9	279.6	279.9	285.7	279.3

OUTFLOW REDUCTION CALCULATION

Original Deep Hole (cfs)	0.64	0.45	0.57	0.36	0.28	0.21	0.32	0.67	0.54	0.56	0.38	0.45
Operation Phase Deep Hole (cfs)	0.58	0.42	0.52	0.33	0.25	0.19	0.28	0.59	0.50	0.52	0.35	0.40
Delta Deep Hole (cfs)	0.06	0.03	0.05	0.03	0.03	0.02	0.04	0.08	0.04	0.04	0.03	0.05
Original Duck (cfs)	0.04	0.03	0.05	0.03	0.02	0.01	0.01	0.02	0.02	0.03	0.01	0.02
Operation Phase Duck (cfs)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta Duck (cfs)	0.04	0.03	0.05	0.03	0.02	0.01	0.01	0.02	0.02	0.03	0.01	0.02
Total Delta Outflow (cfs)	0.10	0.06	0.10	0.06	0.05	0.03	0.05	0.10	0.06	0.07	0.04	0.07

GENERAL NOTES

(1) Original lake area (ac) = 244.1.
(2) Watershed area (ac) = 2519.
(3) Effective area (ac) = 1866.5.
(4) Units are inches of lake level unless otherwise specified.
(5) Runoff=Precip (in.) * Runoff Coeff. * Effective watershed area (ac)/Lake area (ac).
(6) Delta outflow is the summation of the reduction in Deep Hole and Duck Lake outflows to Little Sand Lake.
(7) Negative lake storage values indicate fall in water level.
(8) Negative seepage values indicate outward seepage.
(9) Ordinary High Water Mark = 1591.96 feet.
(10) Outflow (cfs) = $[0.58(L-1590)]^{4.76}$ where L = Lake level in feet.
(11) Seepage rate = Monthly seepage * Lake area. Annual seepage rate is an average of the monthly values.
(12) Original Duck Lake outflows from Dames and Moore (1985); operation phase Duck Lake outflows set at 0.00.

TABLE A.10-14

LITTLE SAND LAKE
ANNUAL WATER BALANCE
OPERATION PHASE
AVERAGE YEAR
HIGH PERIMETER PERMEABILITY CASE

ESTIMATED WATER BALANCE COMPONENTS

GAINS	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	YEAR
Precipitation(in)	2.27	1.92	1.19	1.07	0.86	1.59	2.33	3.49	4.42	3.57	4.27	3.73	30.71
Runoff coeff.	0.15	0.24	0.24	0.24	0.24	0.24	0.24	0.16	0.12	0.13	0.09	0.12	
Runoff (in)	2.64	3.56	2.22	2.01	1.62	2.98	4.33	4.32	4.10	3.61	2.98	3.46	37.83
Delta Outflow (in)	-0.30	-0.20	-0.30	-0.18	-0.13	-0.09	-0.15	-0.32	-0.20	-0.22	-0.13	-0.18	-2.40
TOTAL (in)	4.61	5.28	3.11	2.90	2.35	4.48	6.51	7.49	8.33	6.95	7.12	7.01	66.13
LOSSES													
Evaporation (in)	1.67	0.98	0.98	0.98	0.98	0.98	0.98	3.74	4.21	4.41	3.52	2.23	25.69
Outflow (cfs)	0.79	0.60	0.72	0.47	0.35	0.24	0.35	0.72	0.69	0.74	0.53	0.57	
Outflow (in)	2.38	1.79	2.18	1.41	1.05	0.73	1.04	2.15	2.08	2.24	1.58	1.71	20.35
TOTAL (in)	4.05	2.77	3.16	2.40	2.04	1.72	2.02	5.89	6.29	6.65	5.10	3.94	46.04
LAKE STORAGE (in)	-1.14	0.76	-1.69	-1.07	-1.19	1.18	2.75	-0.14	0.28	-1.37	0.33	1.29	0.00
LAKE LEVEL (ft)	1591.5	1591.6	1591.5	1591.4	1591.3	1591.4	1591.6	1591.6	1591.6	1591.5	1591.5	1591.6	
SEEPAGE (in)	-1.70	-1.75	-1.64	-1.57	-1.50	-1.57	-1.74	-1.74	-1.75	-1.67	-1.69	-1.77	-20.09
LAKE AREA (ac)	240.66	241.29	239.89	239.01	238.02	239.00	241.27	241.15	241.39	240.26	240.53	241.60	
SEEPAGE RATE (gpm)	253.6	261.8	243.9	232.6	221.3	232.6	260.2	260.1	261.9	248.7	252.0	265.1	249.5

OUTFLOW REDUCTION CALCULATION

Original Deep Hole (cfs)	0.64	0.45	0.57	0.36	0.28	0.21	0.32	0.67	0.54	0.56	0.38	0.45
Operation Phase Deep Hole (cfs)	0.58	0.42	0.52	0.33	0.25	0.19	0.28	0.59	0.50	0.52	0.35	0.40
Delta Deep Hole (cfs)	0.06	0.03	0.05	0.03	0.03	0.02	0.04	0.08	0.04	0.04	0.03	0.05
Original Duck (cfs)	0.04	0.03	0.05	0.03	0.02	0.01	0.01	0.02	0.02	0.03	0.01	0.02
Operation Phase Duck (cfs)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta Duck (cfs)	0.04	0.03	0.05	0.03	0.02	0.01	0.01	0.02	0.02	0.03	0.01	0.02
Total Delta Outflow (cfs)	0.10	0.06	0.10	0.06	0.05	0.03	0.05	0.10	0.06	0.07	0.04	0.07

GENERAL NOTES

(1) Original lake area (ac) = 244.1.
(2) Watershed area (ac) = 2519.
(3) Effective area (ac) = 1866.5.
(4) Units are inches of lake level unless otherwise specified.
(5) Runoff=Precip (in.) * Runoff Coeff. * Effective watershed area (ac)/Lake area (ac).
(6) Delta outflow is the summation of the reduction in Deep Hole and Duck Lake outflows to Little Sand Lake.
(7) Negative lake storage values indicate fall in water level.
(8) Negative seepage values indicate outward seepage.
(9) Ordinary High Water Mark = 1591.96 feet.
(10) Outflow (cfs) = $[0.58(L-1590)]^{4.76}$ where L = Lake level in feet.
(11) Seepage rate = Monthly seepage * Lake area. Annual seepage rate is an average of the monthly values.
(12) Original Duck Lake outflows from Dames and Moore (1985); operation phase Duck Lake outflows set at 0.00.

TABLE A.10-15

LITTLE SAND LAKE
ANNUAL WATER BALANCE
OPERATION PHASE
TWO DRY YEARS AFTER AVERAGE YEAR
UNIFORM PERMEABILITY CASE

ESTIMATED WATER BALANCE COMPONENTS

GAINS	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	YEAR
Precipitation (in)	1.44	2.22	1.18	1.11	0.72	1.23	1.65	2.35	3.03	2.52	2.87	2.48	22.80
Runoff coeff.	0.15	0.24	0.24	0.24	0.24	0.24	0.24	0.16	0.12	0.13	0.09	0.12	
Runoff (in)	1.73	4.22	2.24	2.11	1.38	2.35	3.13	2.97	2.89	2.62	2.07	2.38	30.10
Delta Outflow (in)	-0.05	-0.05	-0.15	-0.12	-0.10	-0.07	-0.09	-0.14	-0.19	-0.06	-0.03	-0.03	-1.08
TOTAL (in)	3.12	6.39	3.27	3.10	1.99	3.50	4.69	5.18	5.73	5.08	4.91	4.83	51.80
LOSSES													
Evaporation (in)	1.94	1.11	1.11	1.11	1.11	1.11	1.11	3.91	4.77	5.21	4.02	2.53	29.06
Outflow (cfs)	0.02	0.02	0.08	0.09	0.08	0.05	0.06	0.12	0.11	0.07	0.03	0.02	
Outflow (in)	0.07	0.05	0.25	0.26	0.26	0.16	0.19	0.36	0.35	0.22	0.09	0.06	2.33
TOTAL (in)	2.01	1.17	1.37	1.38	1.37	1.28	1.31	4.27	5.12	5.43	4.11	2.59	31.39
LAKE STORAGE (in)	-0.61	3.45	0.12	-0.06	-1.15	0.45	1.58	-0.88	-1.17	-2.09	-0.93	0.51	-0.77
LAKE LEVEL (ft)	1590.7	1591.0	1591.0	1591.0	1590.9	1591.0	1591.1	1591.1	1591.0	1590.8	1590.7	1590.8	
SEEPAGE (in)	-1.72	-1.78	-1.78	-1.78	-1.76	-1.77	-1.80	-1.80	-1.78	-1.74	-1.72	-1.73	-21.18
LAKE AREA (ac)	232.59	235.44	235.54	235.49	234.54	234.92	236.22	236.13	235.17	233.44	232.68	233.10	
SEEPAGE RATE (gpm)	248.0	259.8	259.9	259.9	255.9	257.8	263.6	263.5	259.5	251.8	248.1	250.0	256.5

OUTFLOW REDUCTION CALCULATION

Original Deep Hole (cfs)	0.11	0.10	0.32	0.28	0.25	0.16	0.20	0.31	0.54	0.23	0.10	0.08
Operation Phase Deep Hole (cfs)	0.10	0.08	0.27	0.24	0.21	0.14	0.17	0.27	0.50	0.21	0.09	0.07
Delta Deep Hole (cfs)	0.01	0.02	0.05	0.04	0.04	0.02	0.03	0.04	0.04	0.02	0.01	0.01
Original Duck (cfs)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
Operation Phase Duck (cfs)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta Duck (cfs)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
Total Delta Outflow (cfs)	0.01	0.02	0.05	0.04	0.04	0.02	0.03	0.04	0.06	0.02	0.01	0.01

GENERAL NOTES

(1) Original lake area (ac) = 244.1.
(2) Watershed area (ac) = 2519.
(3) Effective area (ac) = 1866.5.
(4) Units are inches of lake level unless otherwise specified.
(5) Runoff=Precip (in.) * Runoff Coeff. * Effective watershed area (ac)/Lake area (ac).
(6) Delta outflow is the summation of the reduction in Deep Hole and Duck Lake outflows to Little Sand Lake.
(7) Negative lake storage values indicate fall in water level.
(8) Negative seepage values indicate outward seepage.
(9) Ordinary High Water Mark = 1591.96 feet.
(10) Outflow (cfs) = $[0.58(L-1590)]^{4.76}$ where L = Lake level in feet.
(11) Seepage rate = Monthly seepage * Lake area. Annual seepage rate is an average of the monthly values.

TABLE A.10-16

LITTLE SAND LAKE
ANNUAL WATER BALANCE
OPERATION PHASE
TWO DRY YEARS AFTER AVERAGE YEAR
HIGH PERIMETER PERMEABILITY CASE

ESTIMATED WATER BALANCE COMPONENTS

GAINS	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	YEAR
Precipitation(in)	1.44	2.22	1.18	1.11	0.72	1.23	1.65	2.35	3.03	2.52	2.87	2.48	22.80
Runoff coeff.	0.15	0.24	0.24	0.24	0.24	0.24	0.24	0.16	0.12	0.13	0.09	0.12	
Runoff (in)	1.72	4.18	2.22	2.09	1.36	2.32	3.10	2.96	2.87	2.60	2.06	2.36	29.84
Delta Outflow (in)	-0.05	-0.05	-0.15	-0.12	-0.10	-0.07	-0.09	-0.14	-0.19	-0.06	-0.03	-0.03	-1.08
TOTAL (in)	3.11	6.35	3.25	3.08	1.98	3.48	4.66	5.17	5.71	5.06	4.89	4.81	51.55
LOSSES													
Evaporation	1.94	1.11	1.11	1.11	1.11	1.11	1.11	3.91	4.77	5.21	4.02	2.53	29.06
Outflow (cfs)	0.07	0.06	0.23	0.23	0.21	0.14	0.17	0.27	0.19	0.13	0.07	0.05	
Outflow (in)	0.23	0.20	0.70	0.69	0.65	0.44	0.52	0.84	0.58	0.41	0.21	0.16	5.62
TOTAL (in)	2.17	1.31	1.82	1.80	1.77	1.55	1.63	4.75	5.35	5.62	4.23	2.69	34.69
LAKE STORAGE (in)	-0.33	3.55	-0.05	-0.20	-1.19	0.50	1.51	-1.03	-1.03	-1.83	-0.57	0.83	0.15
LAKE LEVEL (ft)	1591.0	1591.3	1591.3	1591.2	1591.1	1591.2	1591.3	1591.2	1591.1	1591.0	1590.9	1591.0	
SEEPAGE (in)	-1.27	-1.49	-1.49	-1.47	-1.40	-1.43	-1.52	-1.45	-1.39	-1.27	-1.24	-1.29	-16.72
LAKE AREA (ac)	234.96	237.89	237.85	237.68	236.71	237.11	238.36	237.38	236.53	235.02	234.55	235.23	
SEEPAGE RATE (gpm)	185.0	219.7	219.7	216.6	205.4	210.2	224.6	213.4	203.8	185.0	180.3	188.1	204.3

OUTFLOW REDUCTION CALCULATION

Original Deep Hole (cfs)	0.11	0.10	0.32	0.28	0.25	0.16	0.20	0.31	0.54	0.23	0.10	0.08
Operation Phase Deep Hole (cfs)	0.10	0.08	0.27	0.24	0.21	0.14	0.17	0.27	0.50	0.21	0.09	0.07
Delta Deep Hole (cfs)	0.01	0.02	0.05	0.04	0.04	0.02	0.03	0.04	0.04	0.02	0.01	0.01
Original Duck (cfs)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
Operation Phase Duck (cfs)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delta Duck (cfs)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
Total Delta Outflow	0.01	0.02	0.05	0.04	0.04	0.02	0.03	0.04	0.06	0.02	0.01	0.01

GENERAL NOTES

(1) Original lake area (ac) = 244.1.
(2) Watershed area (ac) = 2519.
(3) Effective area (ac) = 1866.5.
(4) Units are inches of lake level unless otherwise specified.
(5) Runoff=Precip (in.) * Runoff Coeff. * Effective watershed area (ac)/Lake area (ac).
(6) Delta outflow is the summation of the reduction in Deep Hole and Duck Lake outflows to Little Sand Lake.
(7) Negative lake storage values indicate fall in water level.
(8) Negative seepage values indicate outward seepage.
(9) Ordinary High Water Mark = 1591.96 feet.
(10) Outflow (cfs) = $[0.58(L-1590)]^{4.76}$ where L = Lake level in feet.
(11) Seepage rate = Monthly seepage * Lake area. Annual seepage rate is an average of the monthly values.

TABLE A.10-17

SKUNK LAKE
ANNUAL WATER BALANCE
OPERATION PHASE
AVERAGE YEAR
UNIFORM PERMEABILITY CASE

ESTIMATED WATER BALANCE COMPONENTS

GAINS	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	YEAR
Precipitation (in)	2.27	1.92	1.19	1.07	0.86	1.59	2.33	3.49	4.42	3.57	4.27	3.73	30.71
Runoff coeff.	0.15	0.24	0.24	0.24	0.24	0.24	0.24	0.16	0.12	0.13	0.09	0.12	
Runoff (in)	3.90	5.00	3.57	3.74	3.69	5.79	6.34	6.22	5.65	5.32	4.45	4.77	58.42
TOTAL (in)	6.17	6.92	4.76	4.81	4.55	7.38	8.67	9.71	10.07	8.89	8.72	8.50	89.13
LOSSES													
Evaporation	1.67	0.98	0.98	0.98	0.98	0.98	0.98	3.74	4.21	4.41	3.52	2.23	25.69
Outflow (cfs)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Outflow (in)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL (in)	1.67	0.98	0.98	0.98	0.98	0.98	0.98	3.74	4.21	4.41	3.52	2.23	25.69
LAKE STORAGE (in)	-0.81	0.60	-1.50	-1.40	-1.59	1.19	2.37	0.65	0.51	-0.83	-0.11	0.93	.00
LAKE LEVEL (ft)	1597.6	1597.6	1597.5	1597.4	1597.3	1597.4	1597.6	1597.6	1597.6	1597.6	1597.6	1597.6	
SEEPAGE (in)	-5.31	-5.33	-5.28	-5.22	-5.16	-5.21	-5.32	-5.32	-5.34	-5.31	-5.31	-5.34	-63.44
LAKE AREA (ac)	9.78	10.32	8.96	7.70	6.26	7.39	9.89	10.05	10.52	9.77	9.68	10.51	
SEEPAGE RATE (gpm)	32.2	34.1	29.3	24.9	20.0	23.9	32.6	33.1	34.8	32.2	31.9	34.8	30.32

GENERAL NOTES

(1) Original lake area (ac) = 15.7
(2) Watershed area (ac) = 375
(3) Effective area (ac) = 112.0
(4) Units are inches of lake level unless otherwise specified.
(5) Runoff=Precip (in) * Runoff Coeff. * Effective watershed area (ac)/Lake area (ac).
(6) Negative lake storage values indicate fall in water level.
(7) Negative seepage values indicate outward seepage.
(8) Ordinary High Water Mark = 1598.09 feet.
(9) Outflow (cfs)= 0 at all times.
(10) Seepage Rate = monthly seepage * the lake area. Annual seepage rate is an average of the monthly values.

TABLE A.10-18

SKUNK LAKE
ANNUAL WATER BALANCE
OPERATION PHASE
ONE DRY YEAR AFTER AVERAGE YEAR
UNIFORM PERMEABILITY CASE

ESTIMATED WATER BALANCE COMPONENTS

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	YEAR
GAINS													
Precipitation (in)	1.44	2.22	1.18	1.11	0.72	1.23	1.65	2.35	3.03	2.52	2.87	2.48	22.80
Runoff coeff.	0.15	0.24	0.24	0.24	0.24	0.24	0.24	0.16	0.12	0.13	0.09	0.12	
Runoff (in)	4.74	7.40	4.33	4.47	3.78	5.73	6.20	4.18	4.95	5.78	5.30	5.66	62.52
TOTAL (in)	6.18	9.62	5.51	5.58	4.50	6.96	7.85	6.53	7.98	8.30	8.17	8.14	85.32
LOSSES													
Evaporation (in)	1.94	1.11	1.11	1.11	1.11	1.11	1.11	3.91	4.77	5.21	4.02	2.53	29.06
Outflow (cfs)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Outflow (in)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL (in)	1.94	1.11	1.11	1.11	1.11	1.11	1.11	3.91	4.77	5.21	4.02	2.53	29.06
LAKE STORAGE (in)	-0.87	3.27	-0.81	-0.72	-1.72	0.71	1.54	-2.70	-2.03	-2.07	-0.98	0.47	-5.91
LAKE LEVEL (ft)	1597.1	1597.4	1597.4	1597.3	1597.2	1597.2	1597.3	1597.6	1597.4	1597.3	1597.2	1597.2	
SEEPAGE (in)	-5.11	-5.24	-5.20	-5.18	-5.11	-5.14	-5.20	-5.32	-5.24	-5.16	-5.12	-5.14	-62.16
LAKE AREA (ac)	5.10	8.06	7.33	6.68	5.12	5.77	7.16	10.07	8.22	6.35	5.46	5.89	
SEEPAGE RATE (gpm)	16.2	26.2	23.6	21.5	16.2	18.4	23.1	33.2	26.7	20.3	17.3	18.8	21.8

GENERAL NOTES

(1) Original lake area (ac) = 15.7
(2) Watershed area (ac) = 375
(3) Effective area (ac) = 112.0
(4) Units are inches of lake level unless otherwise specified.
(5) Runoff=Precip (in) * Runoff Coeff. * Effective watershed area (ac) / Lake area (ac).
(6) Negative lake storage values indicate fall in water level.
(7) Negative seepage values indicate outward seepage.
(8) Ordinary High Water Mark = 1598.09 feet.
(9) Outflow (cfs)= 0 at all times.
(10) Seepage rate = monthly seepage * lake area. Annual seepage is an average of the monthly values.

TABLE A.10-19

OAK LAKE
ANNUAL WATER BALANCE
OPERATION PHASE
AVERAGE YEAR
UNIFORM PERMEABILITY CASE

ESTIMATED WATER BALANCE COMPONENTS

GAINS	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	YEAR
Precipitation (in)	2.27	1.92	1.19	1.07	0.86	1.59	2.33	3.49	4.42	3.57	4.27	3.73	30.71
Runoff coeff.	0.15	0.24	0.24	0.24	0.24	0.24	0.24	0.16	0.12	0.13	0.09	0.12	
Runoff (in)	1.72	2.32	1.44	1.29	1.04	1.92	2.82	2.82	2.67	2.34	1.94	2.26	24.58
TOTAL (in)	3.99	4.24	2.63	2.36	1.90	3.51	5.15	6.31	7.09	5.91	6.21	5.99	55.29
LOSSES													
Evaporation (in)	1.67	0.98	0.98	0.98	0.98	0.98	0.98	3.74	4.21	4.41	3.52	2.23	25.69
Outflow (cfs)	0.33	0.12	0.24	0.10	0.08	0.05	0.11	0.38	0.12	0.20	0.09	0.16	
Outflow (in)	3.44	1.21	2.51	0.99	0.79	0.53	1.14	3.98	1.20	2.04	0.96	1.69	20.48
TOTAL (in)	5.11	2.19	3.49	1.98	1.77	1.51	2.13	7.72	5.41	6.45	4.48	3.92	46.17
LAKE STORAGE (in)	-1.88	1.29	-1.62	-0.37	-0.63	1.24	2.26	-2.18	0.93	-1.30	0.97	1.30	0.00
LAKE LEVEL (ft)	1633.2	1633.3	1633.2	1633.1	1633.1	1633.2	1633.4	1633.2	1633.3	1633.2	1633.2	1633.4	
SEEPAGE (in)	-0.76	-0.76	-0.76	-0.76	-0.76	-0.76	-0.76	-0.76	-0.76	-0.76	-0.76	-0.76	-9.12
LAKE AREA (ac)	70.04	71.03	69.78	69.49	69.01	69.97	71.71	70.02	70.74	69.74	70.49	71.49	
SEEPAGE RATE (gpm)	33.0	33.5	32.9	32.7	32.5	33.0	33.8	33.0	33.3	32.9	33.2	33.7	33.1

GENERAL NOTES

(1) Original lake area (ac) = 69.9.
(2) Watershed area (ac) = 375.
(3) Effective area (ac) = 352.4.
(4) Units are inches on lake unless otherwise specified.
(5) Runoff=Precip (in.) * Runoff Coeff. * Effective watershed area (ac)/Lake area (ac).
(6) Negative lake storage values indicate fall in water level.
(7) Negative seepage values indicate outward seepage.
(8) Ordinary High Water Mark = 1633.17 feet.
(9) Outflow (cfs)= $[0.65 (L-1632)]^{8.47}$ where L = Lake level in feet.
(10) Seepage rate = Monthly seepage * Lake area. Annual seepage rate is an average of the monthly values.

TABLE A.10-20

OAK LAKE
ANNUAL WATER BALANCE
OPERATION PHASE
TWO DRY YEARS AFTER AVERAGE YEAR
UNIFORM PERMEABILITY CASE

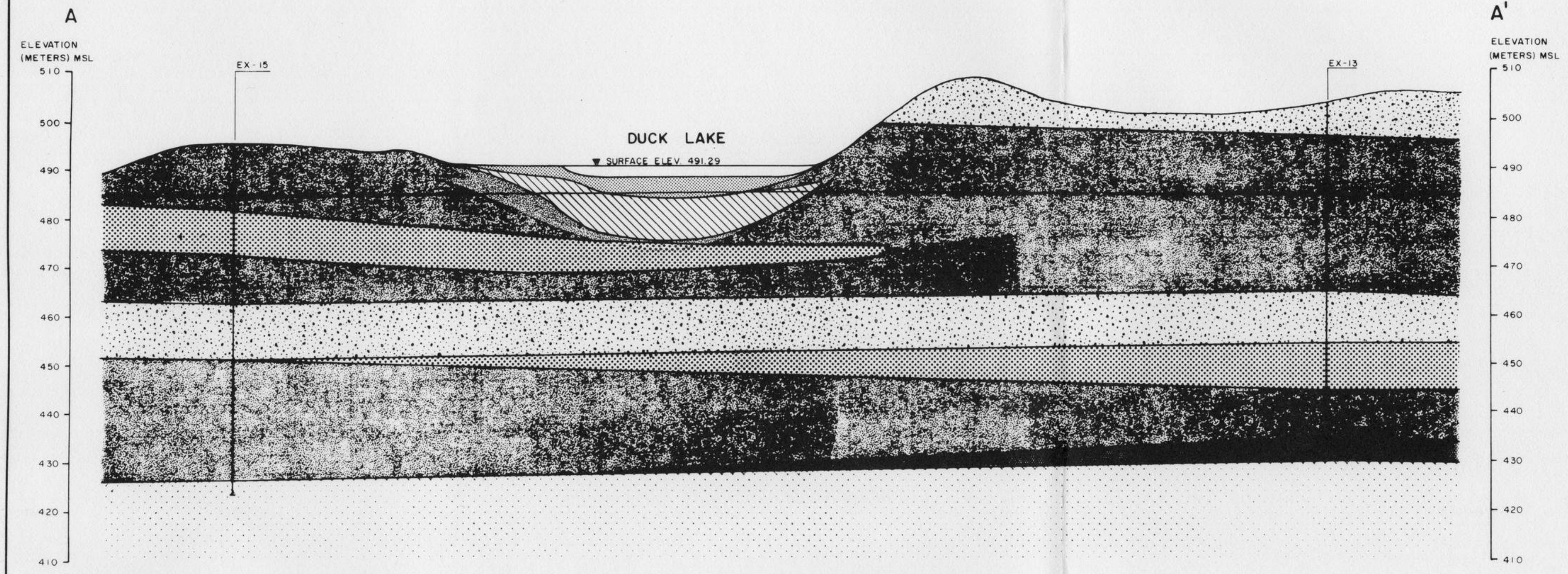
ESTIMATED WATER BALANCE COMPONENTS

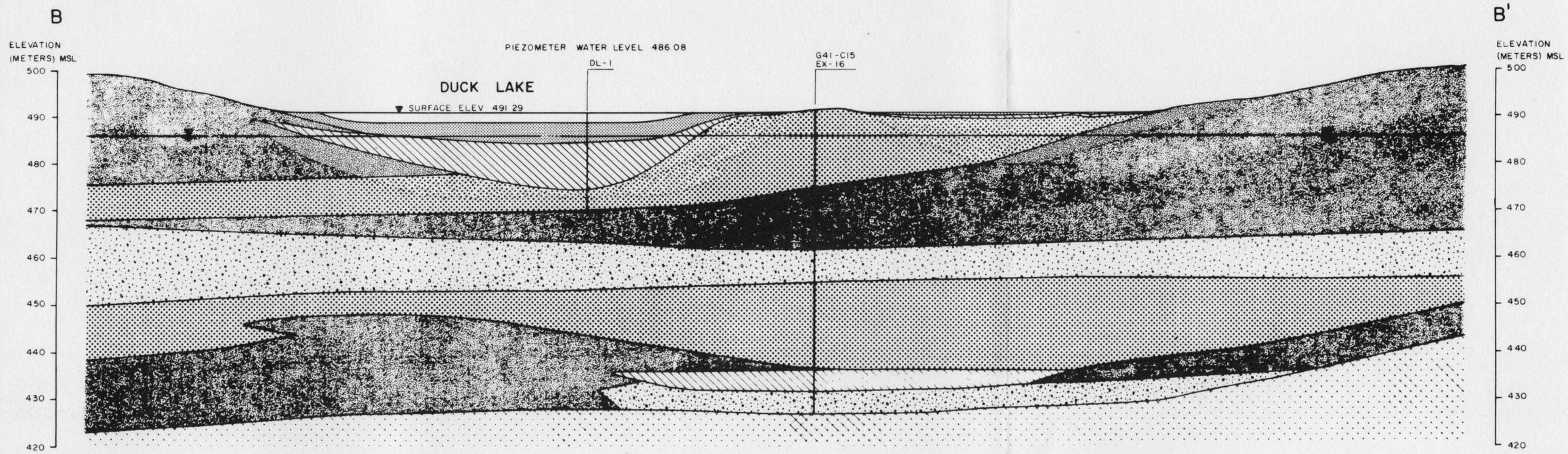
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	YEAR
GAINS													
Precipitation (in)	1.44	2.22	1.18	1.11	0.72	1.23	1.65	2.35	3.03	2.52	2.87	2.48	22.80
Runoff coeff.	0.15	0.24	0.24	0.24	0.24	0.24	0.24	0.16	0.12	0.13	0.09	0.12	
Runoff (in)	1.09	2.69	1.43	1.34	0.87	1.49	2.00	1.90	1.83	1.65	1.30	1.50	19.08
TOTAL (in)	2.53	4.91	2.61	2.45	1.59	2.72	3.65	4.25	4.86	4.17	4.17	3.98	41.88
LOSSES													
Evaporation (in)	1.94	1.11	1.11	1.11	1.11	1.11	1.11	3.91	4.77	5.21	4.02	2.53	29.06
Outflow (cfs)	0.00	0.00	0.03	0.04	0.05	0.03	0.04	0.10	0.04	0.02	0.00	0.00	
Outflow (in)	0.04	0.03	0.35	0.46	0.50	0.29	0.43	1.01	0.42	0.20	0.04	0.02	3.78
TOTAL (in)	1.98	1.15	1.47	1.57	1.61	1.41	1.54	4.92	5.19	5.41	4.06	2.55	32.85
LAKE STORAGE (in)	-0.21	3.00	0.38	0.12	-0.78	0.55	1.34	-1.43	-1.08	-1.99	-0.64	0.67	-0.04
LAKE LEVEL (ft)	1632.8	1633.0	1633.1	1633.1	1633.0	1633.1	1633.2	1633.1	1633.0	1632.8	1632.7	1632.8	
SEEPAGE (in)	-0.75	-0.76	-0.76	-0.76	-0.76	-0.76	-0.76	-0.76	-0.76	-0.75	-0.75	-0.75	-9.07
LAKE AREA (ac)	66.23	68.54	68.84	68.93	68.34	68.76	69.80	68.73	67.90	66.36	65.87	66.39	
SEEPAGE RATE (gpm)	30.8	32.3	32.4	32.5	32.2	32.4	32.9	32.4	32.0	30.9	30.6	30.9	31.9

GENERAL NOTES

(1) Original lake area (ac) = 69.9.
(2) Watershed area (ac) = 375.
(3) Effective area (ac) = 352.4.
(4) Units are inches on lake unless otherwise specified.
(5) Runoff=Precip (in.) * Runoff Coeff. * Effective watershed area (ac)/Lake area (ac).
(6) Negative lake storage values indicate fall in water level.
(7) Negative seepage values indicate outward seepage.
(8) Ordinary High Water Mark = 1633.17 feet.
(9) Outflow (cfs)= $[0.65\ (L-1632)]^{8.47}$ where L = Lake level in feet.
(10) Seepage rate = Monthly seepage * Lake area. Annual seepage rate is an average of the monthly values.

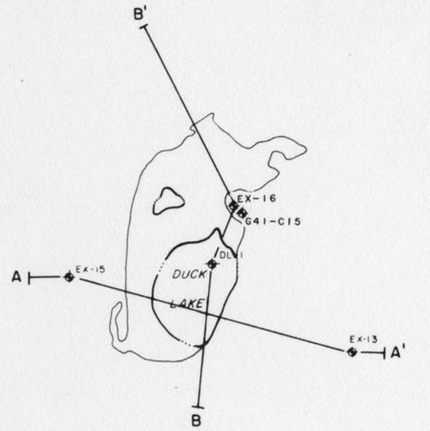
FIGURES





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

FIGURE A.10-1

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
GEOLOGIC SECTIONS THROUGH DUCK LAKE

SCALE AS SHOWN | STATE WISCONSIN | COUNTY FOREST

DRAWN BY RW | DATE 5-23-85 | CHECKED BY MMR
APPROVED BY | DATE | APPROVED BY SHD
APPROVED BY | DATE | EXXON

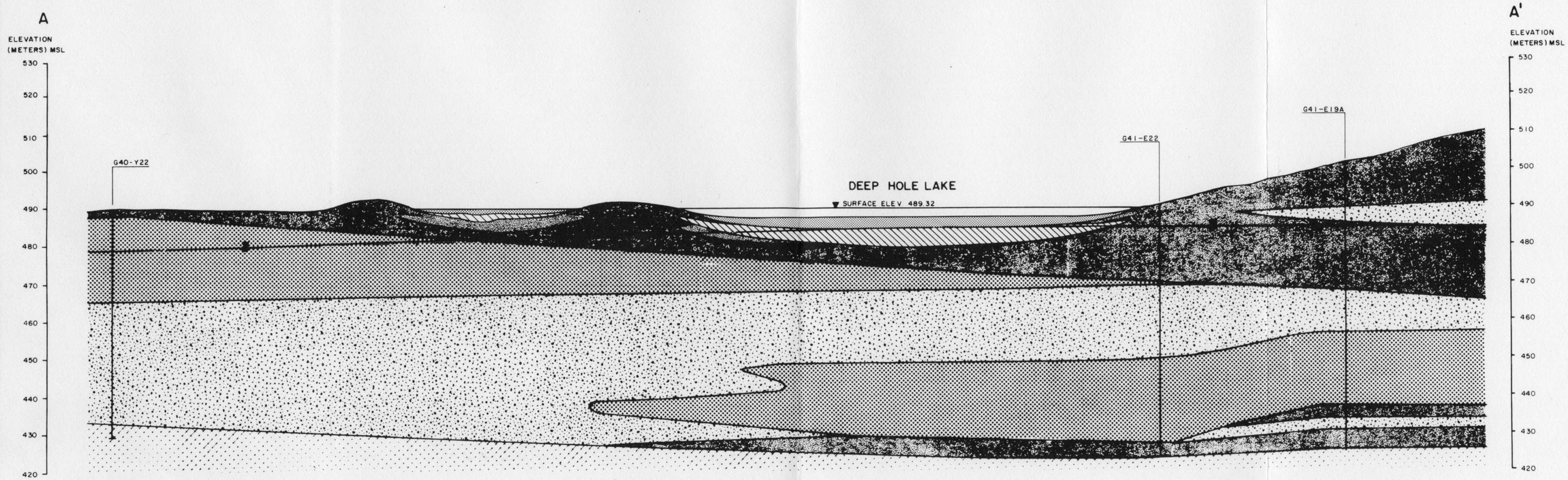
DRAWING NO | SHEET OF | REVISION NO 1

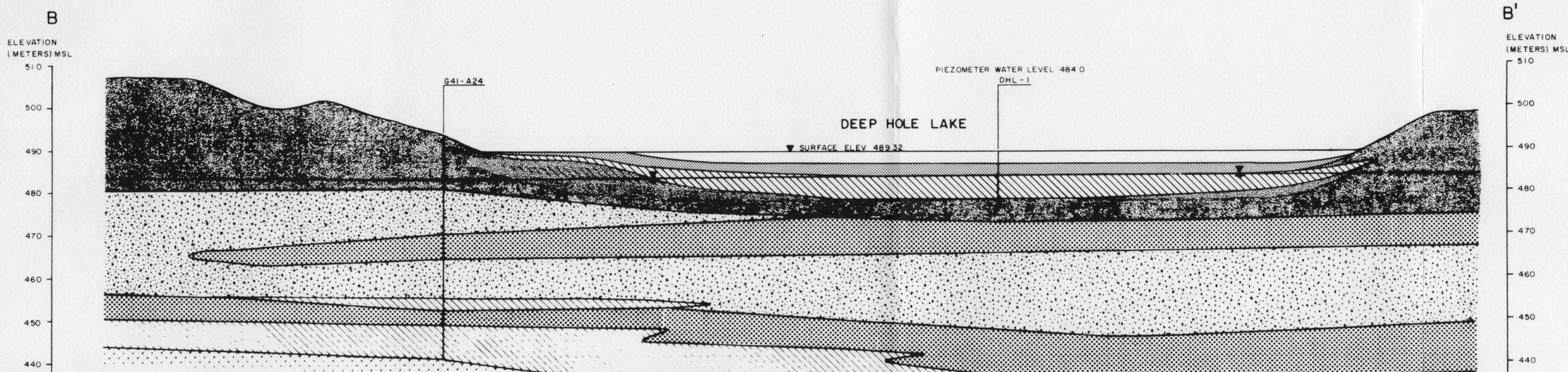
REVISED	DATE	BY	DESCRIPTION
1	7-12-85	DRS	ADDED WETLAND DATA ON NORTH & WEST SIDE OF LAKE

D'APPOLONIA

PROJ. NO. | DWG. NO. 850103-E3

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



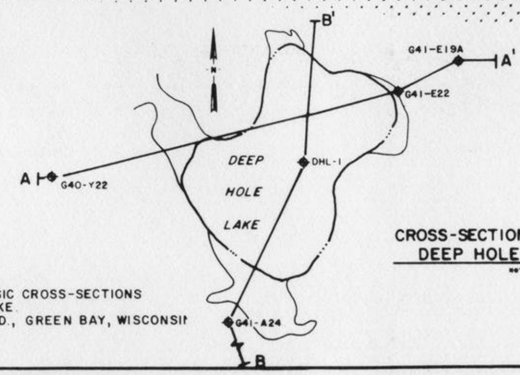


LEGEND

- 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



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

FIGURE A.10-2

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

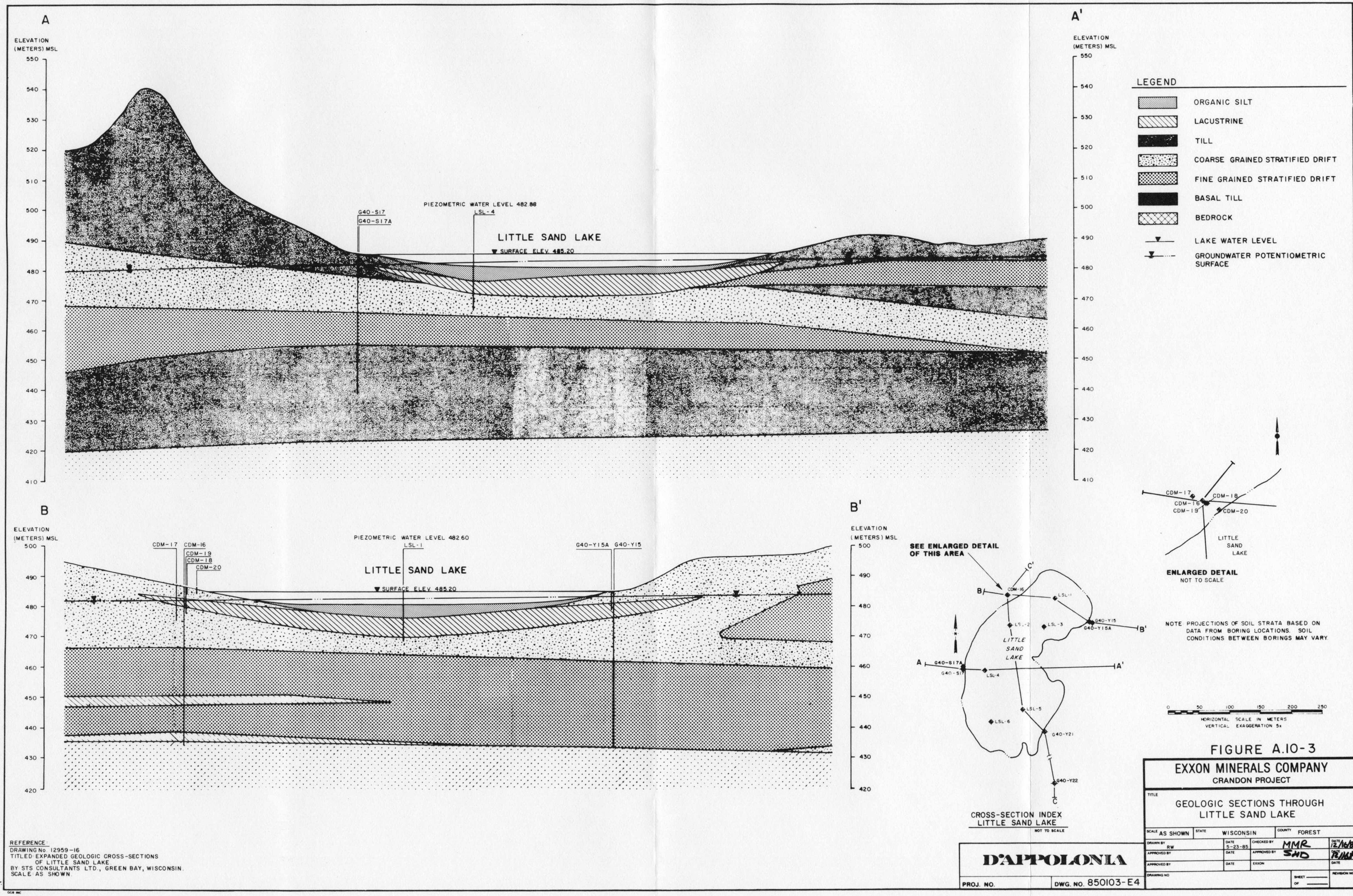
D'APPOLONIA

PROJ. NO.
DWG. NO. 850103-E2

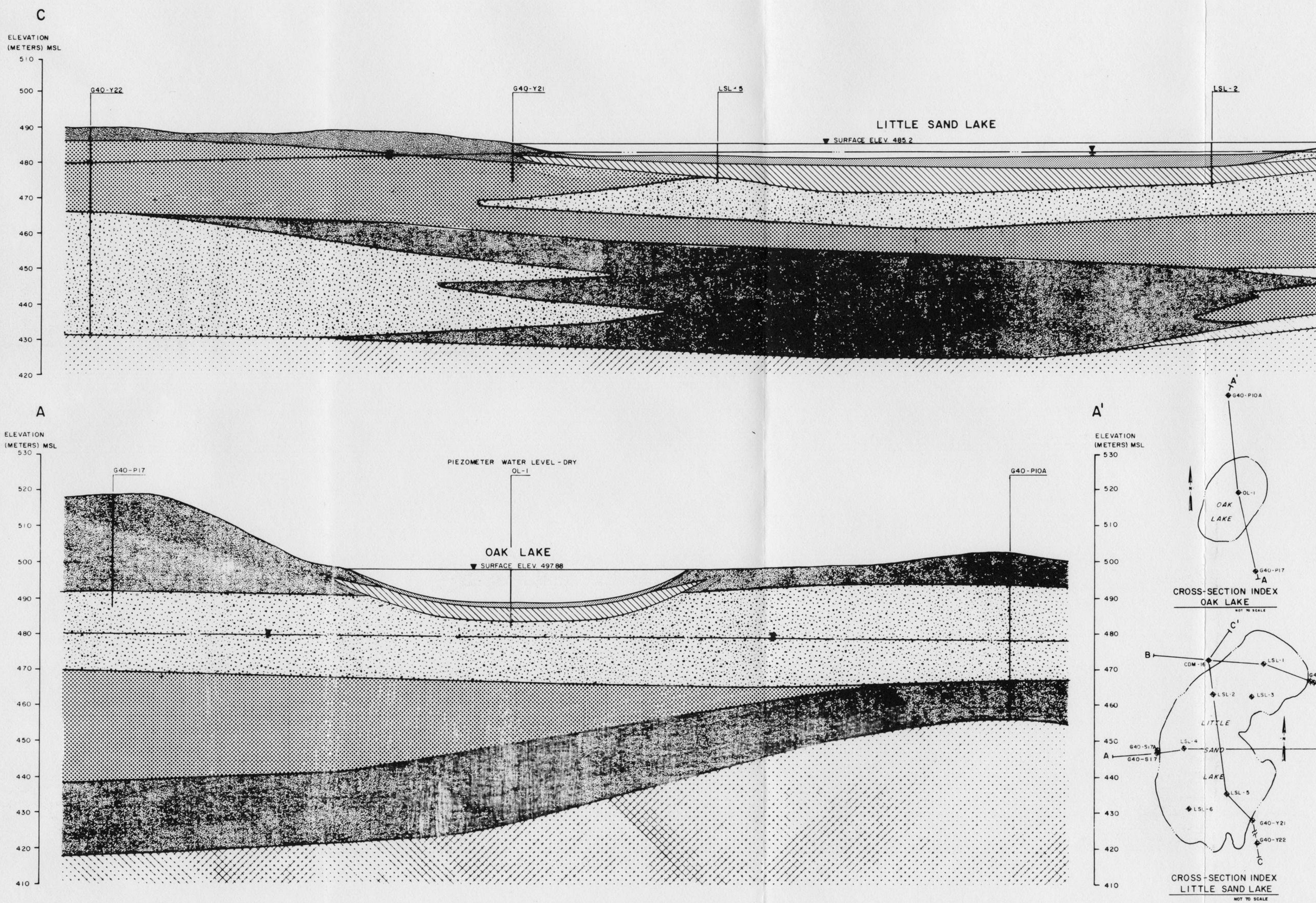
EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: GEOLOGIC SECTIONS THROUGH DEEP HOLE LAKE

SCALE: AS SHOWN | STATE: WISCONSIN | COUNTY: FOREST
DRAWN BY: RW | DATE: 5-23-85 | CHECKED BY: MMR | DATE: 12/16/85
APPROVED BY: | DATE: | APPROVED BY: SHD | DATE: 12/16/85
APPROVED BY: | DATE: | EXXON | DATE:
DRAWING NO. | SHEET ___ OF ___ | REVISION NO. 1



A
A'
ELEVATION (METERS) MSL
550
540
530
520
510
500
490
480
470
460
450
440
430
420
410
PIEZOMETRIC WATER LEVEL 482.88
LSL-4
G40-S17
G40-S17A
LITTLE SAND LAKE
SURFACE ELEV. 485.20
LEGEND
ORGANIC SILT
LACUSTRINE
TILL
COARSE GRAINED STRATIFIED DRIFT
FINE GRAINED STRATIFIED DRIFT
BASAL TILL
BEDROCK
LAKE WATER LEVEL
GROUNDWATER POTENTIOMETRIC SURFACE
B
B'
ELEVATION (METERS) MSL
500
490
480
470
460
450
440
430
420
PIEZOMETRIC WATER LEVEL 482.60
LSL-1
CDM-17
CDM-16
CDM-19
CDM-18
CDM-20
G40-Y15A
G40-Y15
LITTLE SAND LAKE
SURFACE ELEV. 485.20
SEE ENLARGED DETAIL OF THIS AREA
C'
CDM-16
LSL-1
LSL-2
LSL-3
G40-Y15
G40-Y15A
LITTLE SAND LAKE
G40-S17A
G40-S17
LSL-4
LSL-5
LSL-6
G40-Y21
G40-Y22
C
CROSS-SECTION INDEX LITTLE SAND LAKE
NOT TO SCALE
CDM-17
CDM-18
CDM-16
CDM-19
CDM-20
LITTLE SAND LAKE
ENLARGED DETAIL
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
FIGURE A.10-3
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 MMR
APPROVED BY SHD
EXXON
D'APPOLONIA
PROJ. NO.
DWG. NO. 850103-E4
SHEET
OF
REVISION NO.
REFERENCE:
DRAWING No. 12959-16
TITLED EXPANDED GEOLOGIC CROSS-SECTIONS OF LITTLE SAND LAKE
BY STS CONSULTANTS LTD., GREEN BAY, WISCONSIN.
SCALE AS SHOWN.



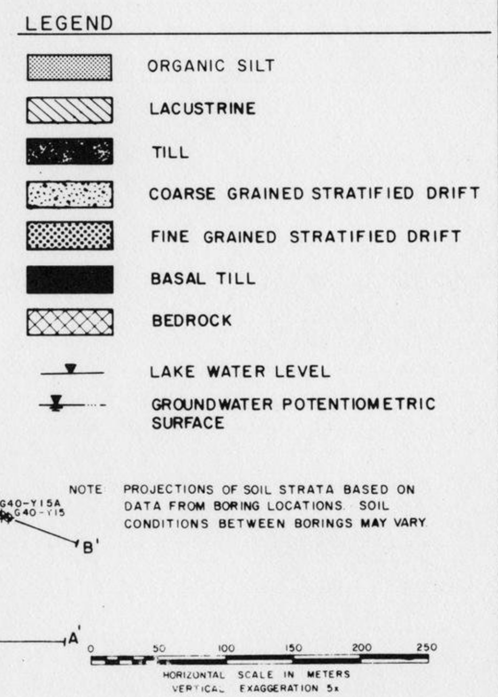


FIGURE A.10-4

EXXON MINERALS COMPANY
CRANDON PROJECT

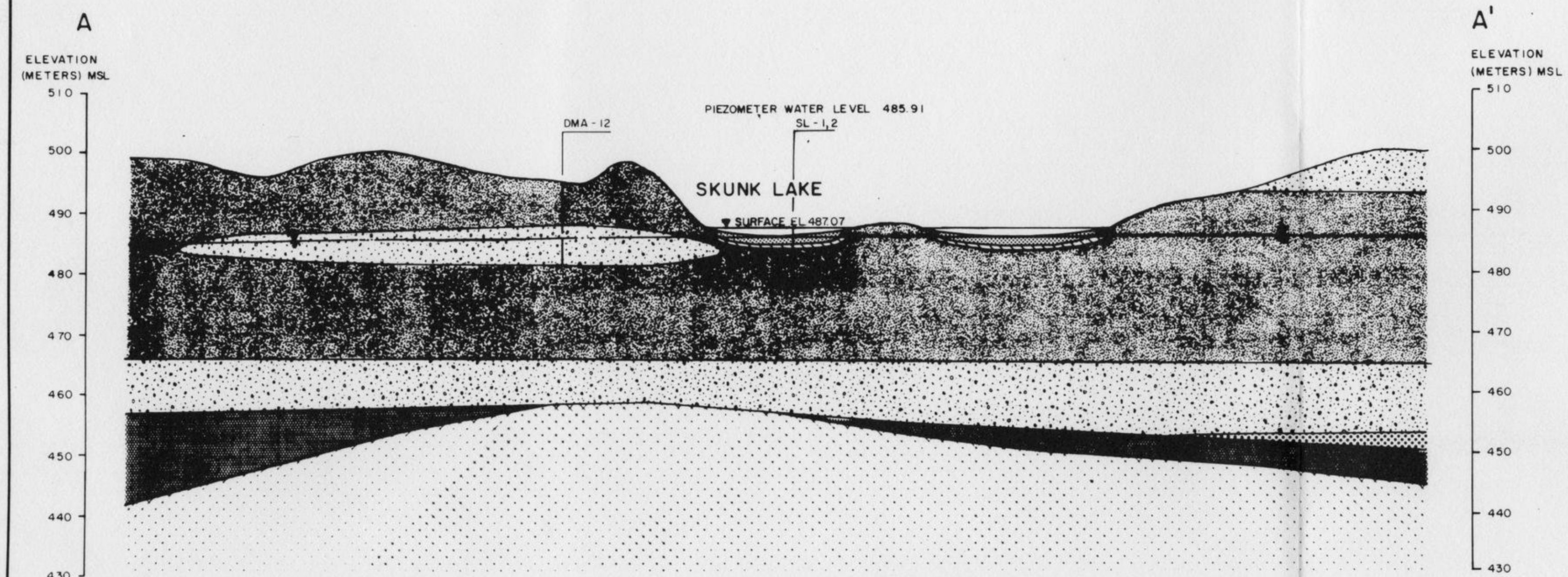
TITLE: GEOLOGIC SECTIONS THROUGH LITTLE SAND LAKE AND OAK LAKE

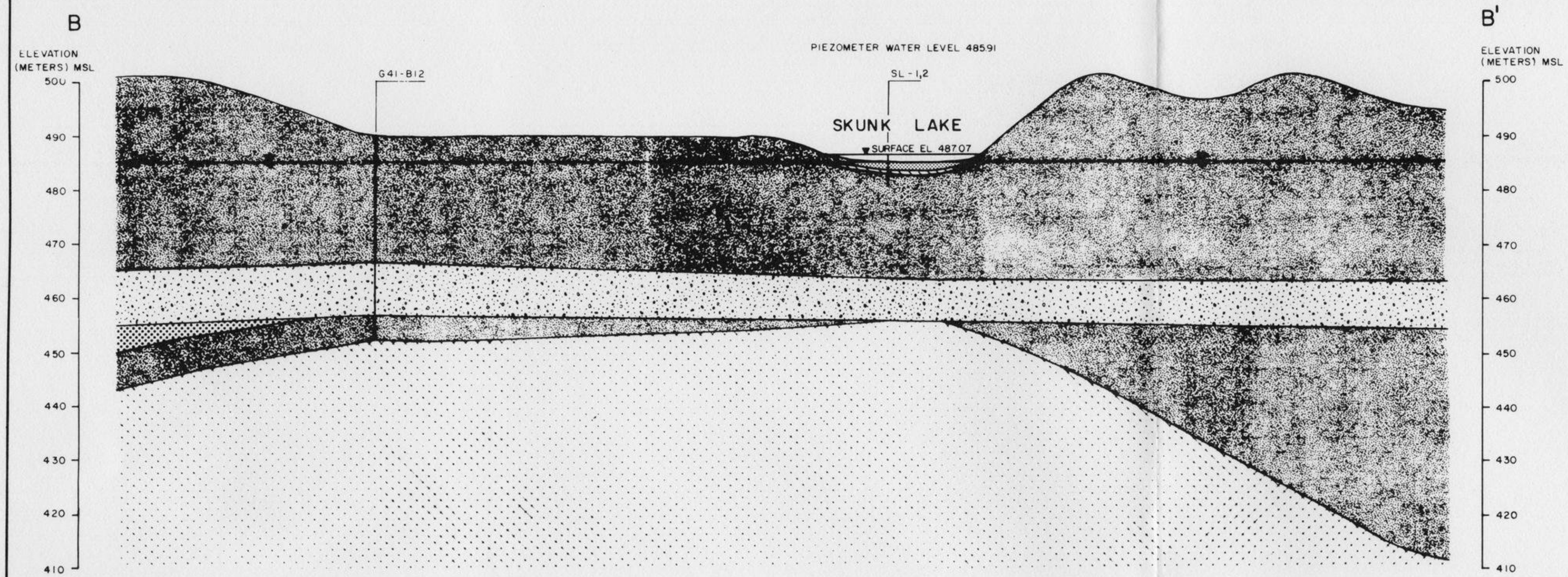
SCALE AS SHOWN	STATE WISCONSIN	COUNTY FOREST	
DRAWN BY RW	DATE 5-23-85	CHECKED BY MMR	DATE 12/16/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/16/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET — OF —	REVISION NO

D'APPOLONIA

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

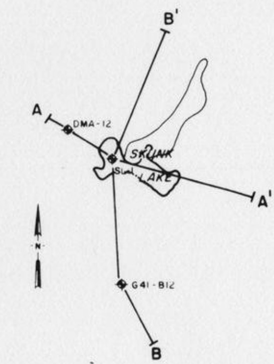
REFERENCE
DRAWING No 12959-17
TITLED EXPANDED GEOLOGIC CROSS-SECTIONS OF LITTLE SAND LAKE AND OAK LAKE
BY STS CONSULTANTS LTD., GREEN BAY, WISCONSIN
SCALE AS SHOWN





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

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

FIGURE A.10-5

EXXON MINERALS COMPANY
CRANDON PROJECT

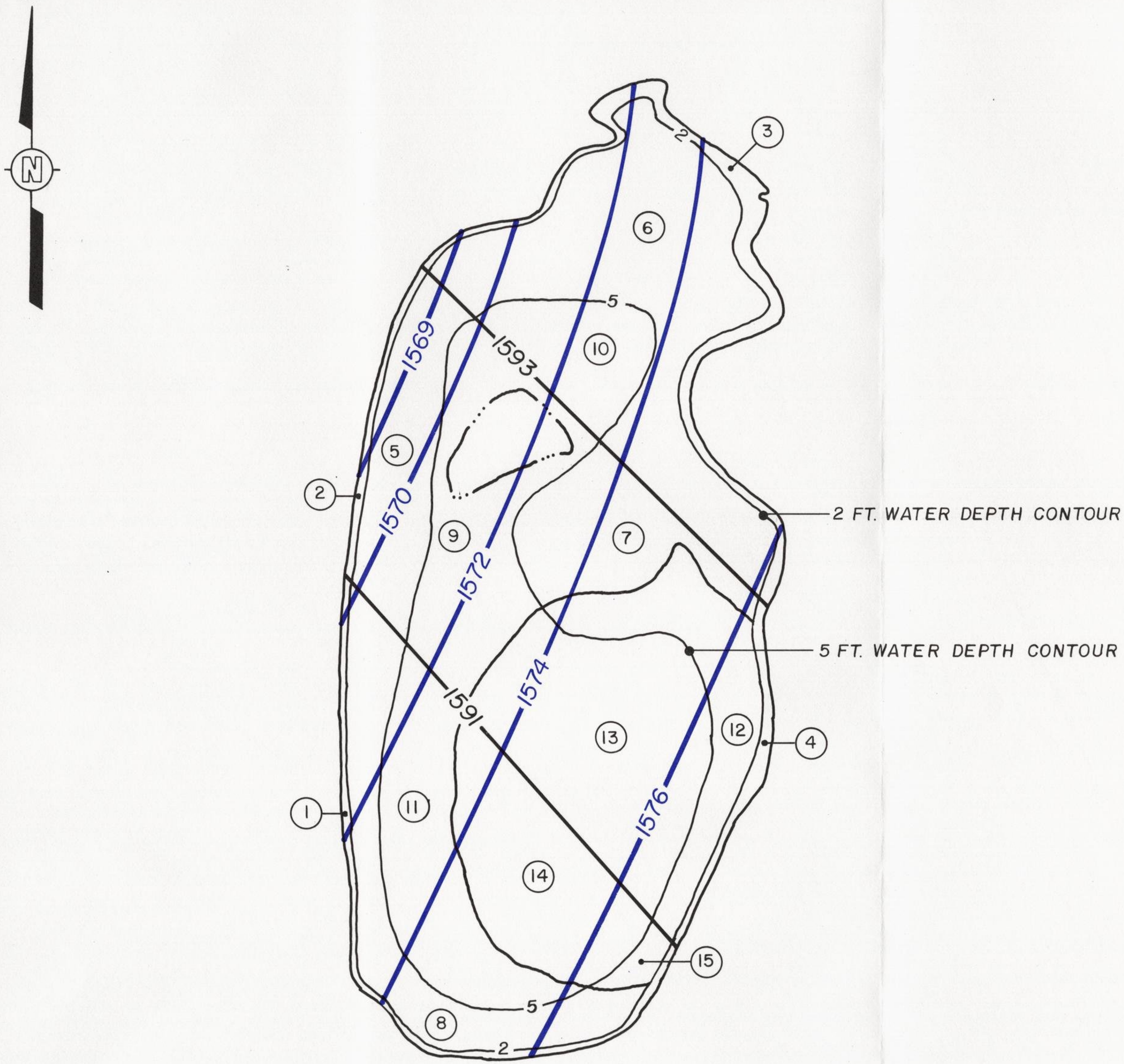
TITLE: GEOLOGIC SECTIONS THROUGH SKUNK LAKE

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

D'APPOLONIA

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

REFERENCE:
DRAWING No. 12959-13
TITLED EXPANDED GEOLOGIC CROSS-SECTIONS OF SKUNK LAKE, BY STS CONSULTANTS LTD., GREEN BAY, WISCONSIN.
SCALE AS SHOWN.



LEGEND

—1593— PRECONSTRUCTION POTENTIOMETRIC SURFACE IN FEET ABOVE MSL.

—1576— PREDICTED POTENTIOMETRIC SURFACE AT YEAR 28 IN FEET ABOVE MSL

(10) ZONE NUMBER

LIMITS OF OPEN WATER (SEE NOTE 4)

NOTES:

1. REFER TO TABLE A.10-1 FOR ZONE PARAMETERS.
2. DEPTH CONTOURS INFERRED FROM INMAN-FOLTZ AND ASSOCIATES, INC. DWG. TITLED "LAKE CONTOUR MAPPING" DATED 1-22-85 AND WETLANDS DEPTH DATA PROVIDED BY EXXON (1985a).
3. TOTAL LAKE AND WETLANDS AREA EQUALS 78.7 ACRES.
4. ZONES 4, 12, 13, 14, AND 15 APPROXIMATE THE MAJOR OPEN WATER PORTION OF DUCK LAKE; OTHER ZONES REPRESENT PERCHED WETLANDS AREAS. (EXXON, 1985 a).

SCALE

0 400 800 FEET

FIGURE A.10-6

EXXON MINERALS COMPANY
CRANDON PROJECT

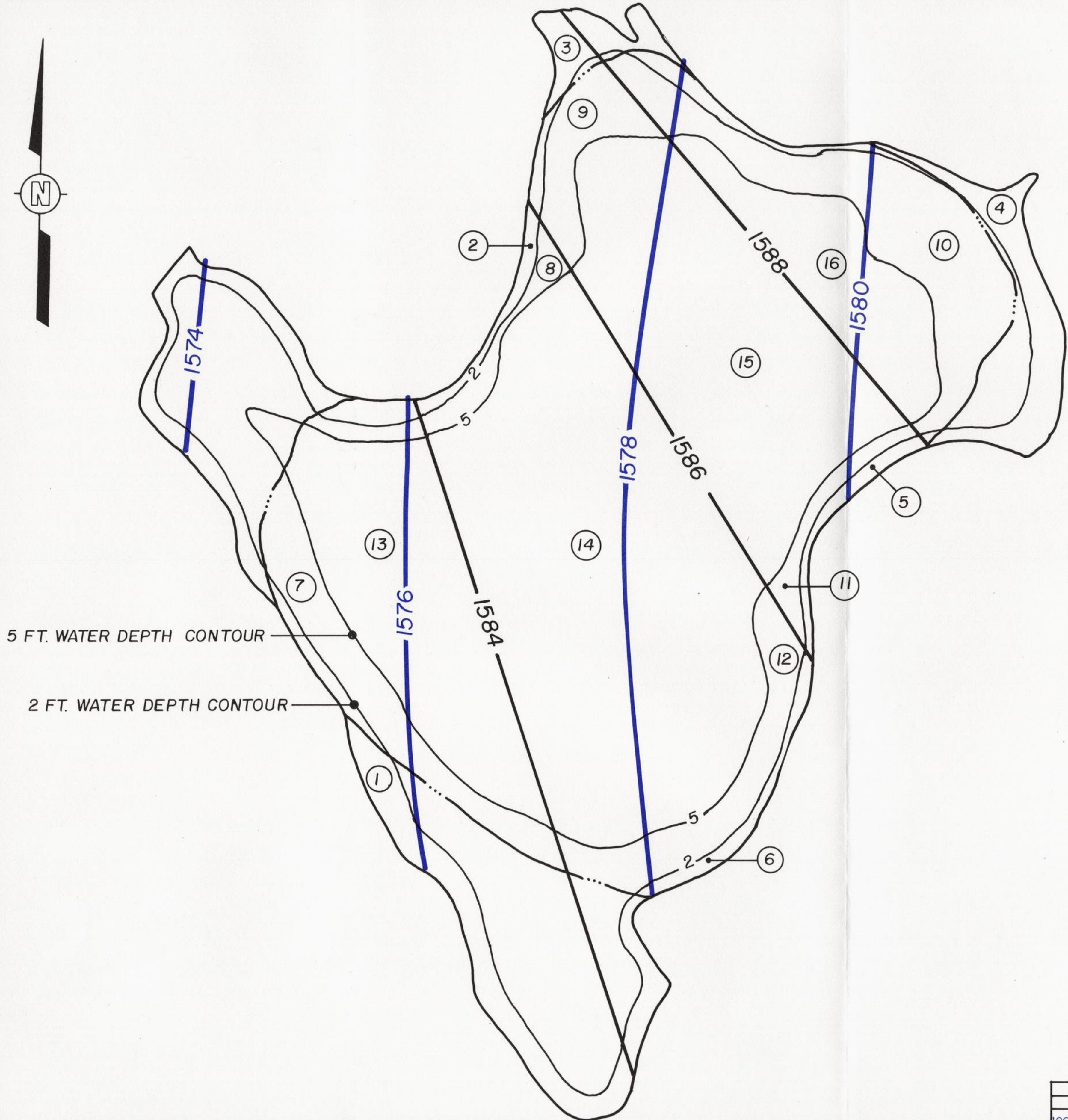
TITLE
LAKE ZONES
DUCK LAKE AND
LAKESIDE WETLANDS

SCALE AS SHOWN	STATE	COUNTY	
DRAWN BY RW	DATE 6-26-85	CHECKED BY MMR	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SMD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO.		SHEET ___ OF ___	REVISION NO.

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B60

41B
41B
100% BLUE



LEGEND

—1588— PRECONSTRUCTION POTENTIOMETRIC SURFACE IN FEET ABOVE MSL

—1580— PREDICTED POTENTIOMETRIC SURFACE AT YEAR 28 IN FEET ABOVE MSL

(10) ZONE NUMBER

LIMITS OF OPEN WATER

NOTES:

1. REFER TO TABLE A.10-2 FOR ZONE PARAMETERS.
2. DEPTH CONTOURS INFERRED FROM INMAN-FOLTZ AND ASSOCIATES, INC. DWG. TITLED "LAKE CONTOUR MAPPING" DATED 1-22-85 AND WETLANDS DEPTH DATA PROVIDED BY EXXON (1985a).
3. TOTAL LAKE AND WETLANDS AREA EQUAL 128.9 ACRES.

SCALE

0 400 800 FEET

FIGURE A.10-7

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE

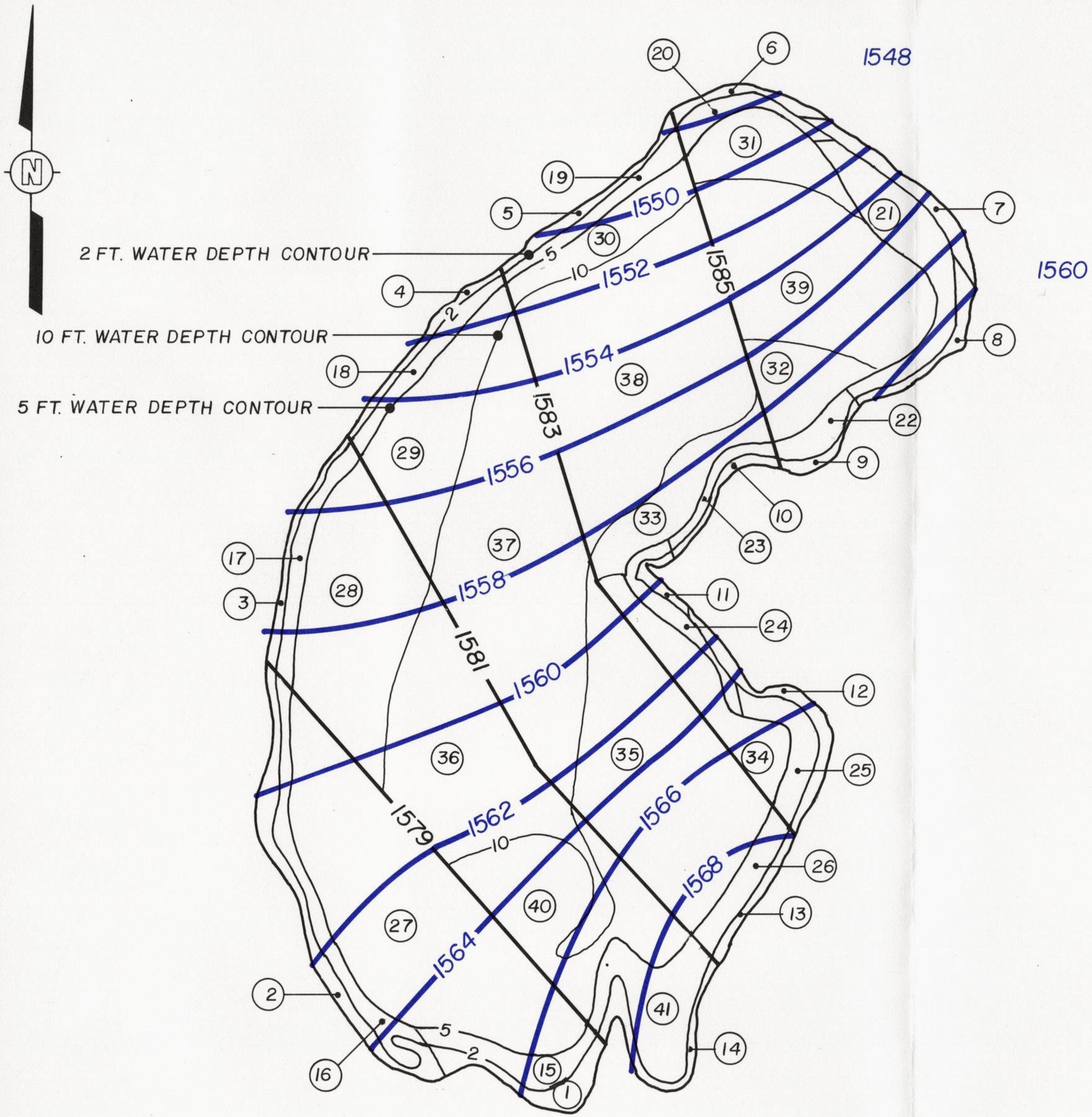
LAKE ZONES
DEEP HOLE LAKE AND
LAKESIDE WETLANDS

SCALE AS SHOWN	STATE		COUNTY	
DRAWN BY RW	DATE 6-26-85	CHECKED BY MMR		DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD		DATE 12/10/85
APPROVED BY	DATE	EXXON		DATE
DRAWING NO			SHEET ___ OF ___	REVISION NO.

40B
40B
100% BLUE

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B59



LEGEND

—1585— PRECONSTRUCTION POTENTIOMETRIC SURFACE IN FEET ABOVE MSL

—1548— PREDICTED POTENTIOMETRIC SURFACE AT YEAR 28 IN FEET ABOVE MSL

(21) ZONE NUMBER

NOTES:

1. REFER TO TABLE A.10-3 FOR ZONE PARAMETERS.
2. DEPTH CONTOURS FROM INMAN-FOLTZ AND ASSOCIATES, INC. DWG. TITLED "LAKE CONTOUR MAPPING" DATED 1-22-85.
3. TOTAL LAKE AREA EQUALS 244.1 ACRES

SCALE

0 400 800 1200 FEET

FIGURE A.10-8

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE

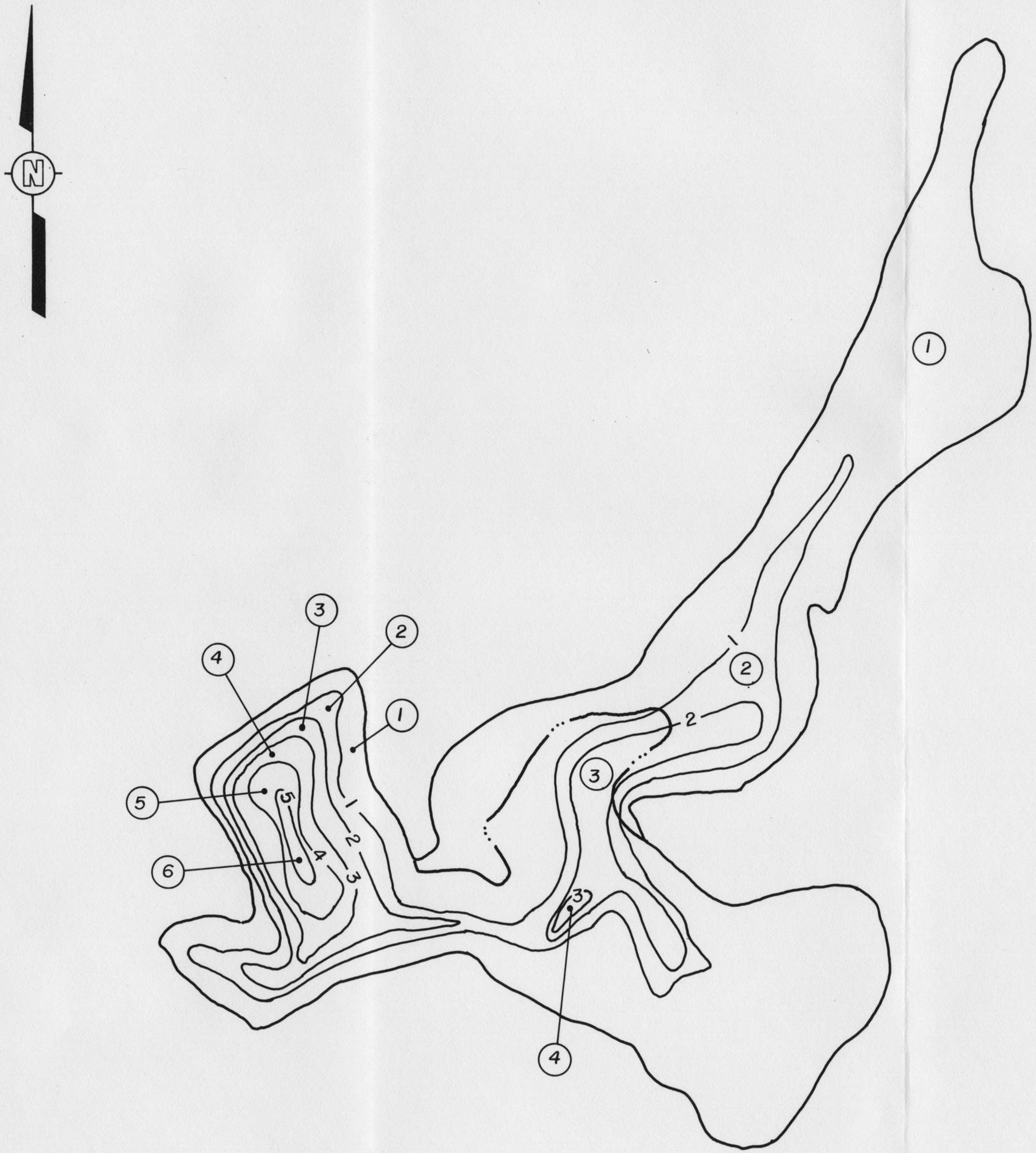
LAKE ZONES
LITTLE SAND LAKE

SCALE AS SHOWN	STATE		COUNTY	
DRAWN BY RW	DATE 6-26-85	CHECKED BY MMR		DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD		DATE 12/10/85
APPROVED BY	DATE	EXXON		DATE
DRAWING NO.			SHEET ___ OF ___	REVISION NO.

39B
39B
100% BLUE

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B58



LEGEND

(2) ZONE NUMBER

—1— WATER DEPTH CONTOUR (FT.)

—···— LIMITS OF OPEN WATER

NOTES:

1. REFER TO TABLE A.10 – 4 FOR ZONE PARAMETERS.
2. DEPTH CONTOURS INFERRED FROM INMAN-FOLTZ AND ASSOCIATES, INC. DWG. TITLED "LAKE CONTOUR MAPPING" DATED 1-22-85 AND WETLANDS DEPTH DATA PROVIDED BY EXXON (1985a).
3. PRECONSTRUCTION POTENTIOMETRIC SURFACE IS 1591 FEET ABOVE MSL UNDERLYING THE ENTIRE LAKE.
4. PREDICTED POTENTIOMETRIC SURFACE AT YEAR 28 IS BELOW BOTTOM OF LACUSTRINE SEDIMENT ELEVATION OF 1586.3 FEET ABOVE MSL.
5. TOTAL LAKE AND WETLANDS AREA EQUALS 15.7 ACRES.

SCALE

0 200 400 FEET

FIGURE A.10-9

EXXON MINERALS COMPANY

CRANDON PROJECT

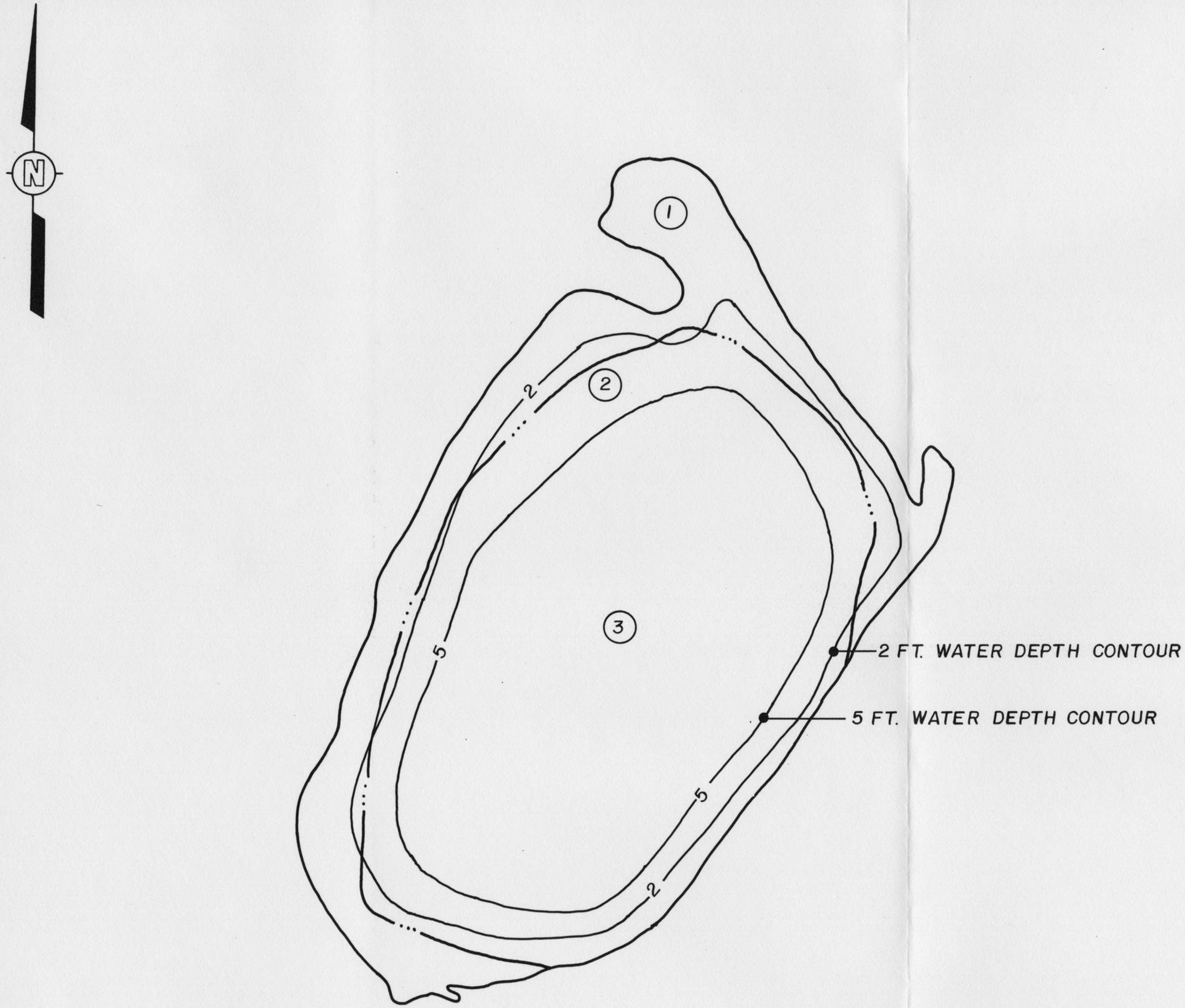
TITLE

LAKE ZONES
SKUNK LAKE AND
LAKESIDE WETLANDS

SCALE AS SHOWN	STATE		COUNTY	
DRAWN BY RW	DATE 6-26-85	CHECKED BY MMR		DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SND		DATE 12/10/85
APPROVED BY	DATE	EXXON		DATE
DRAWING NO			SHEET ____ OF ____	REVISION NO.

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B62



LEGEND

(2) ZONE NUMBER

LIMITS OF OPEN WATER

NOTES:

1. REFER TO TABLE A.10-5 FOR ZONE PARAMETERS.
2. DEPTH CONTOURS INFERRED FROM INMAN-FOLTZ AND ASSOCIATES, INC. DWG. TITLED "LAKE CONTOUR MAPPING" DATED 1-22-85 AND WETLANDS DEPTH DATA PROVIDED BY EXXON (1985a).
3. PRECONSTRUCTION POTENTIOMETRIC SURFACE IS BELOW BOTTOM OF LACUSTRINE SEDIMENTS.
4. TOTAL LAKE AND WETLANDS AREA EQUALS 69.9 ACRES.

SCALE

0 400 800 FEET

FIGURE A.10-10

EXXON MINERALS COMPANY

CRANDON PROJECT

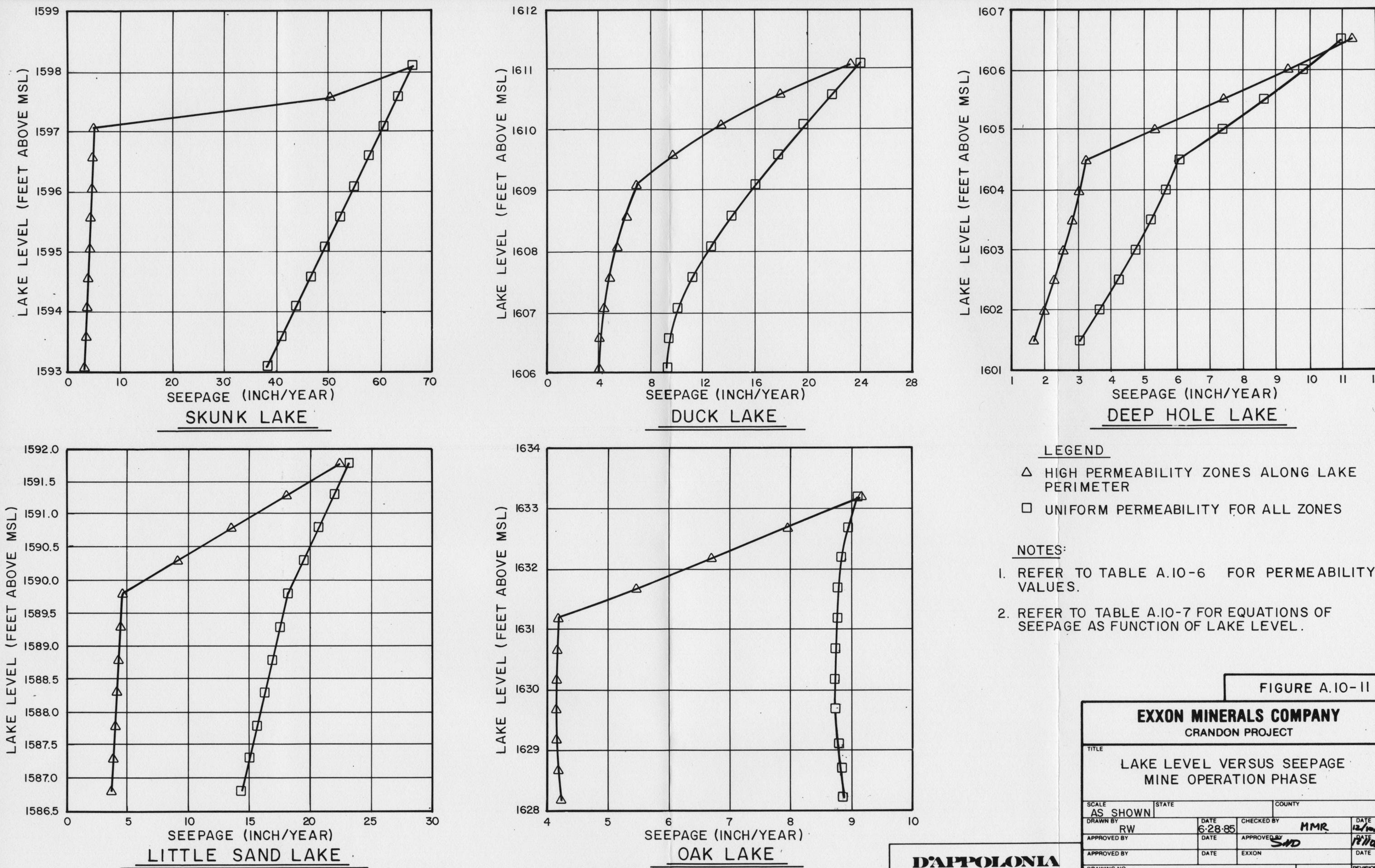
TITLE

LAKE ZONES
OAK LAKE AND
LAKESIDE WETLANDS

SCALE AS SHOWN	STATE		COUNTY	
DRAWN BY RW	DATE 6-26-85	CHECKED BY MMR		DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD		DATE 12/10/85
APPROVED BY	DATE	EXXON		DATE
DRAWING NO.			SHEET ___ OF ___	REVISION NO.

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B61



LEGEND

△ HIGH PERMEABILITY ZONES ALONG LAKE PERIMETER

□ UNIFORM PERMEABILITY FOR ALL ZONES

NOTES:

1. REFER TO TABLE A.10-6 FOR PERMEABILITY VALUES.
2. REFER TO TABLE A.10-7 FOR EQUATIONS OF SEEPAGE AS FUNCTION OF LAKE LEVEL.

FIGURE A.10-11

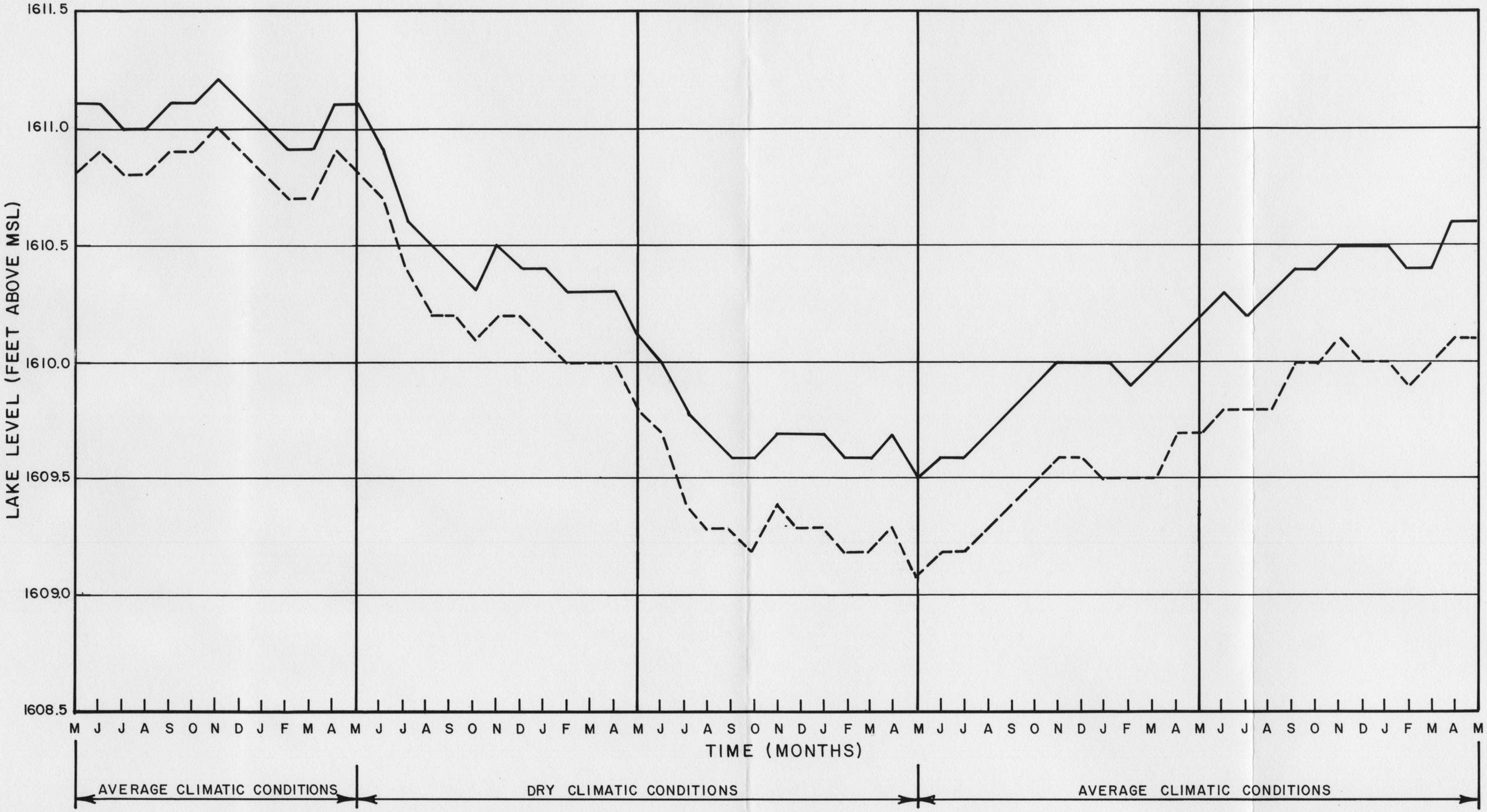
EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
LAKE LEVEL VERSUS SEEPAGE
MINE OPERATION PHASE

SCALE AS SHOWN	STATE	COUNTY	
DRAWN BY RW	DATE 6-28-85	CHECKED BY MMR	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD	DATE 1/11/86
APPROVED BY	DATE	EXXON	DATE
DRAWING NO.		SHEET ___ OF ___	REVISION NO.

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B63



LEGEND

——— ESTIMATED LAKE LEVEL DURING PRECONSTRUCTION PHASE

------ PREDICTED LAKE LEVEL DURING OPERATION PHASE

NOTE

PRECONSTRUCTION LAKE LEVEL ANALYSIS PERFORMED USING LAKE SEEPAGE RATES AND AREAS DETERMINED FROM LAKE LEVELS.

FIGURE A.10-12

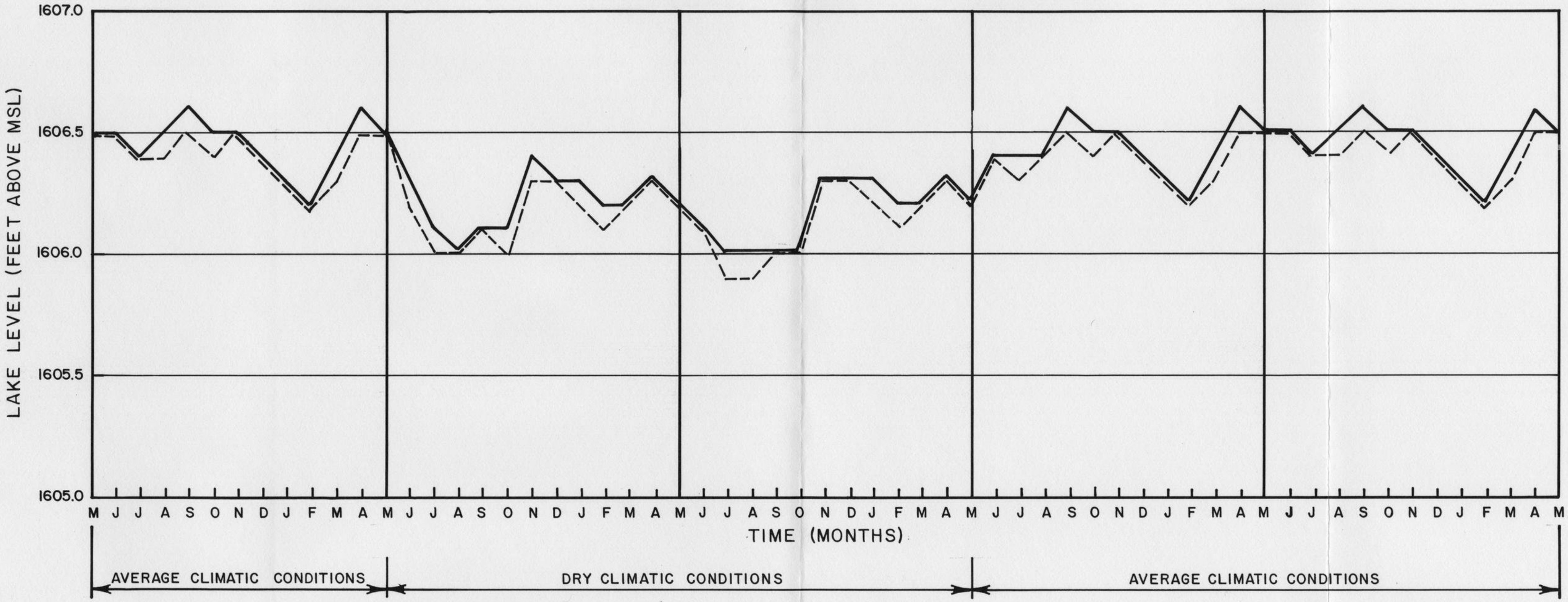
EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
DUCK LAKE
LAKE LEVEL VERSUS TIME

SCALE	STATE	COUNTY	
DRAWN BY RW	DATE 6·28·85	CHECKED BY MMR	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SMD	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO.		SHEET ___ OF ___	REVISION NO.

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B66



LEGEND

——— ESTIMATED LAKE LEVEL DURING PRECONSTRUCTION PHASE

------ PREDICTED LAKE LEVEL DURING OPERATION PHASE

NOTE

PRECONSTRUCTION LAKE LEVEL ANALYSIS PERFORMED USING CONSTANT LAKE SEEPAGE RATE AND AREA.

FIGURE A.10-13

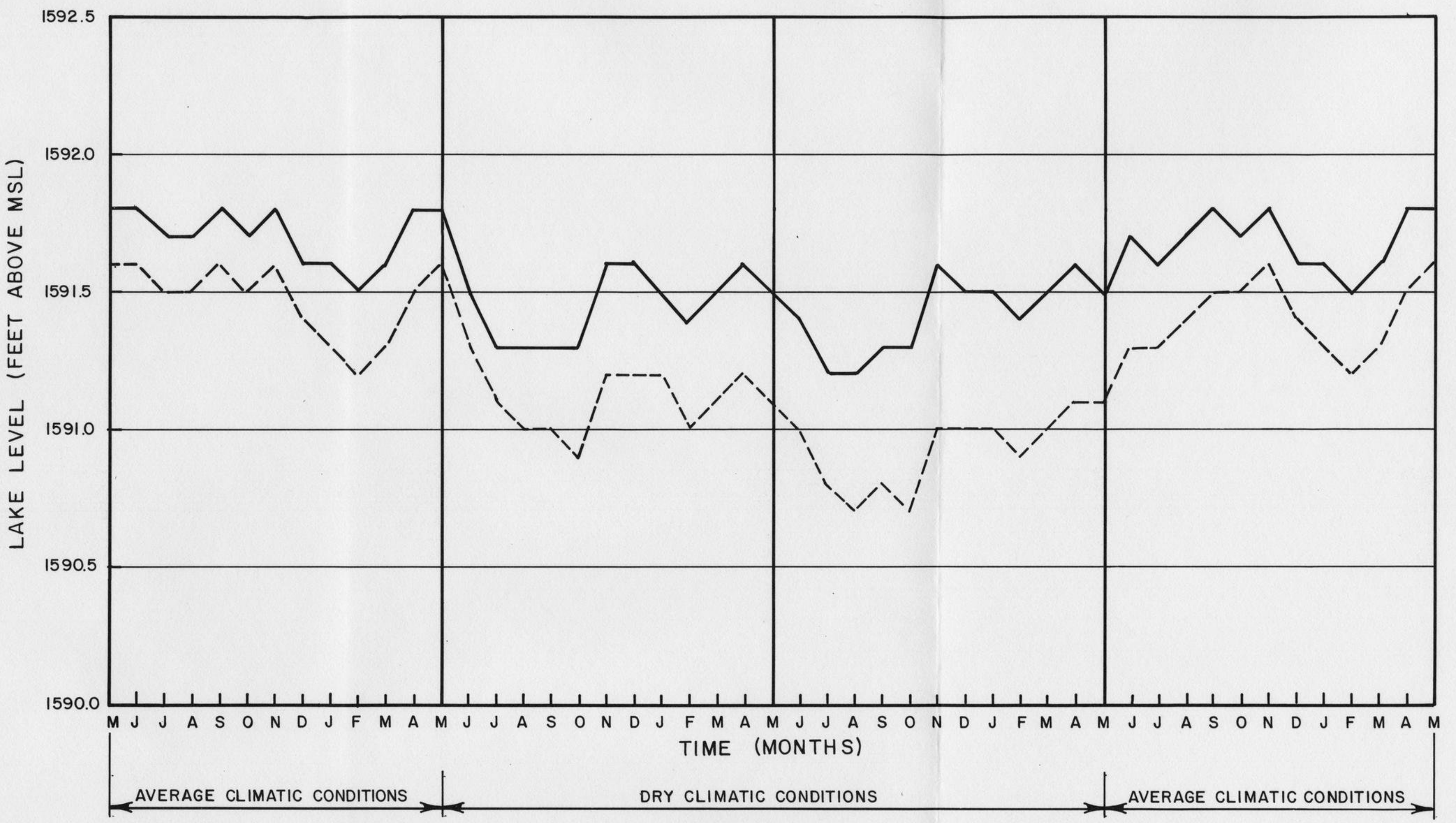
EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
DEEP HOLE LAKE
LAKE LEVEL VERSUS TIME

SCALE	STATE		COUNTY	
DRAWN BY RW	DATE 7·1·85	CHECKED BY MMR		DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD		DATE 12/10/85
APPROVED BY	DATE	EXXON		DATE
DRAWING NO.			SHEET ___ OF ___	REVISION NO.

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B67



LEGEND

——— ESTIMATED LAKE LEVEL DURING PRECONSTRUCTION PHASE

– – – – PREDICTED LAKE LEVEL DURING OPERATION PHASE.

NOTES

1. UNIFORM PERMEABILITY FOR ALL LAKE BED ZONES.
2. PRECONSTRUCTION LAKE LEVEL ANALYSIS PERFORMED USING CONSTANT LAKE SEEPAGE RATE AND AREA.

FIGURE A.10-14

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE: LITTLE SAND LAKE
LAKE LEVEL VERSUS TIME
UNIFORM PERMEABILITY CASE

SCALE | STATE | COUNTY

DRAWN BY RW | DATE 7-1-85 | CHECKED BY MMR | DATE 12/10/85

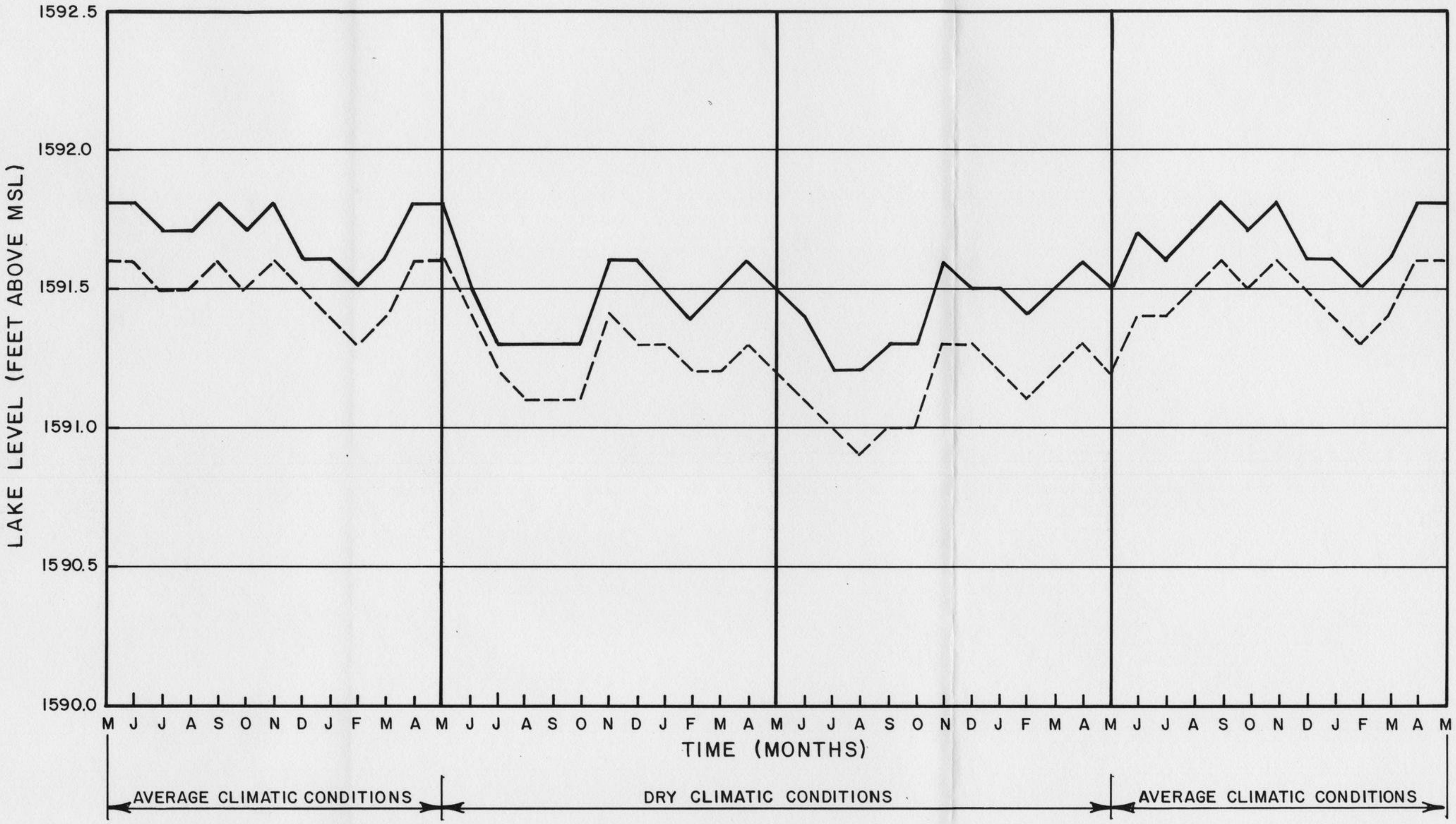
APPROVED BY | DATE | APPROVED BY SHD | DATE 12/11/85

APPROVED BY | DATE | EXXON | DATE

DRAWING NO. | SHEET ___ OF ___ | REVISION NO.

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B68



LEGEND

——— ESTIMATED LAKE LEVEL DURING PRECONSTRUCTION PHASE

– – – – PREDICTED LAKE LEVEL DURING OPERATION PHASE

NOTES

1. HIGH PERMEABILITY ZONES ALONG LAKE PERIMETER.
2. PRECONSTRUCTION LAKE LEVEL ANALYSIS PERFORMED USING CONSTANT LAKE SEEPAGE RATE AND AREA.

FIGURE A.10-15

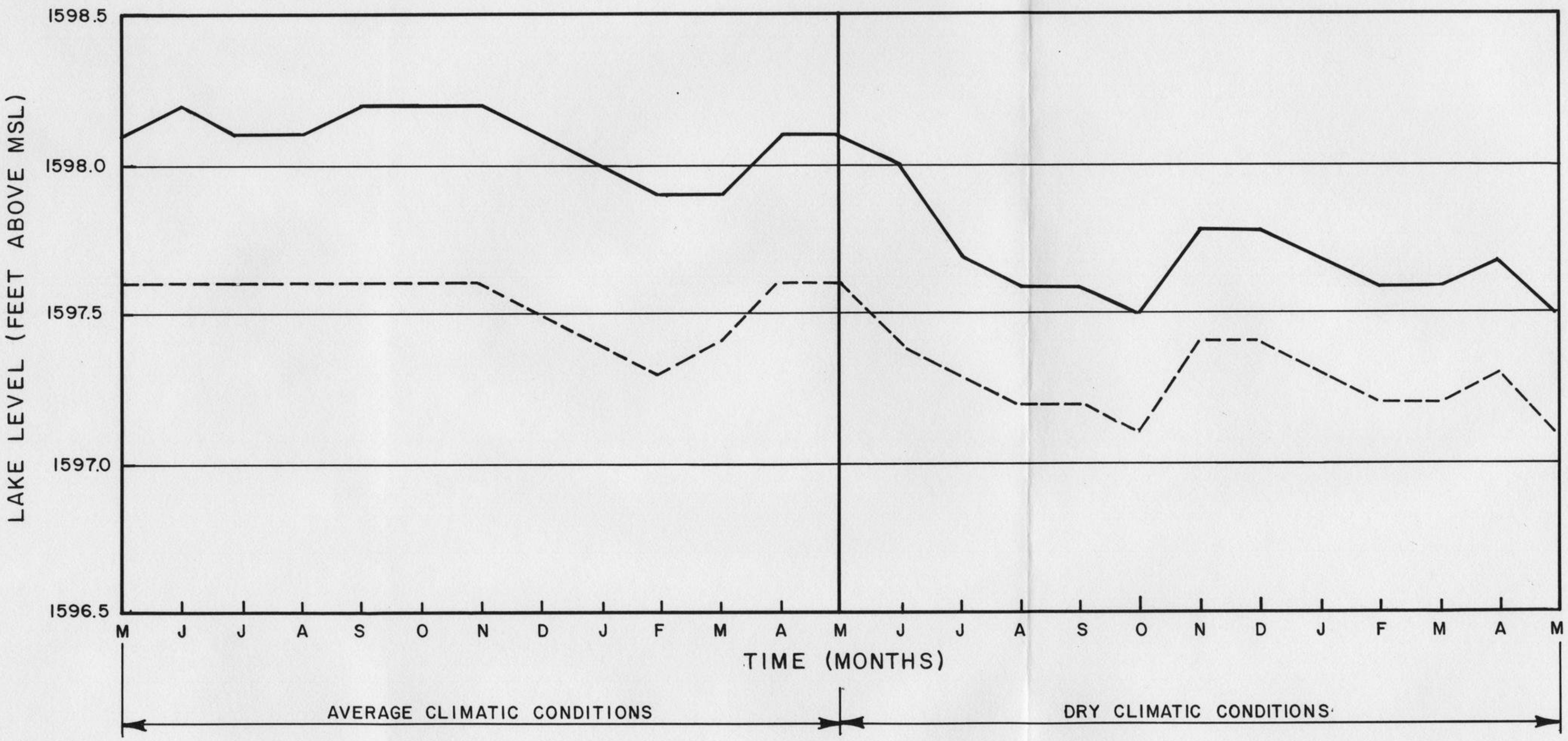
EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
LITTLE SAND LAKE
LAKE LEVEL VERSUS TIME
HIGH PERIMETER PERMEABILITY CASE

SCALE	STATE		COUNTY	
DRAWN BY RW	DATE 7-1-85	CHECKED BY MMR	DATE 12/10/85	
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85	
APPROVED BY	DATE	EXXON	DATE	
DRAWING NO.		SHEET ___ OF ___	REVISION NO.	

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B69



LEGEND

——— ESTIMATED LAKE LEVEL DURING PRECONSTRUCTION PHASE

- - - - - PREDICTED LAKE LEVEL DURING OPERATION PHASE

NOTE

PRECONSTRUCTION LAKE LEVEL ANALYSIS PERFORMED USING LAKE SEEPAGE RATES AND AREAS DETERMINED FROM LAKE LEVELS.

D'APPOLONIA

PROJ. NO. 846498 DWG. NO. B65

FIGURE A.10-16

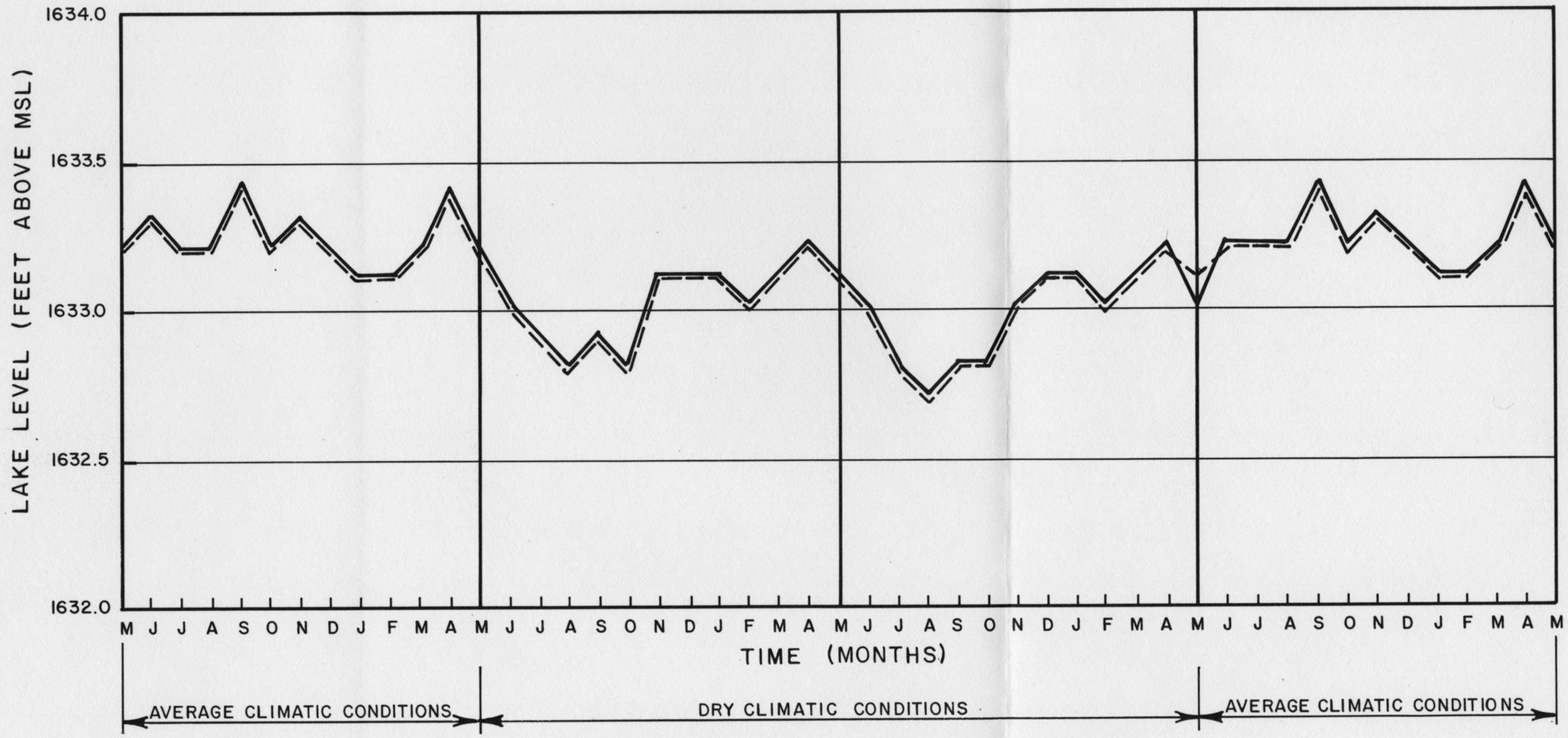
EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE

SKUNK LAKE
LAKE LEVELS VERSUS TIME

SCALE	STATE	COUNTY	
DRAWN BY RW	DATE 7-1-85	CHECKED BY MMR	DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SND	DATE 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO.		SHEET OF	REVISION NO.



LEGEND

——— ESTIMATED LAKE LEVEL DURING PRECONSTRUCTION PHASE

– – – – PREDICTED LAKE LEVEL DURING OPERATION PHASE

NOTES

1. PREDICTED LAKE LEVELS DURING OPERATION PHASE EQUAL PRECONSTRUCTION LAKE LEVELS BECAUSE PRECONSTRUCTION GROUND WATER LEVELS ARE BELOW BOTTOM OF LACUSTRINE SEDIMENTS.

2. PRECONSTRUCTION LAKE LEVEL ANALYSIS PERFORMED USING CONSTANT LAKE SEEPAGE RATE AND AREA.

D'APPOLONIA

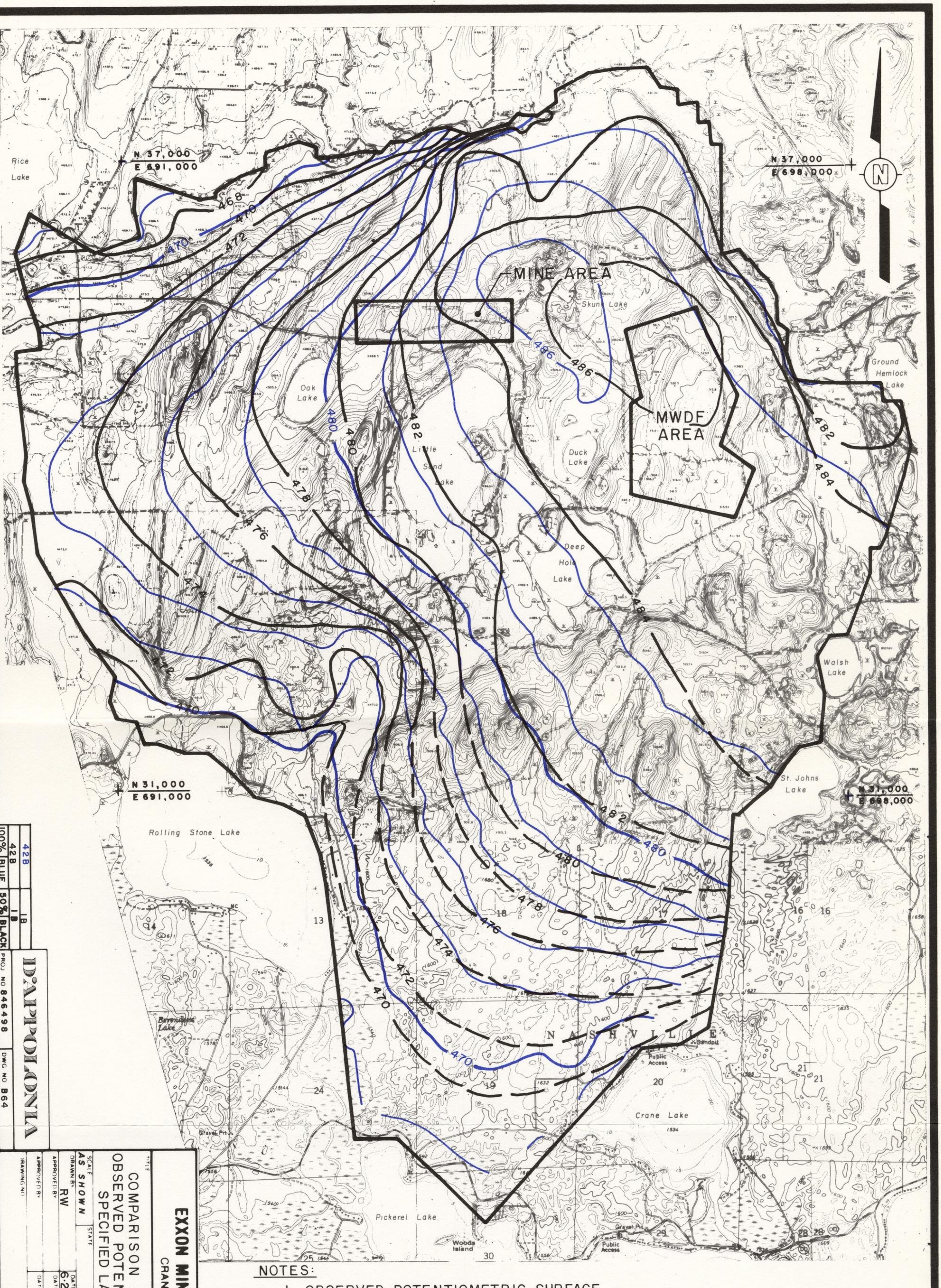
PROJ. NO. 846498 DWG. NO. B70

FIGURE A.10-17

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
OAK LAKE
LAKE LEVEL VERSUS TIME

SCALE	STATE		COUNTY	
DRAWN BY RW	DATE 7·1·85	CHECKED BY MMR	DATE 12/10/85	
APPROVED BY	DATE	APPROVED BY SHD	DATE 12/10/85	
APPROVED BY	DATE	EXXON	DATE	
DRAWING NO.		SHEET ___ OF ___	REVISION NO.	



NOTES:

1. OBSERVED POTENTIOMETRIC SURFACE IS FROM FIGURE A-13.
2. SIMULATED POTENTIOMETRIC SURFACE IS FROM CALIBRATED MODEL INCORPORATING LAKE SEEPAGE RATES SHOWN IN TABLE A.10-6.

SCALE

0 1000 2000 meters

LEGEND

476 — OBSERVED POTENTIOMETRIC SURFACE IN METERS ABOVE MSL

480 — SIMULATED POTENTIOMETRIC SURFACE IN METERS ABOVE MSL

FIGURE A.10-18

EXXON MINERALS COMPANY

CRANDON PROJECT

COMPARISON OF SIMULATED AND OBSERVED POTENTIOMETRIC SURFACES SPECIFIED LAKE SEEPAGE RATES

SCALE: AS SHOWN			
DRAWN BY: RW	DATE: 6-2885	CHECKED BY: MMK	DATE: 12/10/85
APPROVED BY:	DATE:	APPROVED BY: SHD	DATE: 12/10/85

D'APPOLONIA

PROJ NO 846498 DWG NO B64

42B	1B
100% BLUE	50% BLACK

ATTACHMENT A.11

BOUNDARY FLOW RATES

LIST OF TABLES

TABLES

TABLE A.11-1

BOUNDARY FLOW RATES FOR LOW RECHARGE CASE
UPPER HEMLOCK CREEK
SEGMENT AB(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	PRECONSTRUCTION cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	END OF YEAR 3 cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	END OF YEAR 28 cfs
1153	2.5568	.0903	2.3351	.0825	1.6375	.0578
1155	1.5506	.0548	1.3879	.0490	.9139	.0323
1167	.1828	.0065	.1364	.0048	-.3014	-.0106
1171	1.3686	.0483	1.1942	.0422	.7021	.0248
1172	.4783	.0169	.4251	.0150	.2765	.0098
1184	1.9933	.0704	1.9020	.0672	1.5719	.0555
1192	-.3640	-.0129	-.4106	-.0145	-.5939	-.0210
1193	.1322	.0047	.0273	.0010	-.3897	-.0138
1201	1.2316	.0435	1.1891	.0420	1.0226	.0361
1202	.3415	.0121	.2145	.0076	-.2927	-.0103
1203	1.1311	.0399	1.0544	.0372	.7420	.0262
1204	.3023	.0107	.2361	.0083	-.0273	-.0010
1205	.8137	.0287	.7357	.0260	.4094	.0145
1214	.9180	.0324	.8980	.0317	.8156	.0288
1215	-.0281	-.0010	-.0433	-.0015	-.1057	-.0037
1216	.1987	.0070	.1747	.0062	.0710	.0025
1217	.4893	.0173	.4560	.0161	.3113	.0110
1218	1.1492	.0406	1.1213	.0396	.9963	.0352
1220	.6513	.0230	.6332	.0224	.5502	.0194
1223	.9151	.0323	.8958	.0316	.8111	.0286
1224	.2219	.0078	.2161	.0076	.1915	.0068
1225	.6580	.0232	.6469	.0228	.5961	.0211
1226	1.0876	.0384	1.0756	.0380	1.0207	.0360
1227	.3796	.0134	.3742	.0132	.3485	.0123
TOTAL	18.3593	.6484	16.8755	.5960	11.2775	.3983

(a)Refer to Figure A.2-1 of the Attachment A.2 for segment locations.
(b)Refer to Figure A.7-2 for nodal locations.
(c)Nodal flows are positive when direction is out from the model.

TABLE A.11-2

BOUNDARY FLOW RATES FOR LOW RECHARGE CASE
LOWER HEMLOCK CREEK AND SWAMP CREEK BELOW HEMLOCK CREEK CONFLUENCE
SEGMENT BC(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	PRECONSTRUCTION cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	END OF YEAR 3 cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	END OF YEAR 28 cfs
374	.3761	.0133	.3693	.0130	.3030	.0107
414	1.0499	.0371	1.0299	.0364	.8733	.0308
458	.2840	.0100	.2781	.0098	.2406	.0085
459	.5191	.0183	.5045	.0178	.4135	.0146
508	.6846	.0242	.6453	.0228	.4157	.0147
554	1.0429	.0368	1.0062	.0355	.8042	.0284
599	1.2735	.0450	1.2383	.0437	1.0518	.0371
646	.3162	.0112	.3059	.0108	.2521	.0089
647	.6237	.0220	.6006	.0212	.4807	.0170
693	.2066	.0073	.1912	.0068	.1108	.0039
742	.3567	.0126	.3412	.0120	.2629	.0093
789	.4810	.0170	.4668	.0165	.3964	.0140
837	.2705	.0096	.2554	.0090	.1803	.0064
887	.2396	.0085	.2306	.0081	.1875	.0066
940	.8590	.0303	.8251	.0291	.6656	.0235
941	.2775	.0098	.2667	.0094	.2147	.0076
955	1.0163	.0359	.9779	.0345	.8086	.0286
956	.2625	.0093	.2520	.0089	.2053	.0073
996	.6145	.0217	.5784	.0204	.4313	.0152
997	.3078	.0109	.2973	.0105	.2527	.0089
1007	.9529	.0337	.9072	.0320	.7284	.0257
1008	.2324	.0082	.2212	.0078	.1764	.0062
1055	2.2108	.0781	1.9102	.0675	1.0997	.0388
1056	1.7050	.0602	1.4942	.0528	.8904	.0314
1057	1.5883	.0561	1.4409	.0509	.9821	.0347
1058	1.1054	.0390	1.0185	.0360	.7223	.0255
1059	.7338	.0259	.6776	.0239	.4756	.0168
1060	.2245	.0079	.2119	.0075	.1660	.0059
1103	.4845	.0171	.4224	.0149	.2580	.0091
1138	.2658	.0094	.2333	.0082	.1474	.0052
1155	1.5506	.0548	1.3879	.0490	.9139	.0323
1157	.6742	.0238	.6041	.0213	.4170	.0147
1170	.2363	.0083	.2091	.0074	.1369	.0048
1172	.4783	.0169	.4251	.0150	.2765	.0098
1173	1.3372	.0472	1.1653	.0412	.6913	.0244
1174	.6561	.0232	.5581	.0197	.2919	.0103
1175	.7620	.0269	.6818	.0241	.4626	.0163
1176	.7407	.0262	.6513	.0230	.4094	.0145
1177	.6336	.0224	.5410	.0191	.2893	.0102
1178	.2684	.0095	.2400	.0085	.1624	.0057
TOTAL	27.9029	.9854	25.6616	.9062	18.2484	.6444

(a)Refer to Figure A.2-1 of the Attachment A.2 for segment locations.
(b)Refer to Figure A.7-2 for nodal locations.
(c)Nodal flows are positive when direction is out from the model.

TABLE A.11-3

BOUNDARY FLOW RATES FOR LOW RECHARGE CASE
SWAMP CREEK ABOVE RICE LAKE
SEGMENT CD(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	PRECONSTRUCTION cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	END OF YEAR 3 cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	END OF YEAR 28 cfs
1	2.4071	.0850	2.1214	.0749	1.6207	.0572
4	2.5308	.0894	2.2511	.0795	1.7526	.0619
5	1.1140	.0393	.9970	.0352	.7918	.0280
6	3.6783	.1299	3.3010	.1166	2.6310	.0929
11	2.7898	.0985	2.5403	.0897	2.0795	.0734
13	4.0810	.1441	3.6974	.1306	2.9956	.1058
23	.6900	.0244	.6564	.0232	.5908	.0209
26	1.9980	.0706	1.8427	.0651	1.5449	.0546
41	-.0771	-.0027	-.1041	-.0037	-.1577	-.0056
42	.4947	.0175	.4354	.0154	.3158	.0112
43	.2794	.0099	.2425	.0086	.1670	.0059
45	.4623	.0163	.4351	.0154	.3812	.0135
46	1.3166	.0465	1.2300	.0434	1.0566	.0373
47	8.5934	.3035	8.0575	.2845	6.9476	.2454
61	1.3210	.0467	1.1473	.0405	.7864	.0278
63	.2680	.0095	.2426	.0086	.1908	.0067
66	4.4394	.1568	4.2840	.1513	3.9320	.1389
83	1.5008	.0530	1.3245	.0468	.9351	.0330
108	1.5173	.0536	1.3635	.0482	.9916	.0350
137	1.0134	.0358	.9259	.0327	.6843	.0242
163	.9427	.0333	.8717	.0308	.6520	.0230
191	1.2992	.0459	1.2202	.0431	.9228	.0326
225	.2848	.0101	.2726	.0096	.2084	.0074
226	.2825	.0100	.2713	.0096	.2047	.0072
260	.0440	.0016	.0450	.0016	.0334	.0012
297	.0445	.0016	.0457	.0016	.0348	.0012
335	.3127	.0110	.3092	.0109	.2529	.0089
374	.3761	.0133	.3693	.0130	.3030	.0107
TOTAL	44.0047	1.5540	40.3962	1.4266	32.8493	1.1601

(a)Refer to Figure A.2-1 of the Attachment A.2 for segment locations.
(b)Refer to Figure A.7-2 for modal locations.
(c)Nodal flows are positive when direction is out from the model.

TABLE A.11-4

BOUNDARY FLOW RATES FOR LOW RECHARGE CASE
RICE AND MOLE LAKES
SEGMENT DE(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	PRECONSTRUCTION cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	END OF YEAR 3 cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	END OF YEAR 28 cfs
66	4.4394	.1568	4.2840	.1513	3.9320	.1389
88	2.9119	.1028	2.8640	.1011	2.7470	.0970
114	.5495	.0194	.5448	.0192	.5321	.0188
115	.9697	.0342	.9637	.0340	.9481	.0335
116	2.2397	.0791	2.2317	.0788	2.2108	.0781
117	1.4602	.0516	1.4250	.0503	1.3353	.0472
118	-.1961	-.0069	-.2422	-.0086	-.3574	-.0126
133	-.9339	-.0330	-.9995	-.0353	-1.1612	-.0410
158	-1.2443	-.0439	-1.3699	-.0484	-1.6774	-.0592
185	1.2215	.0431	.9938	.0351	.4303	.0152
216	.9164	.0324	.8806	.0311	.7893	.0279
217	.5264	.0186	.4569	.0161	.2854	.0101
251	.2203	.0078	.0365	.0013	-.4303	-.0152
287	1.0804	.0382	.8533	.0301	.2785	.0098
324	1.2037	.0425	.9725	.0343	.3802	.0134
362	.2400	.0085	.1676	.0059	-.0218	-.0008
TOTAL	15.6048	.5511	14.0629	.4966	10.2209	.3609

(a)Refer to Figure A.2-1 of the Attachment A.2 for segment locations.
(b)Refer to Figure A.7-2 for nodal locations.
(c)Nodal flows are positive when direction is out from the model.

TABLE A.11-5

BOUNDARY FLOW RATES FOR LOW RECHARGE CASE
PICKEREL CREEK, UPSTREAM OF ROLLING STONE LAKE
SEGMENT EF(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	PRECONSTRUCTION cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	END OF YEAR 3 cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	END OF YEAR 28 cfs
362	.2400	.0085	.1676	.0059	-.0218	-.0008
403	.5467	.0193	.3020	.0107	-.3450	-.0122
444	1.7551	.0620	1.5351	.0542	.9354	.0330
493	4.1603	.1469	3.9162	.1383	3.2281	.1140
539	3.8179	.1348	3.6371	.1284	3.1225	.1103
583	2.9484	.1041	2.8342	.1001	2.5003	.0883
629	1.9993	.0706	1.9039	.0672	1.6140	.0570
632	.1993	.0070	.1767	.0062	.1071	.0038
679	2.2457	.0793	2.2086	.0780	2.0884	.0738
681	.6618	.0234	.6491	.0229	.6088	.0215
729	.4628	.0163	.4577	.0162	.4420	.0156
TOTAL	19.0373	.6723	17.7881	.6282	14.2798	.5043

(a)Refer to Figure A.2-1 of the Attachment A.2 for segment locations.
(b)Refer to Figure A.7-2 for nodal locations.
(c)Nodal flows are positive when direction is out from the model.

TABLE A.11-6

BOUNDARY FLOW RATES FOR LOW RECHARGE CASE
ROLLING STONE LAKE AND LOWER PORTION OF PICKEREL CREEK
SEGMENT FG(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	cfs
729	.4628	.0163	.4577	.0162	.4420	.0156
730	2.0453	.0722	2.0215	.0714	1.9460	.0687
731	1.9565	.0691	1.9362	.0684	1.8696	.0660
732	3.4183	.1207	3.3993	.1200	3.3390	.1179
733	3.0356	.1072	3.0267	.1069	2.9988	.1059
734	1.5785	.0557	1.5788	.0558	1.5791	.0558
735	3.0999	.1095	3.0952	.1093	3.0651	.1082
736	4.9721	.1756	4.9531	.1749	4.8262	.1704
776	7.5089	.2652	7.4867	.2644	7.2742	.2569
822	5.9361	.2096	5.9234	.2092	5.7775	.2040
870	4.9150	.1736	4.9087	.1733	4.8072	.1698
922	5.2797	.1865	5.2765	.1863	5.1941	.1834
975	3.7988	.1342	3.7957	.1340	3.7513	.1325
1028	.6686	.0236	.6683	.0236	.6618	.0234
TOTAL	48.6761	1.7190	48.5277	1.7137	47.5320	1.6786

(a)Refer to Figure A.2-1 of the Attachment A.2 for segment locations.
(b)Refer to Figure A.7-2 for nodal locations.
(c)Nodal flows are positive when direction is out from the model.

TABLE A.11-7

BOUNDARY FLOW RATES FOR LOW RECHARGE CASE
PICKEREL CREEK TO HEMLOCK LAKE
SEGMENT GA(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	PRECONSTRUCTION cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	END OF YEAR 3 cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	END OF YEAR 28 cfs
1028	.6686	.0236	.6683	.0236	.6618	.0234
1029	4.3411	.1533	4.3411	.1533	4.3062	.1521
1049	12.1385	.4287	12.1322	.4284	11.9990	.4237
1050	6.8525	.2420	6.8461	.2418	6.7637	.2389
1051	4.4108	.1558	4.4077	.1557	4.3633	.1541
1167	.1828	.0065	.1364	.0048	-.3014	-.0106
1080	2.9642	.1047	2.9633	.1046	2.9420	.1039
1081	2.7819	.0982	2.7806	.0982	2.7543	.0973
1082	1.4022	.0495	1.4019	.0495	1.3927	.0492
1089	-2.6332	-.0930	-2.6655	-.0941	-2.9176	-.1030
1090	-1.1136	-.0393	-1.1745	-.0415	-1.5639	-.0552
1091	-3.0051	-.1061	-3.0248	-.1068	-3.2249	-.1139
1093	1.1022	.0389	1.0899	.0385	.9361	.0331
1095	4.5028	.1590	4.4996	.1589	4.4521	.1572
1097	6.8905	.2433	6.8874	.2432	6.8430	.2417
1129	.5286	.0187	.4934	.0174	.3114	.0110
1130	.0182	.0006	-.0749	-.0026	-.5381	-.0190
1131	1.0712	.0378	.9361	.0331	.2974	.0105
1164	.2322	.0082	.1842	.0065	-.0272	-.0010
1165	.8901	.0314	.7331	.0259	.0581	.0021
1166	.6643	.0235	.3631	.0128	-.8742	-.0309
TOTAL	44.8909	1.5853	43.9246	1.5512	38.6335	1.3643

(a)Refer to Figure A.2-1 of the Attachment A.2 for segment locations.
(b)Refer to Figure A.7-2 for nodal locations.
(c)Nodal flows are positive when direction is out from the model.

TABLE A.11-8

BOUNDARY FLOW RATES FOR MIDDLE RECHARGE CASE
UPPER HEMLOCK CREEK
SEGMENT AB(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	PRECONSTRUCTION cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	END OF YEAR 3 cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	END OF YEAR 28 cfs
1153	3.6086	.1274	3.1554	.1114	1.9914	.0703
1155	2.1877	.0773	1.8598	.0657	1.0677	.0377
1167	.4179	.0148	.1790	.0063	-.4354	-.0154
1171	1.9378	.0684	1.5890	.0561	.7804	.0276
1172	.6748	.0238	.5687	.0201	.3295	.0116
1184	2.8003	.0989	2.6069	.0921	2.0675	.0730
1192	-.4636	-.0164	-.5638	-.0199	-.8241	-.0291
1193	.2625	.0093	.0341	.0012	-.5597	-.0198
1201	1.7333	.0612	1.6416	.0580	1.3734	.0485
1202	.5679	.0201	.2912	.0103	-.4363	-.0154
1203	1.6143	.0570	1.4460	.0511	.9957	.0352
1204	.4696	.0166	.3266	.0115	-.0580	-.0020
1205	1.1869	.0419	1.0144	.0358	.5372	.0190
1214	1.2865	.0454	1.2427	.0439	1.1111	.0392
1215	-.0229	-.0008	-.0560	-.0020	-.1489	-.0053
1216	.3006	.0106	.2471	.0087	.0930	.0033
1217	.7141	.0252	.6399	.0226	.4221	.0149
1218	1.6185	.0572	1.5560	.0549	1.3654	.0482
1220	.9275	.0328	.8866	.0313	.7582	.0268
1223	1.2887	.0455	1.2462	.0440	1.1121	.0393
1224	.3142	.0111	.3014	.0106	.2624	.0093
1225	.9269	.0327	.9018	.0318	.8226	.0290
1226	1.5176	.0536	1.4904	.0526	1.4038	.0496
1227	.5324	.0188	.5197	.0184	.4798	.0169
TOTAL	26.4020	.9324	23.1247	.8166	14.5105	.5124

(a)Refer to Figure A.2-1 of the Attachment A.2 for segment locations.
(b)Refer to Figure A.7-2 for nodal locations.
(c)Nodal flows are positive when direction is out from the model.

TABLE A.11-9

BOUNDARY FLOW RATES FOR MIDDLE RECHARGE CASE
LOWER HEMLOCK CREEK AND SWAMP CREEK BELOW HEMLOCK CREEK CONFLUENCE
SEGMENT BC(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	PRECONSTRUCTION cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	END OF YEAR 3 cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	END OF YEAR 28 cfs
374	.5575	.0197	.5365	.0189	.3618	.0128
414	1.5627	.0552	1.5053	.0532	1.2938	.0457
458	.4205	.0148	.4046	.0143	.3539	.0125
459	.6894	.0243	.6542	.0231	.5419	.0191
508	.9297	.0328	.8371	.0296	.5549	.0196
554	1.4409	.0509	1.3553	.0479	1.1064	.0391
599	1.7681	.0624	1.6876	.0596	1.4564	.0514
646	.4427	.0156	.4189	.0148	.3523	.0124
647	.8771	.0310	.8238	.0291	.6751	.0238
693	.3002	.0106	.2645	.0093	.1648	.0058
742	.5058	.0179	.4709	.0166	.3732	.0132
789	.6757	.0239	.6437	.0227	.5559	.0196
837	.3891	.0137	.3545	.0125	.2611	.0092
887	.3406	.0120	.3206	.0113	.2665	.0094
940	1.2154	.0429	1.1390	.0402	.9402	.0332
941	.3932	.0139	.3688	.0130	.3040	.0107
955	1.4320	.0506	1.3470	.0476	1.1352	.0401
956	.3710	.0131	.3479	.0123	.2895	.0102
996	.8755	.0309	.7981	.0282	.6126	.0216
997	.4332	.0153	.4100	.0145	.3542	.0125
1007	1.3435	.0474	1.2456	.0440	1.0204	.0360
1008	.3285	.0116	.3043	.0107	.2480	.0088
1055	3.1228	.1103	2.5279	.0893	1.4209	.0502
1056	2.4128	.0852	1.9907	.0703	1.1948	.0422
1057	2.2432	.0792	1.9429	.0686	1.3512	.0477
1058	1.5646	.0553	1.3838	.0489	1.0062	.0355
1059	1.0436	.0369	.9253	.0327	.6697	.0237
1060	.3174	.0112	.2909	.0103	.2327	.0082
1103	.6837	.0241	.5613	.0198	.3301	.0117
1138	.3751	.0132	.3115	.0110	.1895	.0067
1155	2.1877	.0773	1.8598	.0657	1.0677	.0377
1157	.9481	.0335	.8089	.0286	.5400	.0191
1170	.3333	.0118	.2797	.0099	.1762	.0062
1172	.6749	.0238	.5687	.0201	.3295	.0116
1173	1.8909	.0668	1.5487	.0547	.8038	.0284
1174	.9329	.0329	.7392	.0261	.3298	.0116
1175	1.0737	.0379	.9139	.0323	.5825	.0206
1176	1.0471	.0370	.8701	.0307	.5093	.0180
1177	.9006	.0318	.7166	.0253	.3479	.0123
1178	.3777	.0133	.3215	.0114	.2086	.0074
TOTAL	39.4220	1.3922	34.7996	1.2289	24.5124	.8656

(a)Refer to Figure A.2-1 of the Attachment A.2 for segment locations.
(b)Refer to Figure A.7-2 for nodal locations.
(c)Nodal flows are positive when direction is out from the model.

TABLE A.11-10

BOUNDARY FLOW RATES FOR MIDDLE RECHARGE CASE
SWAMP CREEK ABOVE RICE LAKE
SEGMENT CD(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	PRECONSTRUCTION cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	END OF YEAR 3 cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	END OF YEAR 28 cfs
1	3.3042	.1167	2.7848	.0983	2.2447	.0793
4	3.4976	.1235	2.9826	.1053	2.4436	.0863
5	1.5287	.0540	1.3166	.0465	1.0946	.0387
6	5.0609	.1787	4.3728	.1544	3.6403	.1286
11	4.0557	.1432	3.5705	.1261	3.0511	.1077
13	5.6285	.1988	4.9309	.1741	4.1572	.1468
23	1.0356	.0366	.9665	.0341	.8901	.0314
26	2.7676	.0977	2.4807	.0876	2.1506	.0759
41	-.1307	-.0046	-.1860	-.0066	-.2482	-.0088
42	.7198	.0254	.5984	.0211	.4598	.0162
43	.4014	.0142	.3253	.0115	.2380	.0084
45	.6440	.0227	.5933	.0210	.5330	.0188
46	1.8281	.0646	1.6667	.0589	1.4729	.0520
47	11.8880	.4198	10.8860	.3844	9.6398	.3404
61	1.9210	.0678	1.5642	.0552	1.1488	.0406
63	.3926	.0139	.3402	.0120	.2804	.0099
66	6.1374	.2167	5.8409	.2063	5.4398	.1921
83	2.1911	.0774	1.8255	.0645	1.3759	.0486
108	2.2235	.0785	1.8972	.0670	1.4637	.0517
137	1.4872	.0525	1.2953	.0457	1.0103	.0357
163	1.3860	.0489	1.2259	.0433	.9637	.0340
191	1.9121	.0675	1.7256	.0609	1.3648	.0482
225	.4183	.0148	.3869	.0137	.3070	.0108
226	.4148	.0146	.3843	.0136	.3011	.0106
260	.0650	.0023	.0654	.0023	.0495	.0017
297	.0658	.0023	.0671	.0024	.0516	.0018
335	.4623	.0163	.4487	.0158	.3732	.0132
374	.5575	.0197	.5365	.0189	.4474	.0158
TOTAL	61.8640	2.1847	54.8929	1.9385	46.3448	1.6367

(a)Refer to Figure A.2-1 of the Attachment A.2 for segment locations.
(b)Refer to Figure A.7-2 for nodal locations.
(c)Nodal flows are positive when direction is out from the model.

TABLE A.11-11

BOUNDARY FLOW RATES FOR MIDDLE RECHARGE CASE
RICE AND MOLE LAKES
SEGMENT DE(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	cfs
66	6.1374	.2167	5.8409	.2063	5.4398	.1921
88	4.0271	.1422	3.9352	.1390	3.8020	.1343
114	.7620	.0269	.7522	.0266	.7376	.0260
115	1.3416	.0474	1.3299	.0470	1.3118	.0463
116	3.0857	.1090	3.0701	.1084	3.0457	.1076
117	2.0304	.0717	1.9622	.0693	1.8588	.0656
118	-.2418	-.0085	-.3311	-.0117	-.4636	-.0164
133	-1.2497	-.0441	-1.3765	-.0486	-1.5623	-.0552
158	-1.6572	-.0585	-1.8991	-.0671	-2.2530	-.0796
185	1.7593	.0621	1.3204	.0466	.6703	.0237
216	1.2722	.0449	1.2024	.0425	1.0972	.0387
217	.7512	.0265	.6193	.0219	.4195	.0148
251	.3770	.0133	.0221	.0008	-.5194	-.0183
287	1.5671	.0553	1.1298	.0399	.4611	.0163
324	1.7383	.0614	1.2928	.0457	.6019	.0213
362	.3599	.0127	.2194	.0077	-.0017	-.0001
TOTAL	22.0606	.7791	19.0901	.6742	14.6457	.5172

(a)Refer to Figure A.2-1 of the Attachment A.2 for segment locations.
(b)Refer to Figure A.7-2 for nodal locations.
(c)Nodal flows are positive when direction is out from the model.

TABLE A.11-12

BOUNDARY FLOW RATES FOR MIDDLE RECHARGE CASE
PICKEREL CREEK, UPSTREAM OF ROLLING STONE LAKE
SEGMENT EF(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	PRECONSTRUCTION cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	END OF YEAR 3 cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	END OF YEAR 28 cfs
362	.3599	.0127	.2194	.0077	-.0017	-.0001
403	.8505	.0300	.3761	.0133	-.3812	-.0135
444	2.5086	.0886	2.0795	.0734	1.3759	.0486
493	5.8219	.2056	5.3399	.1886	4.5345	.1601
539	5.3272	.1881	4.9721	.1756	4.3633	.1541
583	4.1064	.1450	3.8813	.1371	3.4849	.1231
629	2.8066	.0991	2.6164	.0924	2.2723	.0802
632	.2953	.0104	.2504	.0088	.1673	.0059
679	3.1183	.1101	3.0429	.1075	2.8999	.1024
681	.9205	.0325	.8949	.0316	.8473	.0299
729	.6407	.0226	.6307	.0223	.6117	.0216
TOTAL	26.7560	.9449	24.3036	.8583	20.1742	.7124

(a)Refer to Figure A.2-1 of the Attachment A.2 for segment locations.
(b)Refer to Figure A.7-2 for nodal locations.
(c)Nodal flows are positive when direction is out from the model.

TABLE A.11-13

BOUNDARY FLOW RATES FOR MIDDLE RECHARGE CASE
ROLLING STONE LAKE AND LOWER PORTION OF PICKEREL CREEK
SEGMENT FG(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	PRECONSTRUCTION cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	END OF YEAR 3 cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	END OF YEAR 28 cfs
729	.6407	.0226	.6307	.0223	.6117	.0216
730	2.8326	.1000	2.7848	.0983	2.6950	.0952
731	2.7109	.0957	2.6693	.0943	2.5901	.0915
732	4.7152	.1665	4.6772	.1652	4.6043	.1626
733	4.1889	.1479	4.1698	.1473	4.1381	.1461
734	2.1839	.0771	2.1839	.0771	2.1845	.0771
735	4.2808	.1512	4.2713	.1508	4.2301	.1494
736	6.9096	.2440	6.8652	.2424	6.6939	.2364
776	10.4928	.3705	10.4325	.3684	10.1503	.3585
822	8.3175	.2937	8.2826	.2925	8.0828	.2854
870	6.9032	.2438	6.8842	.2431	6.7447	.2382
922	7.4264	.2623	7.4106	.2617	7.2964	.2577
975	5.3558	.1891	5.3463	.1888	5.2829	.1866
1028	.9435	.0333	.9426	.0333	.9335	.0330
TOTAL	67.9018	2.3979	67.5509	2.3855	66.2383	2.3392

(a)Refer to Figure A.2-1 of the Attachment A.2 for segment locations.
(b)Refer to Figure A.7-2 for nodal locations.
(c)Nodal flows are positive when direction is out from the model.

TABLE A.11-14

BOUNDARY FLOW RATES FOR MIDDLE RECHARGE CASE
PICKEREL CREEK TO HEMLOCK LAKE
SEGMENT GA(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	PRECONSTRUCTION cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	END OF YEAR 3 cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	END OF YEAR 28 cfs
1028	.9435	.0333	.9426	.0333	.9335	.0330
1029	6.1073	.2157	6.1010	.2155	6.0534	.2138
1049	16.8759	.5960	16.8538	.5952	16.6698	.5887
1050	9.5890	.3386	9.5764	.3382	9.4622	.3342
1051	6.1929	.2187	6.1834	.2184	6.1200	.2161
1167	.4179	.0148	.1790	.0063	-.4354	-.0154
1080	4.1762	.1475	4.1730	.1474	4.1445	.1464
1081	3.9288	.1387	3.9257	.1386	3.8908	.1374
1082	1.9781	.0699	1.9768	.0698	1.9644	.0694
1089	-3.4627	-.1223	-3.5452	-.1252	-3.8876	-.1373
1090	-1.3642	-.0482	-1.5122	-.0534	-2.0402	-.0720
1091	-3.9415	-.1392	-3.9954	-.1411	-4.2713	-.1508
1093	1.7034	.0602	1.6692	.0589	1.4577	.0515
1095	6.2563	.2209	6.2468	.2206	6.1802	.2183
1097	9.5193	.3362	9.5098	.3358	9.4495	.3337
1129	.7778	.0275	.6963	.0246	.4503	.0159
1130	.1556	.0055	-.0581	-.0021	-.6856	-.0242
1131	1.6384	.0579	1.3328	.0471	.4655	.0164
1164	.3704	.0131	.2631	.0093	-.0258	-.0009
1165	1.3695	.0484	1.0217	.0361	.0968	.0034
1166	1.1460	.0405	.4858	.0172	-1.2259	-.0433
TOTAL	64.3782	2.2735	62.0261	2.1904	54.7669	1.9341

(a)Refer to Figure A.2-1 of the Attachment A.2 for segment locations.
(b)Refer to Figure A.7-2 for nodal locations.
(c)Nodal flows are positive when direction is out from the model.

TABLE A.11-15
NODAL FLOW RATES FOR LOW RECHARGE CASE
CONSTANT HEAD NODES AT
SOUTHWESTERN WETLANDS(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	cfs
620	10.8638	.3837	9.6176	.3396	6.6717	.2356
622	-6.7415	-.2381	-7.0586	-.2493	-7.8450	-.2770
635	6.9508	.2455	6.6147	.2336	5.6697	.2002
638	-13.1215	-.4634	-13,2230	-.4670	-13.4989	-.4767
670	19.7045	.6959	18.7437	.6619	16.0166	.5656
671	15.2239	.5376	15.0178	.5303	14.2250	.5024
672	14.2504	.5032	14.1933	.5012	13.8984	.4908
684	.7870	.0278	.7021	.0248	.4573	.0161
685	-1.4812	-.0523	-1.5126	-.0534	-1.6026	-.0566
686	7.7182	-2726	7.6960	.2718	7.5564	.2669
TOTAL	54.1543	1.9124	50.7908	1.7937	41.5487	1.4673

(a)Refer to Figure A.7-1 for location of constant head modes.

(b)Refer to Figure A.7-2 for nodal locations.

(c)Nodal flows are positive when direction is out from the model.

TABLE A.11-16

NODAL FLOW RATES FOR MIDDLE RECHARGE CASE
CONSTANT HEAD NODES AT
SOUTHWESTERN WETLANDS(a)

COMPUTER MODEL(b) NODE NUMBER	NODAL FLOW(c) PRECONSTRUCTION $m^3/sec \times 10^{-3}$	cfs	END OF YEAR 3 $m^3/sec \times 10^{-3}$	cfs	END OF YEAR 28 $m^3/sec \times 10^{-3}$	cfs
620	15.1573	.5353	12.7537	.4504	9.2117	.3253
622	-9.1324	-.3225	-9.7476	-.3442	-10.6767	-.3770
635	9.7000	.3426	9.0405	.3193	11.0857	.3915
638	-17.9319	-.6333	-18.1285	-.6402	-18.4551	-.6517
670	27.3655	.9664	25.4376	.8983	22.0510	.7787
671	21.0838	.7446	20.6431	.7290	19.6315	.6933
672	19.6886	.6953	19.5491	.6904	19.1654	.6768
684	1.1641	.0411	.9963	0.352	.7049	.0249
685	-1.9822	-.0700	-2.0446	-.0722	-2.1515	-.0760
686	10.6830	.3773	10.6260	.3753	10.4452	.3689
TOTAL	75.7959	2.6767	69.1255	2.4411	61.0122	2.1546

(a)Refer to Figure A.7-1 for location of constant head nodes.

(b)Refer to Figure A.7-2 for nodal locations.

(c)Nodal flows are positive when direction is out from the model.

ATTACHMENT A.12

ANALYSIS OF HYDROLOGIC EFFECTS OF PROJECT MODIFICATIONS

ATTACHMENT A.12

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ATTACHMENT A.12

ANALYSIS OF HYDROLOGIC EFFECTS OF PROJECT MODIFICATIONS

This attachment has been prepared to summarize the hydrologic consequences of project modifications and their effect on previous analysis results. Figures A.12-1 and A.12-2 show the revised project schedule while Figure A.12-3 shows the revised project facilities. A tabular summary of project modifications and their hydrologic consequences is presented in Table A.12-1. A discussion of each project modification and its hydrologic effects follows.

For each project modification a comparison has been made between the plans or facilities as included in the hydrologic impact assessment and as revised after completion of the hydrologic impact modeling. The project changes as described below either do not affect the conclusions of analysis as presented or changes tend to provide another measure of conservatism.

A.12.1 Revised Project Schedule

The project schedule has been revised as shown on Figures A.12-1 and A.12-2. The corresponding schedule used in the hydrologic impact assessment is shown in Figures A-3a and A-3b. The revisions to the schedule include: (a) The construction phase has been shortened from four years to three years, (b) The operation phase has been lengthened from 22 to 29 years, (c) The reclamation phase has been lengthened from three years to four years, and (d) The scheduled dates of starting and reclaiming tailing ponds have been adjusted for the new operation schedule.

Year 28 (one year before the end of the reclamation phase) of the impact assessment corresponds to Year 34 of the revised schedule. Since Year 28 of the impact assessment is representative of steady-state conditions, conclusions based upon Year 28 of the impact assessment may be applied to Year 34 of the revised schedule. In other words, the steady state impact of mine dewatering occurs for an additional six years (seven years additional operation minus one year less construction). The amount of time for the potentiometric surface to rebound to original levels during post operations is not changed by the revised schedule; however, the time at which the rebound begins is delayed by six years.

The shortened construction phase and minor revisions to the schedule of tailing pond seepage rates affect the timing of impacts before steady-state conditions are reached; however, the steady state impacts occurring at the end of operation and the corresponding conclusion reached in the hydrologic impact assessment would be unchanged by the revised schedule.

A.12.2 Revised Mining Sequence

The hydrologic impact assessment was originally based upon an assumption of concurrent massive and stringer ore mining. Revised plans are to perform sequential mining of the massive and stringer ore. The hydrologic consequence of this revision would be a delayed build-up of mine inflow rates and a corresponding longer period during which steady-state inflow conditions would be reached. This delayed timing would not affect steady-state conditions upon which conclusions of the hydrologic impact assessment were based.

Accompanying the sequential mining of the massive and stringer ore, will be sequential disposal of the massive and stringer tailings. Massive ore tailings, because of the presence of slightly more pyrite, will have slightly higher acid generating potential (Exxon Minerals Company, 1985). However, because of the tailings ponds operating procedures and the buffering capacity of till and the period required for chemical constitutents to reach ground water, the minor differences in the tailings are not expected to change the predicted water quality or the overall MWDF effects.

A.12.3 Revised Sewage Treatment

The hydrologic impact assessment included a septic tank and soil absorption field adjacent to the mine area. In the revised project facilities this has been replaced by a Sanitary Waste Treatment Plant for sewage treatment with effluent discharged to Swamp Creek. As a result of the revision, approximately 0.001 m^3/sec (20 gpm) seepage on 1.0 ha (2.5 acres) near the mine/mill area would not exist in the revised facilities. The flow rate of 0.001 m^3/sec is only approximately one percent of the maximum mine inflow which could be expected. Therefore, this revision would not represent a significant change to the hydrologic impact of the mine.

A.12.4 Revised Mine/Mill Facilities

Mine/Mill facilities have been revised to provide for an ore processing rate of 7,500 STPD versus the 10,000 STPD facility considered in the hydrologic impact assessment. The area of the site covered by the Mine/Mill facilities is not significantly changed and as a result the assumptions and input data used to simulate these facilities are still the same.

A.12.5 Mine Refuse Disposal Facility

As shown in Figure A.12-3, a 10-acre Mine Refuse Disposal Facility (MRDF) is to be constructed adjacent to the MWDF. The facility will be designed with a seepage control system similar to the MWDF. Since, as described in Section A.12.6, seepage from the MWDF is also to be reduced substantially in the revised facilities, the overall hydrologic impacts of the combined MRDF and MWDF are expected to be less than those previously reported in the impact assessment.

A.12.6 Reduced MWDF Size

The MWDF has been revised to cover an area of approximately 300 acres as shown in Figure A.12-3. The MWDF design used in the hydrologic impact assessment covered an area of approximately 500 acres. The reduction in size of the MWDF reflects a reduction in the north-south dimension with the east-west dimension approximately the same in both designs. Therefore, the impact upon the horizontal dispersion modeling is a reduction in the total mass loading applied to the model with a corresponding reduction in predicted impacts. For the vertical simulation model the mass loading is approximately the same because the east-west dimension is unchanged. However, since revised grading plans for the MWDF may alter the pattern of excess surface water runoff, the vertical simulation has been analyzed using the revised grading plan to determine perimeter recharge values for the MWDF, as discussed in Section A.12.10. Figure A.12-4 shows the steady state concentrations determined from this revised model. The revised grading plan does not significantly alter conclusions based upon the results of the MWDF solute transport model. The concentrations at the compliance boundary are reduced as a result of higher surface water recharge in the area of Pond T4. This higher recharge causes slightly higher concentrations to the southeast or away from the compliance boundary.

A.12.7 Revised Reclaim Ponds

The Reclaim Ponds have been revised in size and location as shown in Figure A.12-3. Since the reclaim ponds are designed for no seepage and since the ponds will be removed after operations, the redesigned reclaim ponds will have no impact upon the results of the steady-state mass transport models. Furthermore, the location of the ponds has no influence on the vertical two-dimensional modeling results because the ponds lie well north of the cross-section analyzed.

A.12.8 Borrow Area

The revised Reclamation Plan for the MWDF area includes a 500,000-cubic yard borrow area. This area is located north of the MWDF as shown in Figure A.12-3. Usage of the borrow area would occur during project Years 34 and 35. The area would be reclaimed in project Year 36. The only possible change to the ground water regime would be a localized short-term change in natural infiltration. Due to the small area affected and short-term change, no significant effects on the ground water will occur.

A.12.9 Reduction in Personnel

In the hydrologic impact assessment potable water well usage by an estimated 800 personnel during operation of the mine was considered. The potable water well usage was estimated to be 3.15×10^{-3} cubic meters per second (50 gpm). Revised plans include approximately 650 personnel on the site, with a corresponding reduction in potable water withdrawal from the aquifer. Hence the ground water impact is reduced slightly, although the change to the modeling results would not be significant because the potable water well usage is small relative to mine inflow.

A.12.10 Revised Reclamation Cover for the MWDF

As discussed in Section A.12.6, the MWDF facility has been revised. In addition to changes to the area of the MWDF, the reclamation cap will be graded such that excess surface water will infiltrate to the perimeter of each individual pond rather than just around the entire MWDF perimeter. Values of the expected infiltration per unit length of perimeter of each individual pond were calculated and used in determining the steady-state concentrations shown in Figure A.12-4. There is no significant change to the MWDF solute transport results.

A.12.11 Elimination of Seepage from Surface Water Drainage Basin Number 2

In revised plans the surface water which collects in drainage Basin Number 2 located north of the mine/mill will be directed to the water treatment facility instead of seeping to ground water. The amount of redirected water is approximately 6×10^{-4} cubic meters per second (9.5 gpm). This would only result in a slight decrease in mine inflow and only a slight change in impact of the mine to surface water.

A.12.12 Summary

Project plan modifications which have been made since the completion of the majority of the ground water impact modeling studies have been reviewed to determine their affect on the site area hydrologic impact assessment. All project changes either have no significant effect on the impact analysis as presented or tend to provide a measure of conservatism in the analysis.

LIST OF REFERENCES

Exxon Minerals Company, 1985, Revised Environmental Impact Report (EIR), Crandon Project, Rhinelander, Wisconsin.

TABLES

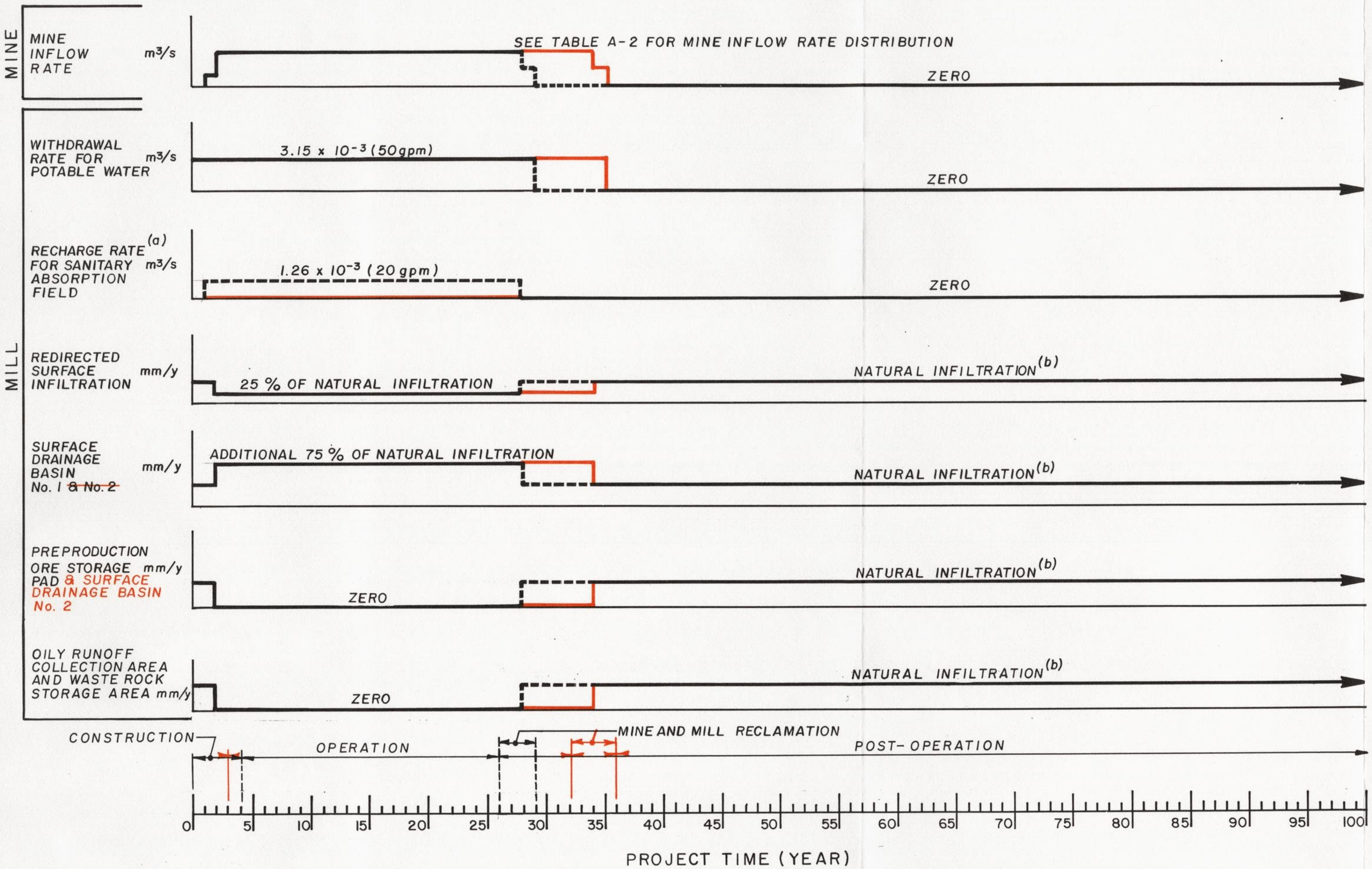
TABLE A.12-1

SUMMARY OF PROJECT MODIFICATIONS

ITEM NUMBER	PROJECT MODIFICATION	PREVIOUS PLAN	EVALUATION OF HYDROLOGIC CHANGE
1	3 Years Construction 29 Years Operation 4 Years Reclamation	4 Years Construction 22 Years Operation 4 Years Reclamation	The Year 28 impacts (steady-state impacts) now occur in Year 34. The timing of the impacts may vary slightly because of the reduced construction phase and delayed build-up of mine inflow. Overall, the timing of impacts will be delayed and the impacts will last several years longer.
2	Sequential mining of the massive and stringer ores and a reduced overall mine size.	Concurrent massive and stringer ore mining and larger overall mine size.	Delayed buildup of mine inflow volume and extended period to reach steady-state inflow condition.
3	Sanitary Waste Water Treatment Plant for sewage treatment with effluent discharged to Swamp Creek.	Septic tank and soil absorption field.	Elimination of an approximate 0.001 m^3/s (20 gpm) seepage over a 1.0 ha (2.5 acres) area near the mine/mill area.
4	Mine/mill area facilities sized for ore processing rate of 7,500 STPD.	Mine/mill area facilities sized for ore processing rate of 10,000 STPD.	The overall surface area for the mine/mill facilities has not changed. The building and other facility changes in the mine/mill area are not significant enough to affect any modeling.
5	On-site, 10-acre, Mine Refuse Disposal Facility. (MRDF)	Off-site disposal of mine related refuse.	Facility seepage of less than 1 gpm will have no noticeable effect on ground water. The MRDF will be designed with a seepage control system similar to the MWDF and with its small size, will have an insignificant impact.
6	An MWDF size of approximately 300 acres.	An MWDF size of approximately 500 acres.	Overall reduced MWDF seepage (on a volumetric basis) would reduce impacts(1).
7	Overall reclaim pond size of approximately 40 acres and location change.	Overall reclaim pond size of approximately 60 acres.	Zero leakage facility with no impact.
8	Provision for a borrow area for 500,000 yd^3 north of the MWDF area.	No borrow area.	No effects or changes expected to the ground water system. The tentative area would occur in Project Years 33 and 34.
9	Approximately 650 personnel.	Approximately 800 personnel.	Slightly reduced potable water usage with no significant change to modeling results.
10	Regraded reclamation cover for the MWDF with infiltration around each individual pond.	Infiltration zone around MWDF perimeter.	No significant effect. Width of MWDF in east-west direction has not changed. Reclamation cap regrading and relocation of infiltration zones would tend to dilute MWDF leachate more uniformly closer to the MWDF(1).
11	Drainage into surface water Basin No. 2 is contained and directed to the water treatment facility.	Surface water Basin No. 2 had a surface overflow outlet to the wetland system north of the mine/mill area.	Slightly reduced infiltration in the mine mill area would change mine inflow an insignificant amount.

(1) Because the width (east-west) of the MWDF has not significantly changed, the vertical simulation results would not change. However, because of the revised grading plan for the MWDF reclamation cap a new model simulation depicting steady-state effects is presented in Figure A.12-4. This simulation shows the cap grading change has not significantly altered the MWDF solute transport results.

FIGURES



NOTES:

(a) PRECIPITATION RECHARGE ALSO OCCURS IN SANITARY ABSORPTION FIELD.

(b) MINE/MILL SURFACE FACILITIES REMOVED, INFILTRATION RESTORED

FIGURE A.12-1

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: MINE AND MILL FACILITIES REVISED SCHEDULE AND HYDROLOGIC DATA

SCALE: AS SHOWN	STATE	COUNTY	
DRAWN BY: RW	DATE: 11-5-85	CHECKED BY: MBL	DATE: 12/10/85
APPROVED BY	DATE	APPROVED BY: SHD	DATE: 12/10/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO.		SHEET ___ OF ___	REVISION NO.

IB / IB / 100% ORG.

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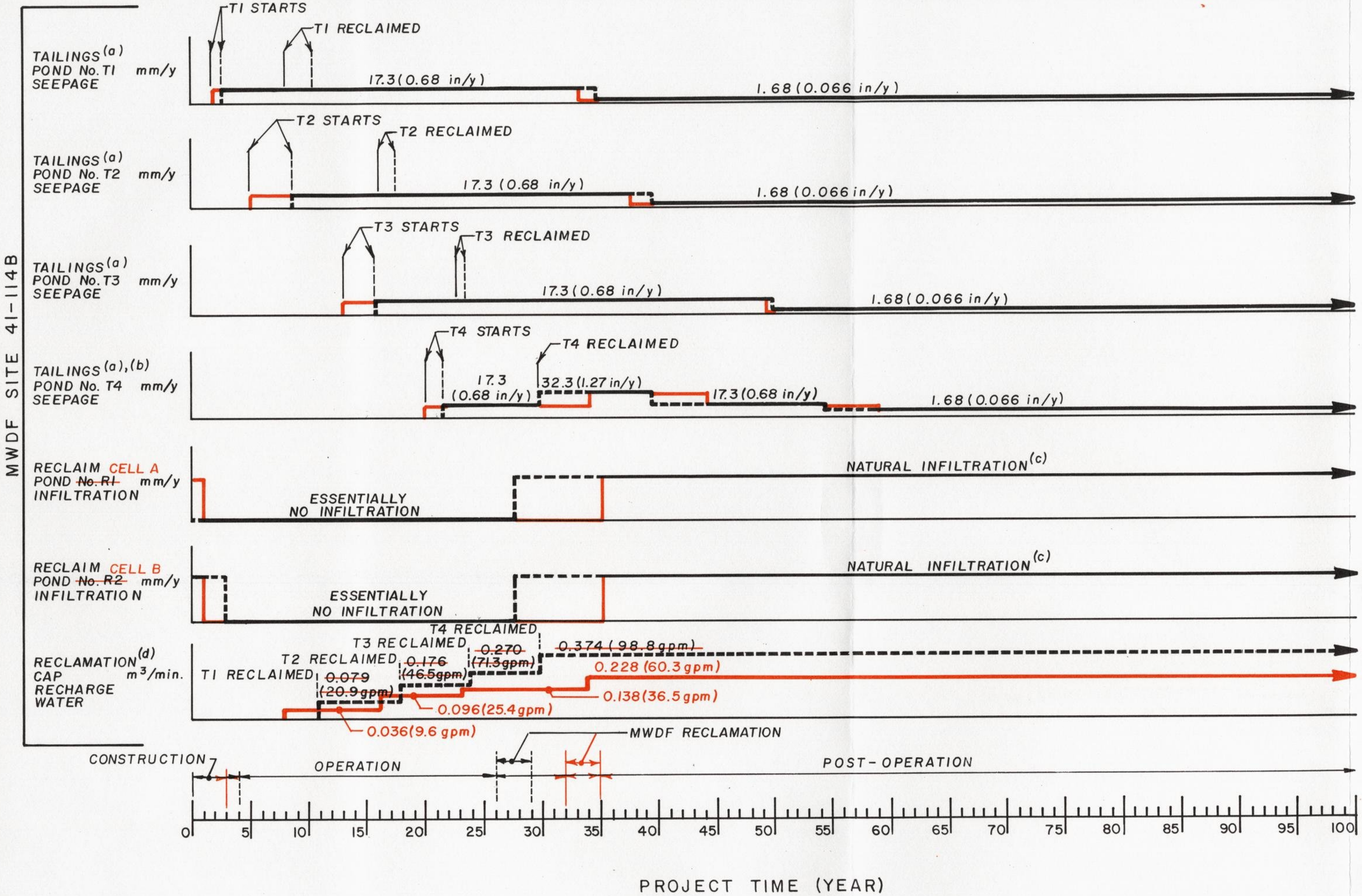
PROJ. NO. 611101 DWG. NO. B1



NOTES:

(a) REFER TO TABLE A-3 FOR DISTRIBUTION OF TAILINGS POND SEEPAGE RATES.

(b) SCHEDULE FOR T4 ASSUMES FULL CAPACITY OF POND IS UTILIZED.

(c) RECLAIM PONDS REMOVED INFILTRATION RESTORED.

(d) RECLAMATION CAP RECHARGE WATER IS DISTRIBUTED ALONG THE MWDF PERIMETER AND INTERNAL EMBANKMENTS.

(e) TAILINGS PONDS START ONE YEAR PRIOR TO ACTUAL USE AND ARE FULLY RECLAIMED TWO YEARS AFTER ACTUAL USE.

FIGURE A.12-2

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: REVISED MWDF SCHEDULE AND HYDROLOGIC DATA

SCALE: AS SHOWN	STATE	COUNTY	
DRAWN BY: RW	DATE: 11-5-85	CHECKED BY: MDL	DATE: 11/20/85
APPROVED BY	DATE	APPROVED BY: SHB	DATE: 11/11/85
APPROVED BY	DATE	EXXON	DATE
DRAWING NO		SHEET ___ OF ___	REVISION NO.

2B
2B
100% ORG.

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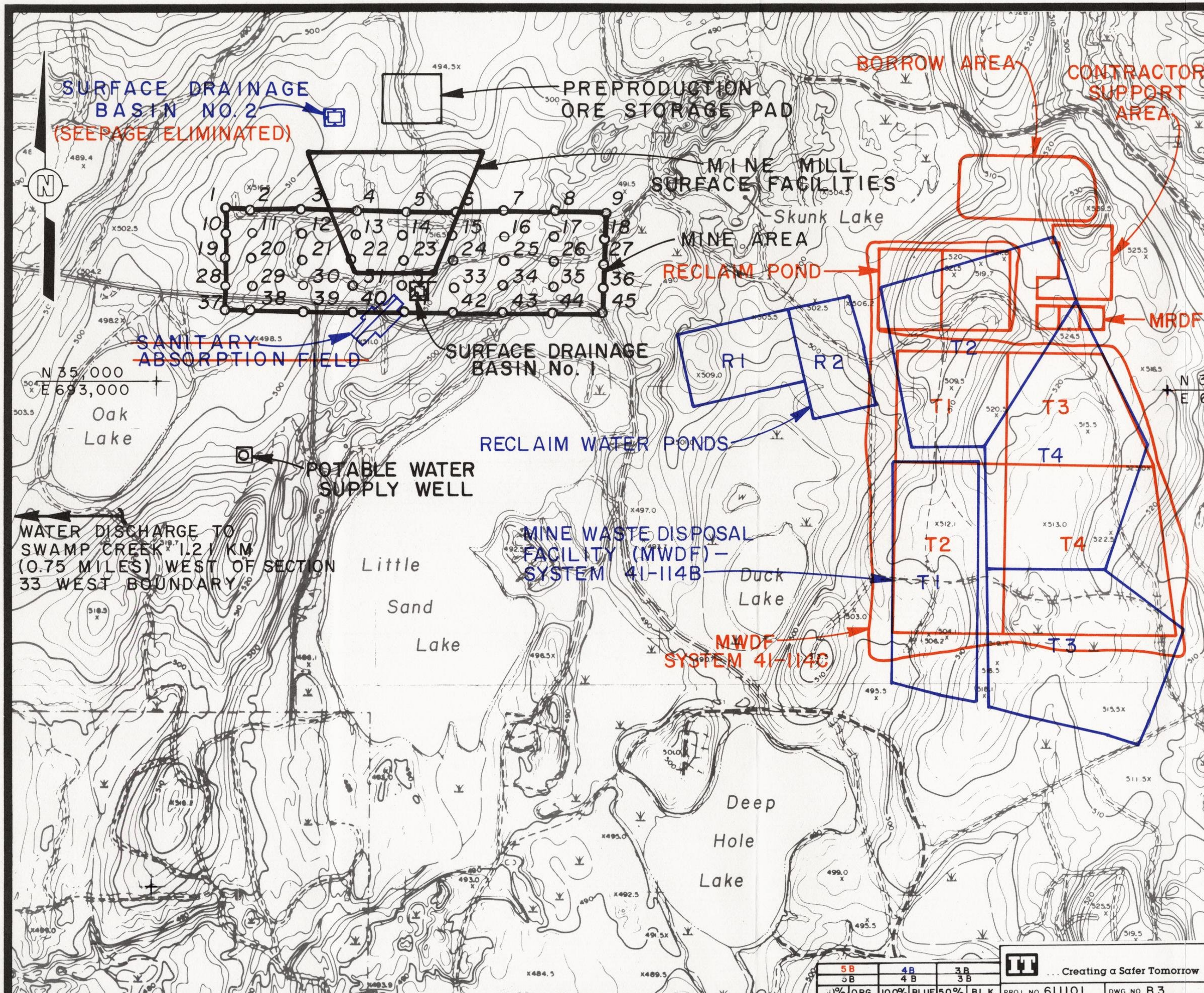
PROJ. NO. 611101 DWG. NO. B2



LEGEND

o^{45} POINTS FOR MINE INFLOW CONSISTENT WITH TAP ASSOCIATES (1984) GROUND WATER INFLOW MODEL

REVISED FACILITIES

PREVIOUS FACILITY LOCATIONS

UNCHANGED FACILITY LOCATIONS

NOTES:

1. REFER TO TABLE A-2 FOR MINE INFLOW RATE DISTRIBUTION.
2. SEE ATTACHMENT A.7 FOR COORDINATES AND NODE NUMBERS

250 0 250 500 750

SCALE IN METERS

FIGURE A.12-3

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE

LOCATION OF REVISED PROJECT FACILITIES AND MINE AREA

SCALE AS SHOWN	STATE		COUNTY	
DRAWN BY RW	DATE 11-5-85	CHECKED BY MDR		DATE 12/10/85
APPROVED BY	DATE	APPROVED BY SHD		12/10/85
APPROVED BY	DATE	EXXON		DATE
DRAWING NO			SHEET ___ OF ___	REVISION NO

5B	4B	3B
5B	4B	3B
0% ORG.	100% BLUE	50% BLK

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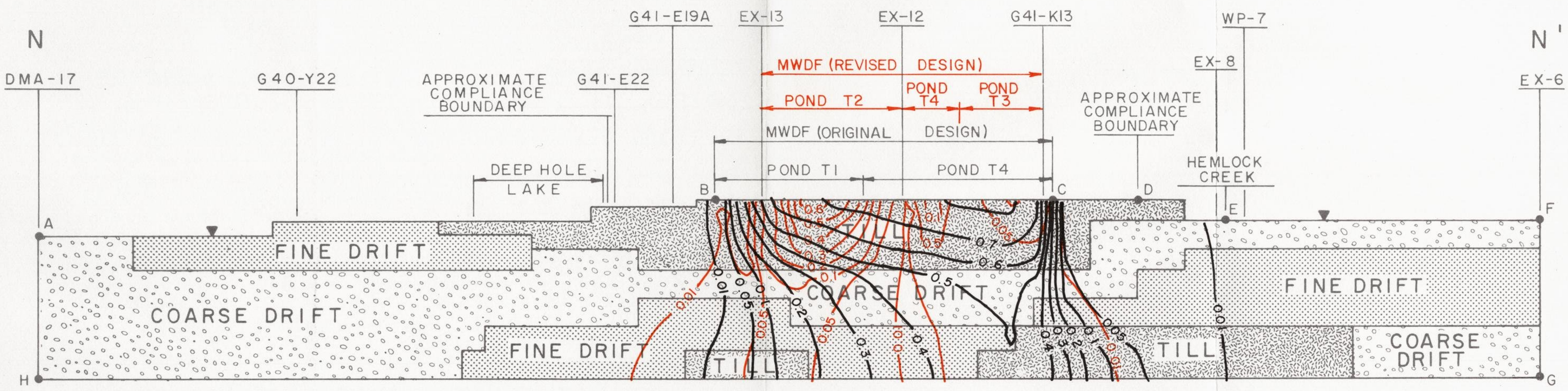
PROJ. NO 611101 DWG NO B3



NOTES:

1. FOR PLAN AND LOCATION OF SECTION N-N' REFER TO FIGURE A-8
2. VERTICAL EXAGGERATION 15X
3. THE ANALYSIS ASSUMES A CONSTANT MASS FLUX AND A RETARDATION FACTOR OF 1.0
4. A RECHARGE RATE OF 216 mm/y (8.5 inch/y) IS USED
5. VERTICAL TO HORIZONTAL PERMEABILITY RATIO, TILL = 1/1, DRIFT = 1/50.
6. LONGITUDINAL DISPERSIVITY = 60 m (197 feet)
7. LONGITUDINAL TO TRANSVERSE DISPERSIVITY RATIO = 50
8. OTHER MODEL INPUT PARAMETERS AND CONDITIONS ARE DISCUSSED IN ATTACHMENT A.7.

LEGEND

A● POINTS REFERRED TO IN TEXT

—0.1— NORMALIZED CONCENTRATION CONTOUR (REVISED MWDF DESIGN)

—0.1— NORMALIZED CONCENTRATION CONTOUR (ORIGINAL MWDF DESIGN)

▼ WATER TABLE (RECHARGE BOUNDARY)

HORIZONTAL SCALE

0 300 600 900 meters

VERTICAL SCALE

0 20 40 60 meters

7B	6B
7B	6B
100% ORG.	50% BLK.

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PROJ NO 611101 DWG NO B4

FIGURE A.12-4

EXXON MINERALS COMPANY

CRANDON PROJECT

TITLE

TWO-DIMENSIONAL VERTICAL MODEL, PREDICTED STEADY STATE NORMALIZED CONCENTRATIONS FOR REVISED MWDF DESIGN

SCALE AS SHOWN	STATE		COUNTY	
DRAWN BY R. Weible	DATE 11-12-85	CHECKED BY M.D.B.		DATE 12/10/85
APPROVED BY	DATE	APPROVED BY S.H.B.		DATE 12/10/85
APPROVED BY	DATE	EXXON		DATE
DRAWING NO			SHEET ___ OF ___	REVISION NO.